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A Virtual Course on Automation of Agricultural Systems

FRANCISCO RODRÍGUEZ, MANUEL BERENGUEL AND JOSÉ LUIS GUZMÁN
Universidad de Almería, Área de Ingeniería de Sistemas y Automática, Ctra. Sacramento s/n, 04120, Almería, Spain. Email: frrodrig@ual.es

SEBASTIÁN DORMIDO
Universidad Nacional de Educación a Distancia, Dpto. de Informática y Automática, C/. Juan del Rosal 16, 28040, Madrid, Spain.

New teaching methods and innovative techniques have recently appeared that aim to enhance students' motivation and improve their education. This paper describes the experience of developing a virtual course on modern automation of agricultural systems. It includes both classical teaching tools and novel teaching methods, taking advantage of new information and communication technologies (ICT). The course is based on the WebCT platform and includes interactive tools and both a virtual and a remote laboratory for greenhouse climate control and fertirrigation teaching/learning.

Keywords: ICT; WebCT; virtual course; agricultural systems; control; automation

INTRODUCTION

AGRICULTURE has been one of the less technically developed sectors as a result of a number of problems, such as socio-economic limitations (such as division of the land into tiny farms, little capital investment and the low value of the end products), the seasonal cycle of the crops and cheap low-skilled manual labour. Furthermore, it is influenced by the huge variety of crops and installations, as well as by adverse and variable orographical and meteorological conditions. Nevertheless, the development of utensils, tools and sophisticated machines to help produce foods and raw materials has been a major preoccupation within the field of agricultural over the last years. Nowadays, the agro-alimentary sector is the object of special attention, and many initiatives are being developed to incorporate new technologies, aimed at increasing production, and achieving diversity, quality, and market presentation requirements, as well as solving the problems of the deficiencies in and scarcity of the manual labour available.

So, technological renovation of the agricultural sector is required and control engineering can play a decisive role. It incorporates automatic control and robotics (AC&R) techniques at all levels of agricultural production: planting, production, harvest and post-harvest processes and transportation. This fact is corroborated by major agricultural engineering associations that coordinate work groups in these subjects, such as the International Commission of Agricultural Engineering (Section VII: Information Systems), the International Society for Horticultural Science (Working groups in Sensors in Horticulture, Greenhouse Environment and Climate Control and Modelling Plant Growth), the European Society of Agricultural Engineers (Special Interest group in Automation & Emerging Technologies and Information Technologies) and The Society of Engineering in Agriculture, Food And Biological Systems (Information and Electrical Technologies Division). Moreover, a society devoted exclusively to the application of the new technologies in agriculture was founded in 1996: The European Federation for Information Technology in Agriculture, Food and the Environment. On the other hand, the most prestigious associations in automatic control and robotics consider the agricultural sector to be high-priority. As an example, the International Federation of Automatic Control has a Technical Committee called the Control in Agriculture and the IEEE Robotics and Automation Association, which supports a Technical Committee on Agricultural Robotics.

Because of this, introductory courses of AC&R are being included in modern agronomy studies. Future agricultural engineers will have to use, understand, and implement the new advances in automation in the sector. In fact, a number of international organizations, such as the International Commission of Agricultural Engineering (CIGR) [1], AFANet (EU Thematic Network) [2], FEANI (Federation Europeenne D'Associations Nationales D'Ingenieurs) [3] and USAEE (University Studies of Agricultural Engineering in Europe) of the EurAgEng (European Association of Agricultural Engineers) [4], have made

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suggestions regarding the subjects that have to be taught in modern agricultural studies with the aim of globalizing agricultural engineering education. Some recommendations focus on the inclusion of classical engineering courses dealing with the analysis and design of control systems, as well as modern courses on systems identification, modern control (optimal, predictive, and robust control), robotics, and image analysis.

This paper describes the development of a virtual course on modern automation of agricultural systems, called Automatic Control and Robotics in Agriculture, and includes both classical teaching tools and novel education methods, taking advantage of new information and communication technologies (ICTs). The course has been developed within the scope of an agricultural engineering Ph.D. programme in the University of Almería (South-East of Spain) and taught in Spanish to students of a number of Latin American countries (Venezuela, Mexico, Colombia, etc.), who had different a priori knowledge on the subjects included in the course. The main features of this course are discussed, including the framework, objectives, the method of grading, etc. The eight units involving the basis of AC&R and machine vision techniques applied to different agricultural fields are also described. Their aim is to motivate students with both a strong theoretical base and engineering skills, which is a major challenge in engineering education. The next section is devoted to comments on the new ICTs that are used in this course, for virtual teaching, interactive tools, and virtual and remote laboratories. The last sections include feedback from the students and some concluding remarks.

COURSE DESCRIPTION

Framework

Automatic control and Robotics in Agriculture is a course included in the Ph.D. programme Agroplasticulture, Agronics, and Sustainable Rural Development, offered by the University of Almería (Spain).

The province of Almería has the largest concentration of greenhouses in the world (covering more than 35 000 hectares). Because of this, agricultural engineering studies are probably the most representative studies in this University, supported by wide educational and research experiences in this field. So, this Ph.D. program has been developed to satisfy the requirements formulated by some Latin American Universities and Agricultural Research Centres. Their interest is in providing their future doctors with a strong theoretical and practical knowledge of agroplasticulture (cropping under plastic greenhouses), on the use of the new technologies in agricultural production in tropical regions, and on the sustainable development of their rural communities.

The programme offers seventeen courses lasting 20 to 30 hours each, covering the following aspects:

- automatic control, electronics, and robotics applied to agricultural processes;
- agrarian economy, markets investigation, and rural sustainable development; and
- management of installations and production engineering in greenhouses.

Spanish Ph.D. courses are divided into two years. During the first year the students must select and attend a minimum of seven courses and during the second year they must produce a supervised research work that will be the basis of their Ph.D. thesis.

