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An Approach for Building Innovative Educational Environments for Mobile Robotics*

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This paper presents an approach to building innovative environments for mobile robotics education. The proposed approach can be used to create new courses or to update existing courses that are currently taught in a traditional way. It has been successfully used to build an innovative teaching environment in the field of indoor mobile robotics at Carlos III University of Madrid. A postgraduate course on intelligent autonomous robots has also been updated based on this approach.

Keywords: tele-education; mobile robotics; remote laboratory; remote experimentation

INTRODUCTION

IN THE LAST DECADE, several educational environments with varying capabilities and philosophies have been developed in order to inspire students' interest in mobile robotics and motivate them to participate actively in the learning process. These systems aim to benefit from the currently available telematics (*tele*communication + infor*matics*) technologies to implement innovative pedagogical paradigms (e.g. distance learning, sharing of course materials, remote and virtual laboratories, etc.).

While there are many benefits to using totally Web-based education, the production of learning content, which incorporates both well-organized theoretical and experimental contents, is still expensive. At the same time, new learning requirements are emerging, with a shift towards personalized learning services. Thus, more cost effective learning environments are required, based on open standards and reusable learning objects. Also, factors such as the increase in bandwidth and the availability of higher speed, secure and reliable network access will play an important role in the user adoption of totally Web-based education systems. Solving these challenging problems will put engineering education on the brink of a new era.

Robotics challenges traditional engineering disciplines because the integrated approach in the selection of means to the intended functional ends must intrinsically involve a team activity, and crossing the boundaries between conventional engineering disciplines. Unlike traditional fields, robotics is still an emerging field that combines the essential elements of mechanical engineering, electrical engineering, and computer science. Relatively few robotics education programmes exist at graduate level, and even fewer exist at undergraduate level. The courses that are in existence are still new and are open to rapid change and new approaches. Course goals can change from year to year as new technologies and theories are introduced into the field at large.

To build an educational environment for a field like mobile robotics, it is recommended that one combines the traditional educational tools with telematics-based tools. The telematics-based tools can support the traditional tools and can solve the traditional teaching constraints of curriculum, class size and limited resources. However, these tools cannot totally replace traditional education tools, especially in a cross-disciplinary field like robotics. A real interaction with a robot is necessary to give the students hands-on robotics experience and to help them to understand real-world problems and be able to identify these problems and formulate applicable cost-effective solutions.

Much of the current research in new robotics education environments is concerned with the use of Web-based instructional activities to map traditional educational models. NASA presents many online robotics courses through the Robotics Alliance project [1]. Many subjects related to mobile robots have been introduced in online courses [2]. McKee has proposed an online environment for teaching robotics and artificial intelligence [3, 4]. The learning taxonomy used in this project was the simple stop–look–act cycle, which provides an interactive form of learning. Many other researchers have tried to build remote and distributed laboratories to facilitate remote experimentation and hardware resources exchange [5].

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The design and the implementation of remote experiments on motor control of mobile robots are addressed in [6], with particular emphasis on user interface enhancement through the use of virtual reality models, as well as on network performance tests. Multilayer software architecture was presented in [7] to facilitate remote interaction with mobile robots. The project TEAM (Tele-Education in Aerospace and Mechatronics) [8] and IECAT (Innovative Educational Concepts for Autonomous and Teleoperated Systems) [9] are two examples of distributed laboratories.

Most of the previous work has been developed to cover certain subjects by providing online experiments or online classes without providing any kind of generic tools for the remote users by which they could customize the learning objects according to their needs. Moreover, some types of tools must be provided to give the student the possibility of playing an active and creative role in the learning process. The face-to-face interaction between the student and the tutor and between the student and the machine is a very important issue in a field like robotics.

This paper presents an approach that can be used to build innovative educational environments for mobile robotics. These environments combine different instructional and constructional activities based on traditional and Web-based education models. The paper is divided into six sections. The first section gives a brief description of the advances in robotics educational environments. The advantages and the disadvantages of the traditional education model (TEM) and the Web-based education model (WEM) are presented in the second section. The third section briefly describes the state of the art of robotics education in Spain. The proposed approach is described in the fourth section followed in the next section by the application of this approach to updating a postgraduate course on intelligent autonomous vehicles. The last section provides the conclusions.

EDUCATION MODELS

The main objectives of the educational environment are to inspire students' interest in the subject and motivate them to participate and play an active role in the learning process. The following sections discuss two education models that can be used to build educational environments.