As the Latin American students cannot physically attend the courses due to the high costs involved, a virtual course has been developed that includes remote and virtual laboratories, interactive tools, and classical distance learning elements. In this way, the students have to travel to Almería only once, to present the research work produced during the course.

Objectives

By following this course the students will be able to do the following.

Acquire a solid base on AC&R technologies to help them:

- analyse controllable systems, recognize their elemental parts and the techniques used in their design;
- understand the evolution that the automation sector is undergoing;
- use basic computer-aided engineering tools for mathematical calculations in engineering, simulation and programming.

Study the agricultural tasks where AC&R techniques can be implemented using elements such as Programmable Logic Controllers (PLCs), computers, and robots.

Use the learned concepts and techniques to analyse the commercial systems currently used in agriculture, compare them by studying their advantages and disadvantages, and select them to fulfil the required features.

Contents

In order to select the contents of this course, an ideal academic two-month period has been considered, composed of 25 hours for theoretical lessons and 15 exercises, as well as laboratory hours distributed over 15 weeks. This schedule is fairly flexible; in fact, a dilemma appeared when preparing it: we had to decide whether the basic subjects of AC&R should come before or after those devoted to applications in agriculture, or if the course should be divided into two modules (one devoted to automatic control and the other to robotics). Based on the experiences of traditional lecturers during the academic courses 1995/96 to 2005/2006, where both approaches had been used, it has been observed that the students preferred the second scheme. This is because AC&R disciplines are not directly related to their acquired knowledge of agronomy. So, if both areas are mixed during the programme that shows the applications of the AC&R techniques to agricultural processes and their fundamentals, the course is easier for the students to understand.

The professional and research experiences of the authors of this course are oriented towards greenhouse crop production (agriculture under plastic cover). This agricultural production model is being exported to many countries, mainly in the Mediterranean area and Latin America. Because of this, a large part of the course is focused on this crop production model and its levels (plantation, production, harvesting, post-harvesting and transport). The application of AC&R to the traditional agricultural sector is also covered in the course: the harvesting of fruits from trees or autonomous tractors, with several relevant references.

Based on these considerations, the contents of this course are divided into two modules each composed of four units, as Table 1 shows.

Study guide

The following information and material are given to the students in each of the eight learning units of the course.

- *Objectives*. Summary of the basic objectives of the unit and the real related problems that the students should be able to solve.
- *Activity planning*. This includes a description of the unit sections and the timing of each one.
- *Documents of the unit*:
  - *Contents*. The unit contents are supplied in html format files, including hyperlinks to other related parts of the documents and interesting URL addresses. A table of contents placed at the beginning of the unit provides direct access to the contents in an easy way.
  - *Exercises*. A set of problems that the students must solve are proposed. All of them deal

Table 1. Contents and timing of the course

Module 1 Automatic control applied to agricultural systems
Unit 1. Modelling and simulation of agricultural systems The design of a control system requires the knowledge of its dynamical behaviour. It is thus necessary to design and implement a model of the system, consisting of a mathematical description of the relations between the controlled variables and the input (disturbance and control) variables. The use of a dynamic model involves the key questions in the design of a control system: coupling of the variables forming the control loops, definition of the limits in the control action, evaluation of the control difficulty (sign and sensitivity of the control actions, speed of response and shape of the controlled variable), and the sensitivity to changes in the process as a consequence of setpoint shifts and disturbances.
Unit 2. Automatic control of dynamic systems The main objective of a control system is the maintenance of a variable into a desired interval with a determined behaviour. There are several processes in the agricultural sector controlled by automatic systems, like the pH of the irrigation solution. Thus, the general procedure to design the control system is described in this unit based on the classical PID algorithms.
Unit 3. Sequential control of processes There are agricultural processes in which it is not sufficient to control the dynamics of the variables, but also the sequential transitions from a state of the system to another. This unit is thus devoted to studying the basic issues involved in the sequential control of agricultural systems using PLCs (Programmable Logic Controllers).
Unit 4. Automatic control of agricultural systems The crop growth is determined by the climatic variables of the environment, the irrigation and the supply of fertilizers. Greenhouse climate and fertirrigation control systems are described in this unit, showing the sensors, actuators, and the different control algorithms used in commercial and research equipment.
Module 2. Robotics applied to agriculture
Unit 5. Manipulation robotics Robot manipulators are indispensable tools for performing repetitive and dangerous tasks, substituting for human labour. Some studies have identified several agricultural tasks that can be carried out by robot manipulators, like the harvesting process. This unit is dedicated to the fundamentals of robot manipulators (elements, control and programming) and has been included in order to understand this technology and its possible applications in agriculture.
Unit 6. Mobile robotics A feature that has contributed to the development of mankind has been its ability to move by itself or by making use of other elements to increase its speed (animals, wheels, motors, etc.). Vehicles allow the displacement of great masses at relatively high speeds, but they require a human worker for the arduous task of driving. Autonomous mobile robots can avoid this problem, as they are characterized by their capacity to move themselves in known (and even unknown) environments without a human decision. Mobile robotics is being used in the field of agriculture for specific tasks (e.g. spraying robots) or for augmenting the autonomy of agricultural machines (e.g. tractors or combine harvesters). These reasons justify their inclusion of this unit.
Unit 7. Machine vision applied to agriculture Machine vision is widely used in the agricultural sector nowadays in applications such as fruit sorting in post-harvesting processes, quality control of the seeds germination in nurseries, or fruit location in harvesting processes. This unit shows the elements and the six processing levels in a machine vision system (acquisition, pre-processing, segmentation, description, identification, and interpretation) together with more usual agricultural applications.
Unit 8. Agricultural robots As mentioned before, agriculture is a sector where robotics (manipulation and mobile) is being widely used. This unit shows both commercial and research robotic developments in order to increase the autonomous level of agricultural machines, production harvest in trees and plants, or processes like transplanting or cutting–sticking.

with an AC&R application in the agricultural field. The exercises include practical applications and situations that are very familiar to the students, in order to help them assimilating the studied concepts and techniques that are unknown for them at the beginning of the course. These exercises must be sent to the teachers via email, constituting the base of the grade.

- *Additional readings*. A set of papers (Journals, Conferences, and Congresses) and spreading slides presentations developed by the teachers are supplied to the students, including research and practical experiences related to the contents of the unit.
- *References*. This box comprises the basic and complementary bibliography used to elaborate on the documentation of the unit.

- Interactive and virtual tools. Many different interactive tools and virtual laboratories have been developed by the authors and some of them are used in this course to help the students to understand the evolved concepts and techniques. These tools will be commented on in the next section.

The students have also to do two practices using remote laboratories located at the automatic control, robotics, and machine vision laboratory of the University of Almería. The first deals with the design and implementation of a greenhouse temperature control algorithm using natural ventilation and heating systems, while the second is devoted to the design and implementation of an algorithm to manage a robotic cell to pick and place pots of ornamentals flowers in a greenhouse.

The main method of communication between the teachers and the students is by email, through which all queries and questions relating to the theory, problems, exercises, and practices can be handled. Furthermore, two debate chat forums are programmed during which all the comments (relative to the concepts treated in each one of the two modules) are discussed. In this way, a traditional classroom can be emulated, because all the course participants (teachers and students) are connected in real time 'talking' about the various applications of AC&R in several countries with different agricultural production models and sharing experiences. Participation in these chats is interesting as it enables questions to arise that could otherwise be ignored.

Course grade

The course grade is achieved based on the three following activities performed by the students.

1. *Exercises*. The students must work through the set of exercises proposed in each one of the learning units and send the solution to the teachers via email for their qualification. These are evaluated between 0 and 10 points, and all the students must attain a minimum of 5 points in each of the units. The evaluated and corrected exercises are fed back to the students, accompanied by comments.
2. *Remote laboratory practices*. As has been pointed out above, two practices are proposed at the end of each module, related to AC&R applications in agriculture. Both are evaluated between 5 and 10 points, and serve to modulate the qualification obtained in the exercises.
3. *Discussion forums*. At the end of each module, a discussion forum is proposed to find out the opinion and comments of the students and teachers about the course. Participation in these activities is also considered to fulfil the grade of the course.

NEW TECHNOLOGIES APPLIED IN THE COURSE

In the last decades our society has been seen huge advances in ICT, giving rise to innumerable changes in enterprise, cultural, social, and educational fields. These advances have promoted the development of new techniques and methods, opening a wide range of possibilities not only in the industrial area (remote control, remote management, flexible timetable, etc.) , but also in the field of education (distance education, interactive tools, remote and virtual laboratories, etc.), the rapid evolution of computers, the Internet, distributed computing facilitates and the development of feasible and cost-effective solutions.

The main advantages of ICT are related to teleaccess, teleoperation, and telecontrol. Until recently, the exchange of information was done using local networks for several reasons: information safety, narrow bandwidths, limited tools for the exchange of information, etc. Thanks to the advances in Internet technologies, a new method for accessing the information has appeared, the teleaccess, providing a way to access the information safely from any part of the world without temporal constraints. Both in the industrial and research/educational fields, high costs are often related to the restricted use of (usually expensive) systems with usage-time constraints, or to the displacements required to control them. With teleoperation (extension of sensorial capabilities and human skills to a remote place) and telecontrol (the specific part of teleoperation whose goal is to send commands to the actuators) technologies, it is possible to control systems remotely through the Internet, thus helping to reduce displacement costs and allowing one to extend the use of time-limited resources or equipment.

New teaching methods and innovative techniques have recently appeared, aimed at enhancing students' motivation and improving their education: multimedia tools, hypertext systems, interactive systems, information exchange between teacher and student through the Internet, access to informationfrom any part of the world without temporal constraints, etc. All these methods are involved and/or described by new terms such as: online learning, e-learning and distance learning [5]. Online learning constitutes just one part of technology-based learning and describes learning via the Internet, intranet and extranet. The levels of sophistication of online learning vary. A basic online learning program includes the text and graphics of the course, exercises, testing, and record keeping, such as test scores and bookmarks. A sophisticated online learning program also includes animations, simulations, audio and video sequences, expert discussion groups, online mentoring, links to material on a corporate intranet or the Web, and communication with corporate education records. The term 'online learning' can be used synonymously with 'Web-based learning' or 'Internet-based learning'. The term 'e-learning' covers a wide set of applications and processes, including computer-based learning, Web-based learning, virtual classrooms, and digital collaboration. E-learning can be defined as the delivery of content via all electronic media, including the Internet, intranets, extranets, satellite broadcast, audio/video tape, interactive TV, and CD-ROM. For this purpose the term e-learning is used synonymously with technology-based learning. Terms like e-learning, technology-based learning and Web-based learning are defined and used differently by different organizations and user groups. *Distance learning* is formed by all characteristics of e-learning plus text-based learning and courses conducted via written correspondence [5].

Based on these concepts, the course summarized in this paper belongs to the online-learning category. WebCT Campus Edition (CE) [6] has been used to set and manage the course structure, documentation availability, multimedia systems, and the control of the evaluation. In order to allow the students to put their knowledge into practice, several tools that will be described in the next section have been used.