Traditional Education Model (TEM)

Lectures, laboratory sessions and student assessment (homework and tests) are the commonly used traditional approaches in any education system. The curriculum content is usually fixed and presented in a linear and sequential way. This model of education is also quite entrenched and the flow of knowledge is largely unidirectional, especially in the large classes, with the exception of occasional questions and discussion. The number of questions and amount of discussion is usually inversely proportional to the class size, so that large classes often become the academic analogy of watching an informational video [10]. Nevertheless, this model has the advantage of providing face-to-face interaction between the students and the teaching staff, and between the student and the machine, and therefore it decreases the students' feeling of isolation, something that they can feel when totally using a Web-based education system.

Web-based Education Model (WEM)

The Internet provides a global, integrated communication infrastructure that enables an easy implementation of distributed systems. This evolution has made participation in tele-education a reality for anyone. The Web-based education model (WEM) uses telematics technology to map the traditional teaching and learning activities in an educational process where the instructor and the students are geographically separated. What is important in the understanding of this model is not the evolution of the hardware or underlying network but the evolution of the usage of the Internet, and the role that it plays in the lives of the users. In the Web-based education model, traditional learning activities are simulated using online classes, virtual, remote or distributed laboratories and online assessment tools. In this model, the conventional techniques of human interaction such as conversation, using a book, a telephone call, TV or a letter have their analogies in telematics-based techniques such as videoconferencing, Websites, Internet telephony and E-mail.

WEM vs. TEM

Although the Web-based education model offers several logistical, instructional and economic advantages, it has many limitations [11, 12]. Among these are the lack of face-to-face interaction, the limitation in bandwidth, the time delay and the security and reliability of Internet-based systems. Table 1 shows a brief comparison between the two models. This comparison shows the need to integrate both the models to build an innovative educational environment that combines various activities based on both the models. In these innovative educational environments, the WEM-based tools are distinguished from TEM-based tools but these tools cannot be viewed as a replacement for, or a competitor to, traditional tools. Instead, they are possible extensions to traditional tools and open new opportunities that are not entirely realized within the traditional model of education, and at an affordable price.

ROBOTICS EDUCATION IN SPAIN

In Spain, the traditional engineering education system is oriented towards producing industrial

Table 1 TEM vs. WEM

Item	TEM	WEM
Accessing and searching for updated materials	✘	✔
Learning from stored anecdotal knowledge	✘	✔
Face-to-face interaction	✔	✘
Immediate feedback/comparison with the other students	✘	✔
Participation level in large classes	✘	✔
Immediate reports of class performance to instructor	✘	✔
Increased students' feeling of control over their learning experience	✘	✔
Decreased students' feeling of isolation	✔	✘
Hands-on engineering experience	✔	✘
Number and variety of learners	✘	✔
Less classroom requirements	✘	✔
System availability and flexibility	✘	✔

engineers with wide specializations. To start the degree course, students must have completed secondary education successfully, as well as passed a university entrance examination. The studies are organised in three cycles, each of which leads to a degree that is fully recognised by the State. Each cycle constitutes an educational unit, with specific educational aims and an autonomous academic status. Universities have academic autonomy and freedom to design their own syllabuses—which might differ, to a certain extent, from one university to another—leading to the same official qualifications. Theoretical subjects consist of theory credits and practical credits. The workshops and laboratory sessions are aimed at the consolidation and integration of the students' knowledge [13].

The tele-education sector in Spain is an active sector that has expanded rapidly to occupy an important place in the Spanish educational scene. Many specialized universities, such as the National University of Distance Education (UNED) and the Open University of Catalonia (UOC), offer a variety of courses based on the Web-based education paradigm [14, 15]. Other traditional universities have adopted this paradigm to facilitate communication between all the university community members and to improve the teaching and learning processes. The Carlos III University of Madrid has developed a new Web-based environment called 'Campus Global' that allows students and staff access to personalized educational resources and services [16].

A considerable number of higher education institutions in Spain are now offering robotics education as a part of industrial automation courses at undergraduate level. In recent decades, the number of specialized robotics courses at postgraduate level as well as vocational training courses, has been increased in Spanish universities and research centres.

The Polytechnic High School at Carlos III University of Madrid has established some robotics courses within an integrated interdepartmental doctoral programme of electrical, electronic and automatic engineering, which encompass task and movement planning of robots, integrated automation, advanced modelling and simulation of dynamic systems, industrial automation and intelligent autonomous vehicles.