Virtual learning with WebCT

WebCT Inc. is the world's leading provider of integrated e-Learning systems for higher education. WebCT CE allows course designers to create an interactive learning environment that brings instructors and students together in a virtual classroom. This online course management solution combines course development and delivery tools with a comprehensive course administration system. The users only need to know how to use a standard Web browser (the students for access and the teacher for the design and management tasks). WebCT CE provides several elements to design the course interface (colours, design of the page); a set of educative tools to facilitate the learning, communication and collaboration; and a set of administrative tools to help the teacher organize the distribution of the course. With WebCT CE, online courses can be created as an entirety or complement classroom-based courses, providing the course materials (text, equations, images, video and audio). Furthermore, WebCT CE permits: (1) evaluation of the students by means of quizzes and assignments; (2) communication with the students via discussions, email, real-time chat sessions, and an interactive whiteboard; (3) learning using a searchable index, glossary, and image database for each course; (4) the encouragement of student interaction by enabling the creation of student homepages and online presentations; (5) sharing of the course content with other designers and institutions; (6) recording, maintaining, and communicating grades; (7) student self-evaluation through self tests and progress tracking; and (8) obtaining data that allows the effectiveness of the course to be analysed [6].

The course can be found at the URL address of the Virtual Learning Unit (VLU) of the University of Almería, which manages all the e-learning activities organized by this University. One must log into WebCT CE with a student identification and password in order to get access to this course. This virtual course has been organized in the following four sections.

- *General information*. The contents, the planning, the grade method, and the study guide of the course are described in this section.
- *Calendar*. This section is used by the teachers to communicate the important dates to the students, such as the exam dates, chat sessions, or other classroom events.
- *Learning units*. This section groups all the documents of the course. The objectives, unit planning, and learning resources for each one of the eight units are described. The learning resources are given in a table of contents for quick access to a determined content, additional readings, unit exercises, references used, and remote laboratory practice if it is the final unit of a module. The students have permission to download or print all these documents if they prefer hard copies.
- *Communication tools*. WebCT CE includes some tools to facilitate the communication between the teachers and the students. This course uses three of them. 'Discussions' is a forum where messages can be sent and replied to within predefined topic areas; the messages content is generally limited to issues related to the topic area. 'Mail' is used when confidentiality is important, when the issue is specific to the message recipient, or when the issue is outside of the topic areas. Both 'Discussions' and 'Mail' use the same terminology and functionality, and allow students, instructors, and teaching assistants to engage in course communications at any time. 'Chat' allows logged-in users to exchange information in real time. Chat sessions can be pre-scheduled, or users can communicate with whoever happens to be logged in at the time. Chat is restricted to text-only communication [6].

Interactive tools for teaching AC&R

Interactive tools are one of the most remarkable advances that have arisen in the educational field, thanks to unprecedented challenges in the new technologies. Interactive tools are powerful elements that help the students to enhance their skill, motivation, and ability to understand and solve control problems, attempting to 'demystify' abstract mathematical concepts through visualization by using specially chosen examples [7]. The AC&R theory covers many topics and a good engineer must handle the basic concepts, techniques and ideas, and must be able to use all of them in real problems. The need for providing students with both a strong theoretical base and engineering ability is a major challenge in AC&R education [8].

As commented in [7], the continuous increase in computer processing power allows the use of interactive tools to merge the synthesis and analysis phases of classical engineering iterative design techniques into one. In this way, the modification of any configuration, parameter, or element in the system produces an immediate effect in the rest, and thus the design procedure becomes really dynamic and the compromises that can be achieved are identified more easily.

Many tools for control education have been developed over the years, incorporating the concepts of dynamic pictures and virtual interactive systems [9]. Nowadays a new generation of software packages has appeared, based on objects that admit a direct graphic manipulation and are automatically updated, so that the relationships between them are continuously maintained. Ictools and CCSdemo [8, 9], developed in the Department of Automatic Control at Lund Institute of Technology or SysQuake in the Institut d'Automátique of the Federal Polytechnic School of Lausanne [10] are good examples of this new educational philosophy of teaching.

The authors of this course have experience in this field (e.g. [7, 11, 12–14]) and reduced versions of three interactive tools have been used to enhance students' knowledge and skills in modelling, control and robotics, evolving only the concepts that an agricultural engineer requires. These tools are sent to the students via email and can be obtained by contacting the authors. One consideration that must be kept in mind is that the tool's main feature, interactivity, cannot be easily illustrated in a written text. Nevertheless, some of the advantages of the application are shown below.

Systems modelling and analysis tool

The tool has been developed using Sysquake [10] and was created using the huge library of interactive components developed by Professor Dormido. This tool helps students to perform the study, analysis, and simulation of dynamic systems interactively. The application is available in two versions, one for first order systems (Fig. 1(a)) and other for second-order systems (Fig. 1(b)). The reason for paying attention to first- and second-order dynamical systems is twofold. First, these kinds of systems described by ordinary first- and second-order differential equations (which have a direct interpretation in the Laplace domain using block diagrams based on the transfer function concept) are described in all the classical control textbooks and can be found elsewhere (e.g. [15, 16]). Secondly, many agricultural systems, when linearized around an operating point, can be described as first-order linear dynamical systems (e.g. dependence of greenhouse temperature with vents opening or heating, water level in tanks, etc.) or second-order ones (e.g. valves, level of tanks in series, etc.). Descriptions of these can also be found in agronomical textbooks (e.g. [17, 18, 19]). Using the tool it is possible to modify the different characteristic parameters of the systems using the knobs or hovering directly over the graphs, and to observe the dynamical responses and the pole placement of the systems (which determine the behaviour of the system) immediately. Some comments regarding nonlinear modelling are included in the course and related references.

Analysis and design of PID (proportional, integral, and derivate) controller's tool

Once the students have the necessary knowledge of analysis and modelling dynamical systems and

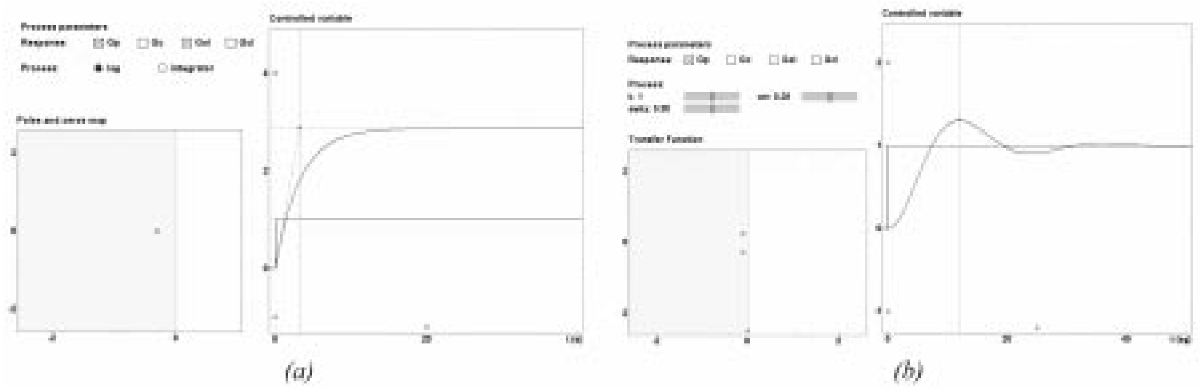

Fig. 1. Interactive tools for modelling and analysis of systems: (a) first-order systems; (b) second-order systems.

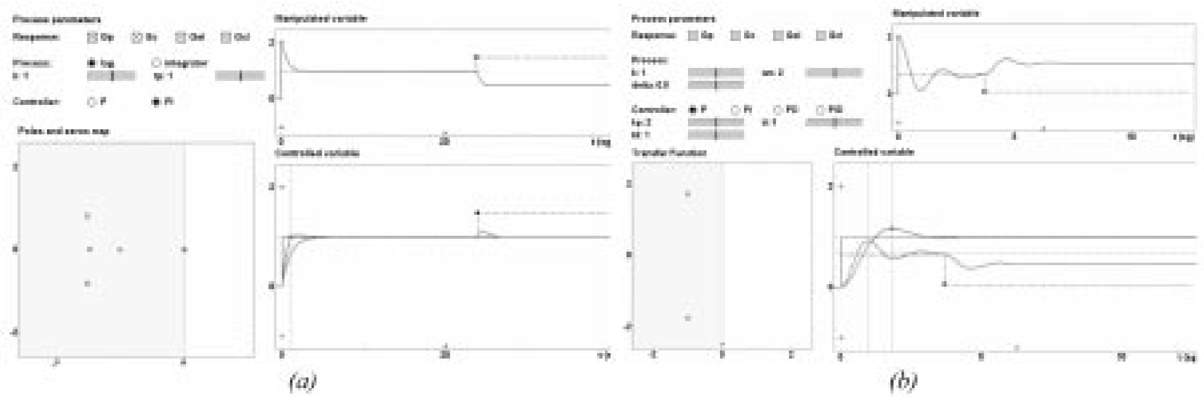

Fig. 2. Analysis and design of PID controllers: (a) first-order systems; (b) second-order systems.

design of classical controllers, they can use another interactive tool (an extension of the previous one) to see the effects of the PID algorithm when controlling agricultural processes. The action of this controller is based on the error, error integral, and error derivative between the desired trajectory and the real process output. Several application examples, such as pH control of the solution of fertilizers, greenhouse temperature control, etc., are shown. A description of this kind of control algorithm can be found in any control book and even in several agricultural textbooks (e.g. [15, 16, 18]). The tool allows one to interactively re-tune the controller, compare the open-loop and closed-loop responses, study the response to disturbances, and perform the typical analysis of the control system design. The tool is available in two versions: for first order systems (Fig. 2(a)) and for second order systems (Fig. 2(b)).

Virtual lab for teaching greenhouse climate control

The main aim of the tool is to facilitate the study and understanding of the main issues involved in modelling and climatic control of greenhouses. The tool consists of a graphic screen connected to the algorithms and a model implemented in Matlab/Simulink [20]. This model is used by the students to understand the process dynamics in order to obtain the model parameters. In this way, they can design the controllers and test them in the virtual lab. The tool is shown in Fig. 3, where the laboratory screen has been divided into three parts [21]: greenhouse synoptic, a set of graphs to show the different variables, and several buttons and sliders to allow the modification of the control parameters.

The greenhouse synoptic is shown in the left upper part of the main screen. In this area it is possible to monitor the crop growth and the effect of the control signals through the actuators' movements: natural ventilation, shade screen, and heating based on a boiler. The lateral and roof ventilation positions are changed taking into account the value of the associated control signal. The actual value of the vents opening is shown as a percentage below the roof ventilations and next to the right side ventilation. The shade screen is located between the greenhouse and its cover; its length can be modified based on the associated control signal. The third actuator is the heating. This system has been represented by a boiler, a pump and several pipes. A colour code is used: pump and boiler off/on (blue/green); pipe temperature (grey to red, based on its value). The numerical value of the pipes temperature is shown next to the boiler, as can be seen in Fig. 3, where an example of heating is shown. The crop growth is considered as a disturbance for the system, and it is possible to modify this parameter in the graphical screen. Several plants are shown in the synoptic where their size is changed, based on the value of this disturbance.

Regarding the other parts of the tool, several graphs with different variables are shown on the right of Fig. 3. From left to right and up to down, the graphs contain the following information: (1) variables related to the temperature evolution: inside temperature, outside temperature, and day and night temperature setpoints; (2) information about the control signals: vents opening, shade screen opening, temperature of the heating pipes, and integral signal of the heating controller to explain anti-windup schemes; (3) information about the radiation: outside PAR radiation, inside PAR radiation, radiation setpoint, and the dead-zone for shade screen controller; (4) wind speed and (5) the relative humidity. The evolution of the outside temperature and wind speed are important for control purposes, as the proportional gain of the gain scheduling controller for the temperature control with ventilation shown in the last graph depends on these variables.