DESCRIPTION OF THE APPROACH

The proposed approach can be used to build innovative teaching environments that are more efficient and cost effective and provide more motivating courses for the students. This approach can also be used to update courses that are currently taught in the traditional way. It has successfully been used to build an innovative teaching environment in the field of indoor mobile robotics at Carlos III University of Madrid, as described in the next section.

As shown in Fig. 1, this approach combines different activities to solve the traditional teaching constraints of curriculum, class size and limited resources and to increase the students' motivation to have an active and creative role in the learning process. The following subsections describe in details the different activities that can be involved in the educational environment.

Instructional activities

Instructional activities can combine two types of activities based on the traditional education model and the Web-based model as shown in Fig. 1.

TEM-based activities. These activities encompass the traditional methods commonly used in any education system, such as lectures, laboratory sessions, seminars and student assessments (homework and tests). In this model, the effective instruction is guided by general pedagogical approaches and specific instructional practices. These practices have to focus on the curriculum, the prior experiences and knowledge of the students, learner interests, student learning styles, and the developmental levels of the learner. The traditional activities have the advantage of providing face-to-face interaction between the students and teaching staff and between the student and the machine, and therefore they decrease the students' feeling of isolation. In the traditional education model, different instructional models have been proposed to select and to structure teaching strategies, methods, skills, and student activities for a particular instructional emphasis [17].

WEM-based activities. These activities are implemented based on a Web-based education model to map traditional teaching and learning activities. In this indirect instruction model, the teacher arranges the learning environment, provides opportunities