The last part of the tool corresponds to the control parameters. This window is located below the greenhouse synoptic as seen in Fig. 3. In the first column there are three buttons, three edit fields, and one checkbox. The buttons allow initializing, pausing, and reinitializing the simulation; in the edit fields it is possible to modify the temperature and radiation setpoints, while the checkbox is used to start the simulation during the day or the night. The next two columns contain

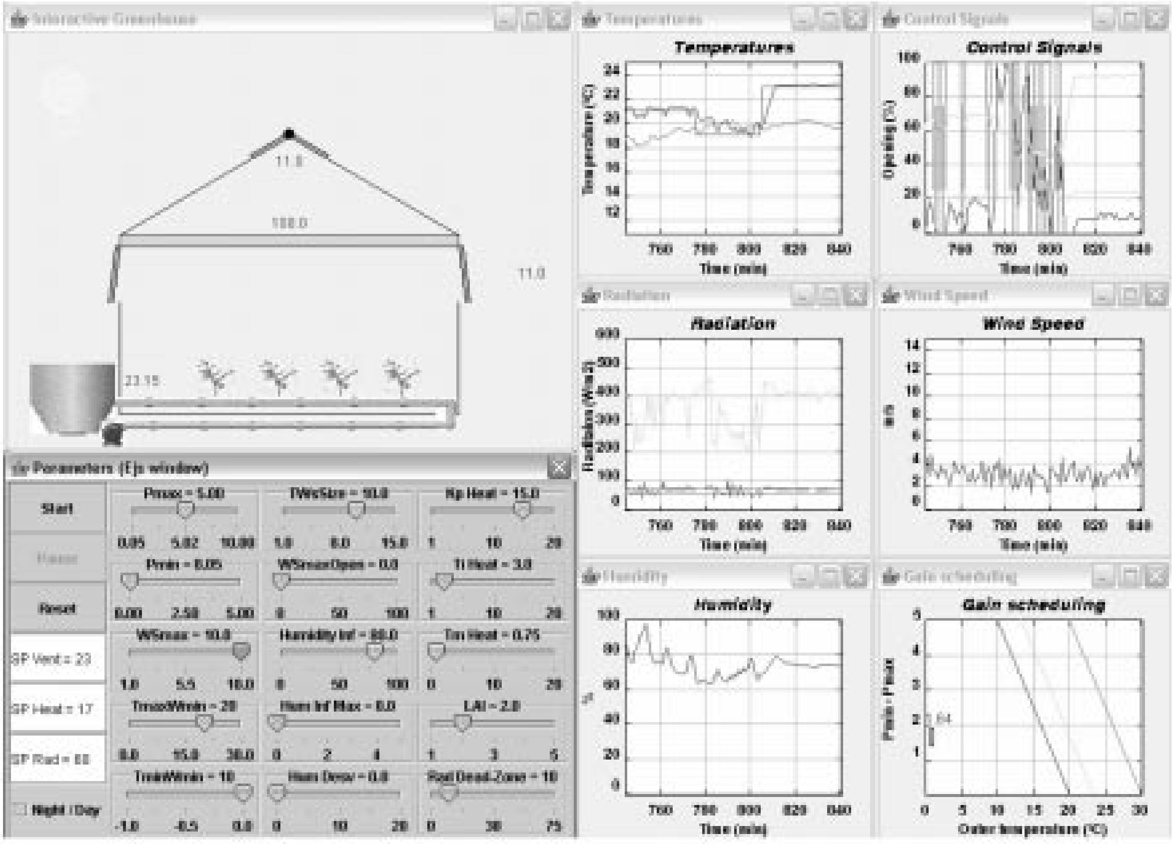

Fig. 3. Main screen of the virtual lab for teaching greenhouse climate control.

the control parameters related to temperature control with ventilation using a gain scheduling controller, to account for the influence of the wind speed and the outside temperature in the calculation of the controller parameters. The other parameters of these columns allow one to set the maximum opening for the ventilation when the wind exceeds the maximum speed, and also to modify the parameters associated to the setpoint modification based on the humidity. With respect to the last column, the first three parameters are used to modify the parameters of a PI+anti-windup temperature controller using heating. The last two parameters allow modifying the effect of the crop growth based on Leaf Area Index (LAI) and the dead zone of the on/off controller for the radiation control with shade screen, respectively. The control algorithms are described in [19] and [20].

The environment Easy Java Simulations (EJS) is a software tool designed for the creation of discrete computer simulations [22]. It was used to develop the tool, because it is easy to use, the development language is available in many platforms (Java), it can be connected to Matlab/Simulink, and very good results have been obtained in previous works.

Manipulation robotics tool

The advances experimented with in the inclusion of interactive tools within the robotics education framework have not been as significant as those in the automatic control field. However, many local simulation tools and remote and virtual labs have been used, as is shown in the next section.

A tool has been developed (in Spanish) aimed at defining and programming a robotized cell interactively (see Fig. 4) [23]. This tool is used to learn the basic concepts of manipulation robotics that can be encountered in basic textbooks (actuators, sensors, morphology, kinematics modelling and control, robot programming, etc., e.g. [24]) using typical cell robots and programming languages. The following operations can be performed with the tool.

- *The configuration of the simulation screen*. The user can define the number of cell views. There are several views configured by default: central view, left view, etc. It is also possible to change the shading view: solid, meshed, or softened.
- *The definition of the simulation environment*. The application allows defining personalized environments with several objects and devices.
- *The definition of the robots positions*. It is possible to move the robot interactively with knobs, dragging over the robot with the mouse, or introducing the desired positions from the keyboard. The user can record the different positions that have been reached by the robot at any time.