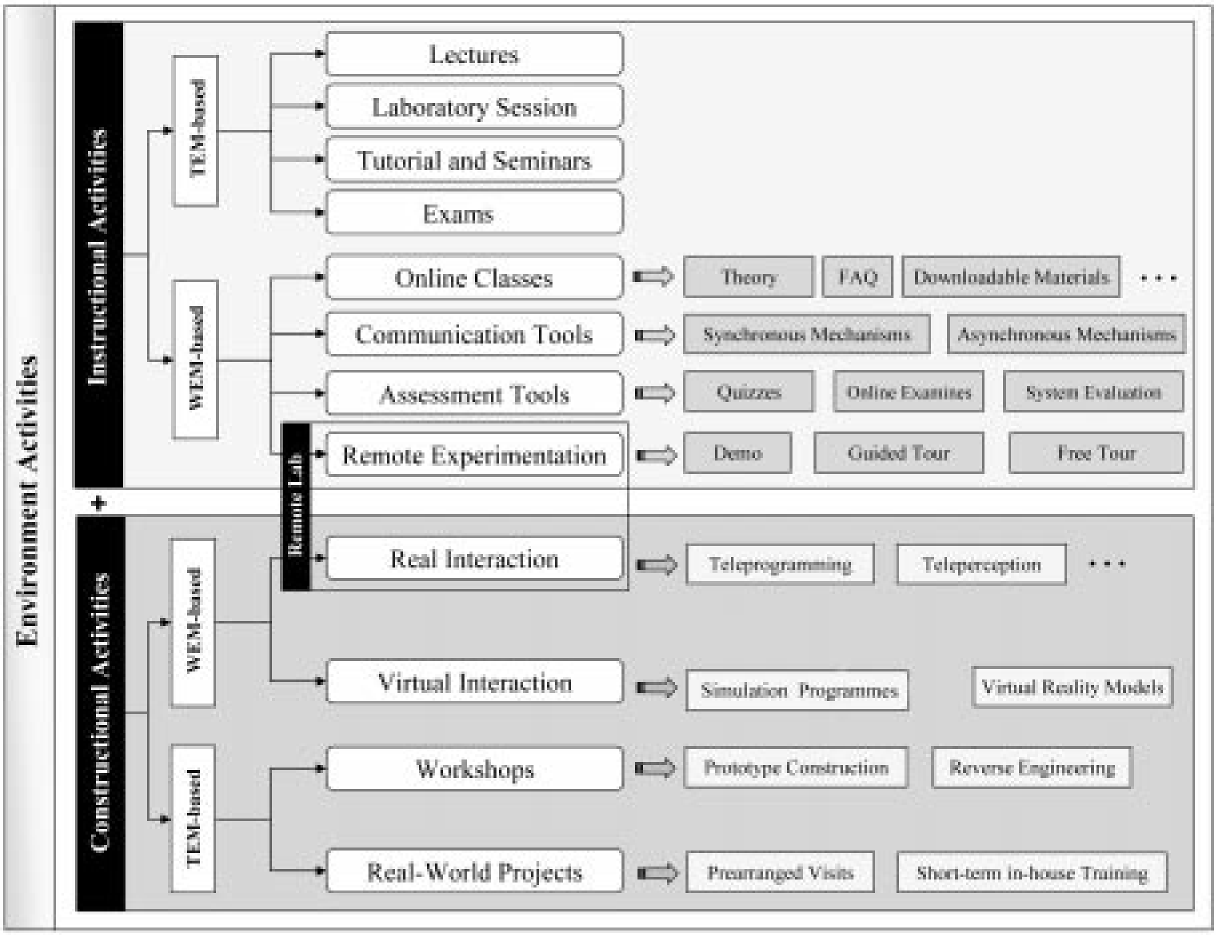


Fig. 1. Environment activities.

for student involvement and, when appropriate, provides feedback to students while they conduct the inquiry [18]. In other words, the role of teachers and students change. Teachers are changed from lecturers to assistants. Students are changed from listeners to active participants. These activities involve online classes, a remote laboratory, assessment tools and communication tools.

Online classes

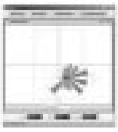
Online classes are used to map the traditional classroom. Bourne *et al.* proposed the organization of online lecture material according to well-known taxonomies in education [10]. Barrett's Learning Taxonomy proposes that learning should be divided into four categories: literal, inferential, applicative and evaluative. Merrill's Learning Taxonomy classifies the learning outcomes into three categories: a performance or remember, use, and find (create) [10]. In this taxonomy, the learning content is classified as fact, concept (classification), procedure and principle. Table 2 shows examples of learning outcomes in a mobile robotics course according to Barret and Merritt taxonomies.

Remote laboratories

Remote laboratories can be considered innovative environments that can be used to provide remote interaction with mobile robots for educational and research purposes. They can be defined as network-based laboratories where the user and the real laboratory equipment are geographically separated and where telecommunication technologies are used to give users access to laboratory equipment [7]. Such laboratories have the advantage of not being restricted to synchronized attendance by instructors and students: thus they have the potential to provide constant access whenever they are needed by students.

Many such remote facilities can be put together to form a framework or a distributed laboratory that can be used to provide a coordinated set of experiments for students with hardware facilities physically spread over different locations, but accessible via the Internet. The project IECAT in which we have participated is an example of such a framework in the field of autonomous and teleoperated systems [9]. Such frameworks aim to be electronic workspaces for distance collaboration and experimentation in research or in another creative activity, to generate and deliver results using distributed information and communication technologies. They assist in the exchange of existing hardware resources and educational materials between the partners.

Table 2 Learning outcomes

Knowledge	Example	Barrett	Merrill
Identification	What is a robot? What are the main components of a mobile robot?	Literal	Remember Fact
Recognize types of components and circuits	 Given these sensorial data, determine what is the source of these data?	Inferential	Use Concepts (Classify into categories)
Linkage to real world complexity	 This figure indicates that there are some measures out of the range of the lab borders. What is your hypothesis for this unexpected result?	Applicative	Use principles
Specifications	Evaluate line following skill, then design and build a circuit to implement the control strategy in a micro robot.	Evaluative	Find Principles

The building of such laboratories for laboratory experiments in a field such as mobile robots requires expertise in a number of different disciplines, such as Internet programming, telematics and mechatronics systems, etc. Also an intuitive user interface is required so that inexperienced people can remotely control the robot. The implementation of such a laboratory is basically based on the concept of tele-operation or remote control [7].

Online assessment

The method of assessment is an important aspect of every course. Traditionally, the manual handling of assessments incurred a major overhead in the marking and processing of these assessments. So, in most courses, assessments or quizzes are usually kept to the minimum necessary to assess progress or competence accurately. Using telematics technology, it will be easy to construct systems that automatically correct and handle quizzes for the teaching staff and that reduce the time taken to carry out other forms of assessment. Evaluative tests can be used to provide online assessments. Student first take an exam and then, based on the results of the exam, customized learning activities can be generated to reinforce the areas in which the students scored poorly. Moreover practice tests can be designed to cover the experimental issues as a simulation to traditional laboratories.

Communication tools

An essential part of any learning experience is communication. Two communication mechanisms (synchronous such as text/audio/video chat, Internet telephony and video-conference and asynchronous such as E-mail, newsgroups and mailing lists) can be implemented to provide communication between students and teaching staff.