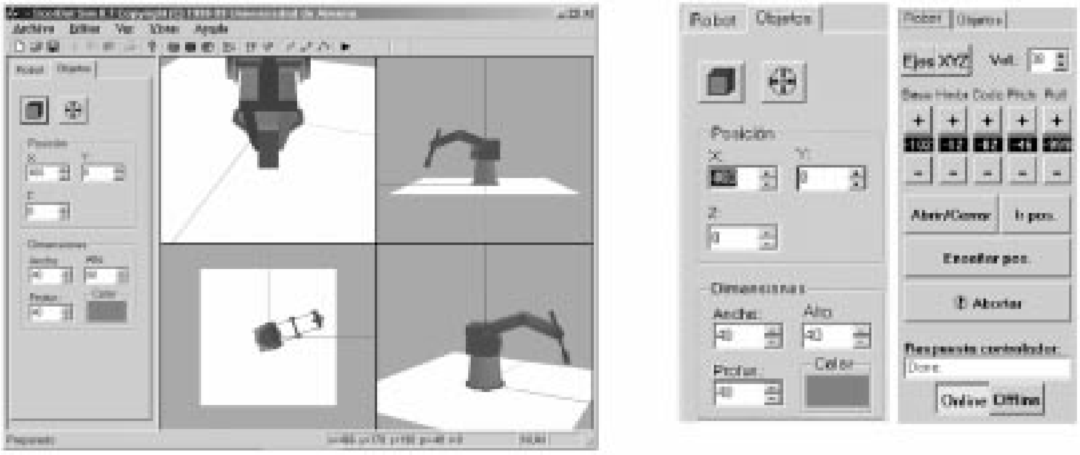

Fig. 4. Interactive tool for manipulation robotics: (a) main screen; (b) definition of objects and positions.

- *The running programs*. Once the cell elements and the robot positions have been defined, it is possible to run a program in the new virtual cell. The program can be run step by step or in a complete cycle.
- *The visualization of information*. This screen shows the information of the different elements: final position of the robot, values of each articulation coordinates, input and output states of the controller, etc.

The main features of this tool are based on a robotized cell that is installed in the University of Almería, which is described in the next section.

Teaching AC&R using WWW

Sometimes it is necessary to incorporate contents with a strong experimental component and let the students apply their acquired knowledge to real systems. Traditionally, local simulation tools or local laboratories have been used for this purpose, but with space and time constraints. Nowadays, and thanks to advances in ICT, especially in Internet technologies, the laboratory environment can be transferred to distance education. Based on these premises, two new concepts have appeared within the distance education framework: virtual laboratories and remote laboratories. The first of these are a new kind of simulation tools that is much more powerful than the traditional ones, allowing the simultaneous use of remote simulation modules by the students. On the other hand, remote laboratories permit the students to perform the main laboratory activities remotely, without requiring their presence at the place where the hardware is placed, in such a way that they can control and monitor physical devices 24 hours a day at any time and anywhere, interacting with the teacher without having to travel to the university. Remote labs help the students to put into practice the concepts that they have learned by remotely accessing real systems.

In order to provide this course with the strong practical component that it requires, two remote labs have been used. One important aspect of a remote laboratory is for students to feel that they are controlling a real system. One way to do this is by using visual feedback. Because of this, a video server (AXIS 2400) and two charge coupled device (CCD) cameras have been used to view the remote labs that are presented in the next two subsections.

Web-based remote control laboratory using a greenhouse scale model

Taking into account the contents of the course, it was considered necessary to have the opportunity to perform quasi-real tests using a greenhouse without temporal and spatial constraints. Keeping this in mind, a greenhouse scale model (Fig. 5) was developed under the framework of the *DAMOCIA* project (Computer-Aided Design for the Construction of Automated Greenhouses) financed by ESPRIT Information Technologies Programme of the European Union (http://www.cordis.lu/esprit/home.html) (Special Action P7510) [25].

Several sensors have been installed to measure the main variables to be controlled: inside air temperature and humidity and inside photosynthesis active radiation (*PAR*). An external meteorological station has also been placed to measure outside temperature, global and PAR radiation, humidity, wind speed and wind direction. The solar radiation variations are simulated using a 500 W focus placed on the greenhouse scale model. Wind speed is also simulated using a direct current (DC) ventilator controlled via the serial port. There also exists the possibility of reading data from files obtained from experiences in real greenhouses. From the control point of view, the scale model is provided with a natural ventilation system (with two DC motors for roof and lateral vents aperture), a forced ventilation system (with a DC ventilator), a simulated irrigation and fertilization system (with leds), a simulated distributed pipes heating system (with leds), a heating system using resistances, and a shade screen (with one DC motor). The motors are activated using a set of relays controlled by the serial port. Two control modules for serial ports (based on RS232 protocol) have also been used for acquiring the data.

A tool has been developed that incorporates the acquisition and control interfaces to allow the students to perform tests remotely [26]. A Website for the remote laboratory (http://aer.ual.es/maqueta/) has been created, whose main page is shown in Fig. 5. The remote lab management tool was developed using LabVIEW [27]. An example of the application is shown at the left bottom of Fig. 5.

The greenhouse scale model is used in the laboratory sessions for implementing basic control tasks using the main actuators installed in greenhouse climate control systems and the fertilisers and irrigation elements. It allows the use of different types of controllers, because the greenhouse, the correcting equipment, and the power supply constitute an independent system. On the other hand, different types of control algorithms can be implemented in order to study the variable response of the actuators.

Using this remote lab the students can test the modelling and control results obtained analytically and with simulations (using the interactive tool presented in the previous section). The algorithm can be developed in Matlab [28] and at the end of the tests, a Webpage with graphical and text results is automatically created. An example of greenhouse temperature control using the heating system is shown at the right bottom of Fig. 5, where the temperature tracks the setpoint trajectories.