Constructional activities

Constructionism is an active learning process in which students construct things that are personally meaningful to them or others around them [19]. Instead of being served up information in the traditional one-way setting, students develop their own knowledge and understandings of a subject through physical construction and implementation of their ideas. The constructional activities give the students the opportunity to physically construct and implement the ideas derived from the course. These activities include TEM-based activities and WEM-based activities as shown in Fig. 1.

TEM-based activities. The TEM-based activities such as the design and construction of new prototypes or reverse-engineering of existing systems are used to provide face-to-face interaction between the students and teaching staff and between the student and the machine, therefore decreasing the students' feelings of isolation. These activities also involve actively encouraging students to be in contact with real-world robotics projects through prearranged visits to the robotics industry, participating in related scientific events and short-term in-house training. These activities give the student valuable hands-on engineering experience.

WEM-based activities. The WEM-based activities pretend to increase the feeling of control that students have over their learning experience, which is one way of increasing student motivation. In these activities the role of the teacher shifts from lecturer/director to that of facilitator, supporter, and resource person. These activities offer two types of interaction to students. Real interaction with robots is provided through the remote laboratory. This helps student to perform remotely many interactive learning activities, such as teleperception, teleprogramming and telediagnostics. The other type is virtual interaction through simulation programs and virtual reality models.

Expected benefits

Many benefits are expected from applying this approach to building an integrated educational environment or to update currently taught engineering courses, as shown in Table 3.

CASE STUDY

The proposed approach has successfully been used to build an innovative educational environment in the field of indoor mobile robotics at Carlos III University of Madrid [9]. This environment is not a public access environment and only IECAT partners and Carlos III University community members can use it. This section describes the use of this approach to update a

Table 3 Expected benefits

Activities	Benefits		
	Students	Faculty members	Institutions
Instructional activities			
TEM-based	Real interaction with each other, with staff members, and with machine. Decreased feeling of isolation.	Keep direct contact with other staff members and with students.	Take advantage of the already established installations. Keep the merit in the academic values and culture.
WEM-based	Increased flexibility and availability where there are no physical barriers. Increased accessing and searching for updated materials. Learning from stored anecdotal knowledge. Immediate feedback and comparison with other students. Increased communication where the Web provides many communication tools by which students can talk with each other, individually or as a group, and send questions or hold conversations, oral or text, with their educator.	Broader time frame to deliver online courses. Increased participation. Immediate reports of online class performance. Easier and time-saving handling of online assessments. Increased communication.	Exchange educational resources with other institutions. More scheduling flexibility. Easier and more time-saving processing of assessments results. Increased communication between university community members. Increased employee satisfaction. Competitive advantage.
Constructional activities			
TEM-based	Increased creativity where these activities help students to construct things that are personally meaningful to them or others around them. Increased participation and working in team. Increase students' ability to identify practical problems and to formulate cost-effective applicable solutions. Real interaction with real-world robotics industry and events, which leans to increase students' hands-on engineering experience.	Higher teaching effectiveness through undergraduate applied research projects. Industry contacts.	Nurture creativity in the students. Force students to practise team communication skills and prepare them for the real world environment. Improve quality level of graduates. Establish relationships with robotics industry.
WEM-based	Increased availability where these activities are not restricted by the synchronous attendance of students and educators. Increased motivation to participate proactively in the learning process.	Longer time for research productivity.	Short on-campus training time. Competitive advantage.

postgraduate course on intelligent autonomous vehicles.

INTELLIGENT AUTONOMOUS VEHICLES COURSE

This course is offered to postgraduate students within an integrated interdepartmental doctoral programme of electrical, electronic and automatic engineering. The course offers different theoretical and experimental knowledge about intelligent autonomous robots. Based on the proposed approach, many activities have been integrated to update the teaching strategy of this course. The next subsection describes the different pedagogical scenarios.

Implemented activities

The following subsections describe the instructional and constructional activities that have been implemented and integrated into the course modules in order to update them.

Instructional activities. Many instructional activities have been implemented based on a Web-based education model to support the traditional teaching.