Remote programming of robot manipulators

As mentioned in the previous section, it was necessary to develop a remote robot programming laboratory to test on a real robot cell the programs used in the simulation tests previously performed using the interactive tool (see Fig. 4).

The robotic cell is shown in Fig. 6(a); it comprises the following elements.

- *Mechanical arm*. Robotic manipulator Scorbot ER V-Plus of Eshed Robotec Ltd with five degrees of freedom.
- Multitasking *controller* in real time, which allows several programs to run simultaneously.
- *Teach pendant,* which allows the control of the joints, the definition of the positions using the auto-learning method, and the execution of programs that are in the controller.
- A *conveyor* with an alternating current (AC) engine, which is controlled using a speed regulator connected to the robot controller.
- Photoelectric *sensors* to detect the presence of an object on the conveyor.
- *Vision system* composed by a CCD colour camera and a capture video card with frame grabber.
- *Computer* connected to the controller via RS-232 to manage the cell.

In order to access remotely to the system and to test the algorithms, a system developed in Java, Javascript and C++ Builder has been used [29] (see Fig. 6(b)). The students can write an ACL (Advanced Control Language) program via Web, can compile it and check the errors remotely. Once

Fig. 5. Greenhouse scale model, Website, and practice results.

(a) Robotized cell (b) Web site for remote programming (in Spanish)

Fig. 6. Robotics remote lab

the program is error-free, it can be tested in the real cell.

At present, there are many trends in greenhouse crop production of ornamental plants to optimize the soil surface, so that the installation of conveyors to move pots to a work-station where the grower can carry out the basic operations on the plants, such as planting or grafting, is required. In order to load and unload the pots, robot manipulators are used. In the proposed exercise, the students have to design and implement a program that simulates this kind of work. They have to detect the presence of a pot being carried on a conveyor, and pick and place it at a determined location, based on the input states of the system.

FEEDBACK FROM THE STUDENTS

To obtain feedback from the students, the teachers opened forums by asking a variety of questions regarding the schedule of the course, contents, etc. The general opinion of the students (11 answers were obtained) is that the quality and material of the course are quite adequate, fulfilling what they expected. The use of interactive tools and remote labs was surprisingly positive for them, as they had the opportunity of putting into practice the knowledge they had gained. As we expected, the main difficulty in following the course was in those units where basic concepts of modelling and control were introduced, as a mathematical basis on differential equations and Laplace transforms was required (not all the students had the same previous knowledge that the students on these issues). Obviously, those units devoted to AC&R applications in agriculture were well accepted and understood by the students. The students also pointed out that the course should include more forums and even chat sessions, but from our view this is a quite time-consuming task and sometimes what the students want from the teacher is to obtain the answer to exercises that they should obtain by themselves.

On the other hand, each of the students looked for different agricultural systems in their respective countries where the techniques learned during the course could be applied. In fact, some of the students intend to incorporate these aspects into their Ph.D. theses.

CONCLUSIONS

This paper describes a virtual online course on automation and robotics applied to agricultural systems, and more specifically, to greenhouse crop production. It has been developed using ICT technologies for teaching all the related concepts and techniques, because they facilitate learning and access to remote laboratories by the students from different geographical areas.

The theoretical part of this course was developed using hypertext systems, and it was complemented with several exercises. As pointed out in [7] and based on this experience, a general recommendation for automatic control and robotics engineering education is that students be made aware of problems and potential solutions arising from the increasing complexity of our agricultural technological systems. Laboratory experience (real or interactive) is extremely important as a part of control learning. The goals of control education that might be kept in mind regardless of the specific choice of material or the structure of the course are the following:

- to provide the basis for lifetime learning so that new control problems can be dealt with;
- to establish and maintain high standards of excellence for the experience of learning the foundations of control.

From the authors' point of view, the teacher must transmit his or her experiences and ideas to the students but not all; some of these ideas have to be found out by the students themselves. The hypertext systems, interactive tools, and remote labs are very powerful elements, helping the students to enhance their skill, motivation, and ability to understand and solve engineering problems.

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Francisco Rodríguez is an associate professor of systems engineering and automatic control at the University of Almería (Spain). He obtained his telecommunication engineering degree from Madrid Polytechnics University (Spain) and his Ph.D. degree from the University of Almería, in 2002. Currently he is a researcher and member of the Automatic Control, Electronics, and Robotics group of the University of Almería. His scientific interests are focused on the application of modelling, automatic control, and robotics techniques to agricultural systems and education.

Manuel Berenguel is an associate professor of systems engineering and automatic control. He is responsible for the Automatic Control, Electronics, and Robotics Group at the University of Almería, Spain. He obtained an industrial engineering degree and a Ph.D. from the University of Seville, Spain, where he received an award for the best engineering thesis of the year. He was also a researcher and associate professor at the University of Seville for six years. His research interests are in the fields of predictive, adaptive, and robust control with applications to solar energy systems, agriculture, and biotechnology.

José Luís Guzmán obtained a computer science engineering degree in 2002 and a Ph.D. in 2006 both from the University of Almería, Spain, where he is a researcher of the Automatic control, Electronics, and Robotics group. Currently his scientific interests are focus on the field of control education and model predictive control techniques, with applications to interactive tools, virtual and remote labs and agricultural processes.

Sebastián Dormido holds a degree in physics from the Complutense University in Madrid, Spain (1968) and a Ph.D. from University of The Basque Country, Spain (1971). In 1981, he was appointed professor of control engineering at the Universidad Nacional de Educación a Distancia. His scientific activities include computer control of industrial processes, model-based predictive control, robust control, and modelling and simulation of continuous processes. He has authored and co-authored more than 150 technical papers in international journals and conferences. Since 2002, he has been president of the Spanish Association of Automatic Control CEA-IFAC, where he promotes academic and industrial relations.