1. *Online classes* Many online classes have been designed to present the basic knowledge of robots as a general issue and indoor mobile robotics as a main subject. This knowledge includes introductory concepts, robots classifications, mobile robot anatomy, control architectures of mobile robots, sensors commonly used in mobile robots and mobile robots applications. The class has also been supplemented by FAQ pages, a search engine, a digital library and downloadable materials.
2. *Remote laboratory* An online laboratory in a field such as mobile robotics must have a live

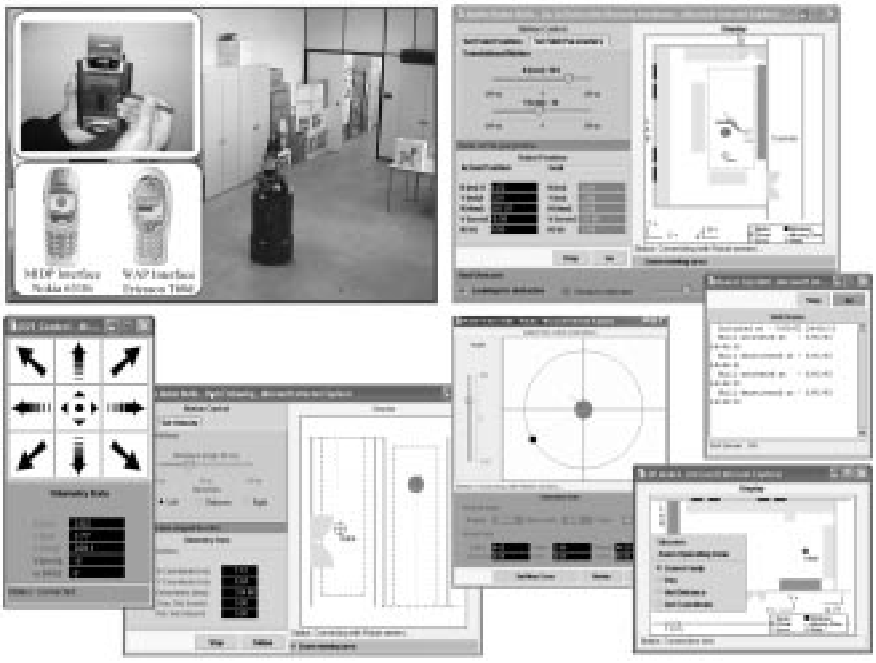


Fig. 2. Screenshot of skill interfaces.

performance characteristic, not just virtual reality or simulation programmes. A multi-layered architecture has been implemented in order to reach this goal [7]. The knowledge is presented to the user using three types of tutoring tours. These tours are classified according to the level of guidance of the tutor into: fully guided, unguided, and guided tours. The fully guided tour is a demonstration tour that demonstrates basic concepts without any intervention on the part of the student. The unguided tour, or free tour, does not determine any order or any tasks at all. This tour provides generic tools to the user and let him/her customize the experiment according to his/her needs. These generic tools include 2D model for the robot and the lab, an odometry data panel, a sonar data panel, a laser data panel, a motion controller and a network camera. The guided tour aims to present different specified courses with direct interaction between the student and the tutor. The experimental components of the courses are provided by using interfaces of different types of skills as shown in Fig. 2.

The following examples show some of the experiments that have been implemented and are presented through the guided tour.

Direct control

This experiment aims at familiarizing the user with the mobile robot motion control and positioning using different interaction elements such as a PC or any MIDP (Mobile Information Device Profile)-enabled device such as a handheld PDA or cellular phone. The remote user can send direct control commands to move the robot B21 from RWI forward, backward or to turn it left or right. Using a network camera, a 2D-graphical model, and the odometry data (actual location with respect to the initial point, translational and rotational robot velocities), the remote user will be able to view the effect of the commands that they have sent.

Go-to-goal skill

By using this automatic skill, the user can send the robot to a certain point in the lab. To activate this skill the user has to set the skill parameters such as goal point, robot velocity and maximum error. The skill can provide information as to whether the robot has achieved the goal or not. When this skill is deactivated it might supply information about the error between the current robot position and the goal. This skill has also been combined with a perceptive skill called 'detect obstacle' that helps to avoid an obstacle during motion [20].

Environment modelling and robot localization

The modelling skill can be used to construct an environment map using sensory data. The constructed map is then used to remotely estimate the robot's position by computing sets of poses that provide a maximal-quality match between a set of current sensor data and the map. The remote user can compare the result of the localization algorithm with the odometry data to determine the error [21] as shown in Fig. 3.

3. *Assessment tools* Evaluative tests can be used to provide online assessments. A student first takes an exam and then, based on the results of the exam, customized learning activities can be generated to reinforce the areas in which the student scored poorly. Moreover, practice tests

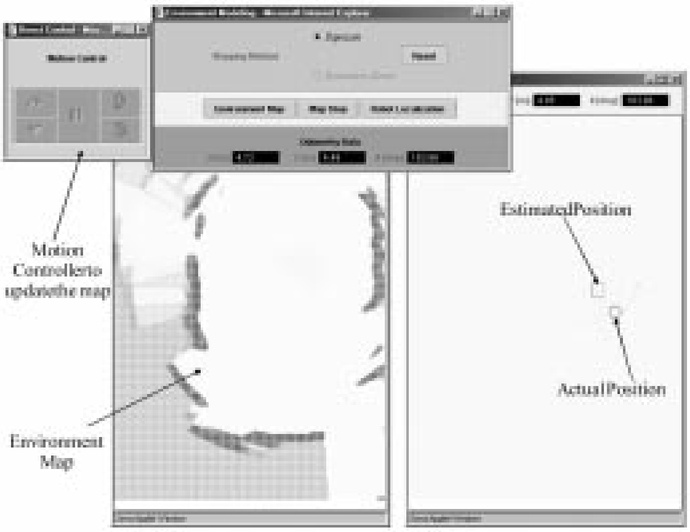


Fig. 3. Modelling and localization experiment.

can be designed to cover the experimental issues as a simulation to traditional laboratories. Three types of tests have been designed as online assessment tools. Online quizzes are used to evaluate the student's background in mobile robotics in general. Time restricted theoretical tests are used to evaluate the student's knowledge in the theoretical topics of the course. Time restricted experimental tests are designed to help the student to understand practical problems.

Constructional activities

Two types of constructional activities have been implemented based on the two education models described in the second section.

1. *TEM-based activities* TEM-based activities such as the design and the construction of new prototypes or reverse-engineering of existed systems are used to provide face-to-face interaction between the students and teaching staff and between the student and the machine, and therefore increase student motivation and decrease the students' feeling of isolation. These constructional activities also help to increase student creativity and team work. Students are asked to build robotic prototypes using lab kits such as Vex Robotics Starter Kit, Lego or Fischertechnik parts (including motors) as hardware components, the handy board (Motorola 88HC11 based or 16-bit Siemens 80C167) micro controller board for control, commonly used sensors and other components. A tele-operated rover can also be built and programmed by the students.
2. *WEM-based activities* The WEM-based constructional activities include interactive learning activities such as teleprogramming, telemonitoring, telediagnostic, telemaintenance and teleperception, etc., which can be incorporated into the remote laboratory to provide real interaction with the robot. The following subsections describe two implemented experiments that cover these activities.

Teleperception

The objective of this experiment is the perception of environment using multi-sensor data (sonar and laser). The experiment is divided into two parts: without robot motion and with robot motion. The objective of the first part is to understand the operation of sonar and laser sensors and to be familiar with the readings. The second part aims at recognizing the real environment using sensor data. Figure 4 shows the use of accumulative readings of sonar and laser sensors in determining the obstacle zone remotely.

Teleprogramming

Teleprogamming provides an asynchronous approach that helps the student to create a series of commands that is then downloaded into the robot and executed in order to examine new algorithms or realize a certain mission. An interface has been developed to help students to write a sequence plan to combine simple skills in order to obtain more complex skills as shown in Fig. 5. A skill represents the robot's ability to perform a particular task [22]. The simple skills can be classified into perceptive and sensorimotor skills [23].

1. *Perceptive skills* Those skills that interpret the information obtained from sensors or other perceptive or sensorimotor skills.
2. *Sensorimotor skills* Those skills that obtain as input the information provided by sensors or other perceptive skills and, based on this information, choose the most adequate actions for the actuators.

The skill servers are implemented based on two level control architecture called AD (Automatic and Deliberative levels) [24].

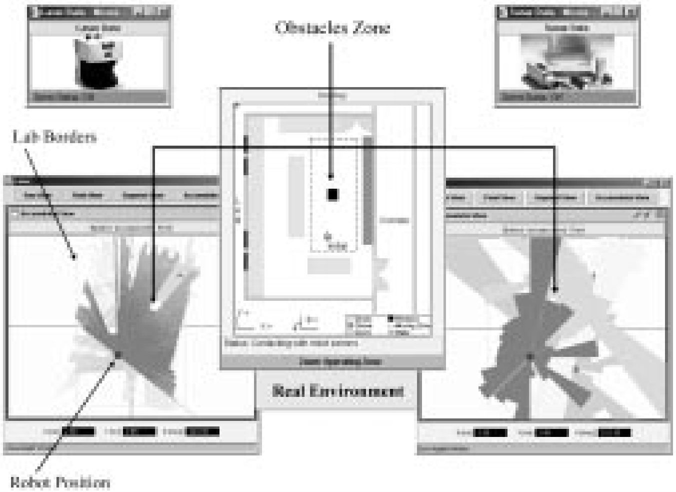


Fig. 4. Environment perception experiment.

Fig. 5. Teleprogamming.

Figure 5 shows a screenshot of the sequencer interface and the sequence plan of the GoToLab complex skill. This skill is used to send the robot to a certain room and it is generated using the sequencer by combining various simple skills such as GoToPoint, FindDoorLaser, Approach-Door, CrossDoor and WallFollowing [21].

In addition, a low-level commands editor is now under development to facilitate interaction with the remote robot using low-level commands or a group of commands in the form of a programming script. The user will be able to teleprogram the robot or to send low-level commands via the Internet to the robot's base server to perform many tasks, such as adjusting the robot control parameters, increasing/decreasing robot velocity, reporting battery state, setting the Watch Dog timer, that can be used for safety or diagnostic purposes, etc.

Evaluation

As mentioned above, the proposed activities have been used to update a postgraduate course on intelligent autonomous vehicles within an integrated interdepartmental doctoral programme of electrical, electronic and automatic engineering.

Table 4 Student feedback

Question	Agree	Strongly agree
The learning objectives were clear	43%	57%
The course was well presented	29%	71%
The lab was easily accessible	29%	71%
The corrected exercises contained helpful comments	43%	57%
The system was essential to the course	14%	86%
The system was reliable	43%	57%
The system was easy to use	29%	71%

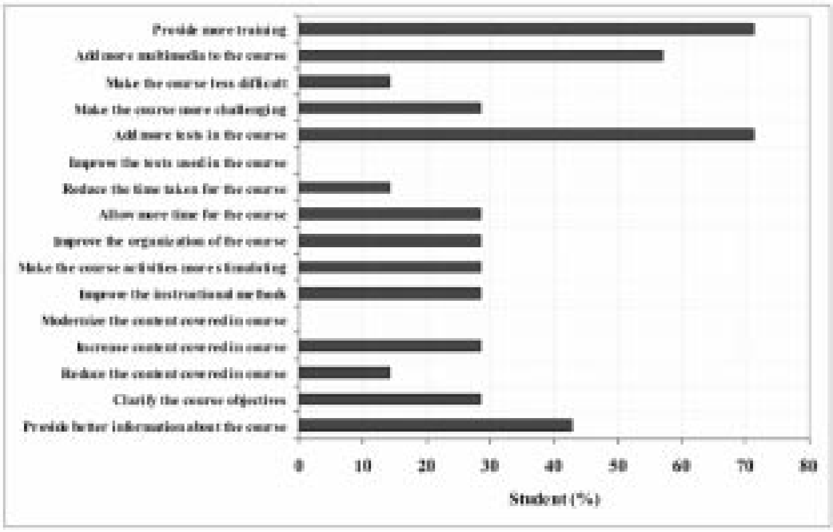


Fig 6. Students' suggestions.

Student feedback was gathered using an online questionnaire. The student responses were uniformly positive as to the use of the different proposed activities, especially the use of the remote laboratory. Most of the students felt that the online experiments helped them to achieve a deeper understanding of the subject material. Table 4 shows examples of students' feedback.

Figure 6 summarizes the students' opinions in regard to how to improve the system.

CONCLUSIONS

Different educational activities have been combined in order to develop an innovative teaching environment in the field of indoor mobile robotics. These activities are classified into instructional activities and constructional activities. The instructional activities aim at presenting theoretical and practical knowledge of the course to the students. The constructional activities give the students the opportunity to physically construct and implement the ideas derived from the course.

The instructional and constructional activities have been implemented using both Web-based and traditional models. The Web-based tools have been used to support traditional tools and to increase the feeling of control that students have over their learning experience, which is one way to increase student motivation. Nevertheless these tools cannot totally replace traditional educational tools, especially in a cross-disciplinary field such as robotics. The real interaction with the robot is unquestionably necessary in order to give the student hands-on robotics experience and to help them to understand real-world problems and be able to identify those problems and formulate cost-effective applicable solutions.

This approach can be used to create new courses or to update courses that are currently taught in the traditional way. It has successfully been used to build an innovative educational environment in the field of indoor mobile robotics at Carlos III University of Madrid. A postgraduate course on intelligent autonomous vehicles has also been updated based on this approach.

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