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Educational Tool for Design and Implementation of an Autonomous Mobile Robot*

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In engineering education, the theory presented in lectures must be supported by experimental exercises. Such exercises can be implemented using educational tools. In this study, an educational tool is presented to teach advanced control processing of an autonomous mobile robot to both undergraduate and graduate students in electrical and computer engineering. Using this educational tool, engineering students can learn many fundamental aspects of control processes and image processing and develop RF communication algorithms by using micro controllers in a practical way. The tool has a flexible structure and a user-friendly graphical interface. The simulator improves collaborative study, which provides more flexibility for the students performing the laboratory experiments. The developed animation software is able to create or modify various algorithms in control. This enables students to practice and interpret the controllers via drawing conclusions by changing the parameters of the fuzzy logic controller (FLC). Students' feedback indicated that theory in lectures on control systems and robotic were only appreciated after the laboratory exercises.

Keywords: mobile robot; educational tool; collaborating learning; control systems and robotic education

INTRODUCTION

ENGINEERING EDUCATION requires the use of recent instructional strategies, pedagogical methods and innovations in education technologies. As instructors, our aim is to produce efficient engineers who are equipped with qualified knowledge and real life experience, who can integrate the skills they have gained with theoretical knowledge and who are experienced enough to cope with the changing dynamics of the world. Therefore, we need to place students in actual learning environments and provide them with the real learning materials that are closely related to the latest industrial technologies.

The most significant challenge in engineering education is to provide a real physical training system; this is not always possible in practice. Therefore, specially designed simulators are used as primary education tools to change theoretical knowledge into practical experiences. These simulation-based educational tools offer students a real opportunity to validate the theoretical class discussions and provide them with a professional real-environment experience. However, one should bear in mind that well-designed simulators do not necessarily provide a worthwhile training. The students should be carefully observed by instructors in well-executed and well-designed laboratories. The proper use of simulators improves students' learning activities and their skills, and enriches their learning experiences.

The use of mobile robots in electric engineering and control systems and robotic education has gained popularity over the last two decades [1–9]. In the literature, different applications have been discussed for mobile robot navigation. Reported methods include behavior-based navigation of a vehicle that has a combination of several behaviors, including trajectory tracking [10, 11], target tracking [12], obstacle avoidance [13–15], landmark recognition systems [16, 17], and soccer robot navigation [18, 19] for mobile robot navigation. There are also methods using fuzzy logic based mobile robot navigation, and numerous studies of structured indoor laboratory environments [10, 16, 18, 19], while [14, 20, 21] discuss outdoor navigation using fuzzy systems. In general, indoor applications include corner detection, door detection, wall-following, path planning, trajectory tracking, and seeking the goal position [22]. Outdoor applications comprise garage-parking, parallel parking, stair climbing, scrambling over rubble, and human-like driving using a GPS system [23–25]. Researchers on internet based mobile robot navigation have proposed

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various control strategies. These controls have been made for unknown and dynamic real world conditions. The technological advancements that have been produced by this research now enable users to connect to a web site and remotely control a robot manipulator or a mobile robot [26, 27].

Recently, many autonomous mobile robots have been put forward as educational tools for engineering education. They have a controller, digital signal processing, ultrasonic sensors, telecommunication interface, microcontroller, motion motors and mechanical components that can be implemented on a computer, and mechanical and electronic engineering classes to design and program the items mentioned above [28–30]. With the intention and aim of creating autonomous learners who will be responsible for their own learning, we have designed an autonomous mobile robot (MBR-01) as a vision-based educational tool.

The MBR-01 has been designed as an educational tool for control systems and robotics courses. Its aim is to teach the fundamental skills of control systems, autonomous robots, FLC, image processing, edge detection, RF communication techniques and internet base remote control. The speed control of MBR-01 has a trajectory tracked curvature using fuzzy algorithms. The position control uses the trajectory tracked by optical sensors and a CCD camera. In addition, a fuzzy controller has been included in the microcontroller unit to control its position. The mobile robot can automatically track any variable trajectory and can be remotely controlled by the host computer using the wireless image transferring unit mounted on the MBR-01 for different applications.

As well as the vocational and professional considerations mentioned above, translating this mobile robot to an academic platform also has many pedagogical advantages in terms of effective teaching and learning. It offers an opportunity for students to control the speed and position of the autonomous mobile robot and experience a real environment situation. It provides a flexible educational scheme. This is important for integrating students into the learning environment and allowing them to work collaboratively and benefit from each others' knowledge through discussion and method by trial and error, rather than relying on deductive methods. Furthermore, the collaborative environment of the laboratory encourages students' interdependence and enables them to take an active role in the control engineering learning processes.

This paper describes the content of the course and educational foundations, presents the developed simulator and introduces the methods and the analysis of the results. This is within the framework described above and with the aim of investigating the pedagogical significance of this educational tool. Finally, the results obtained are given, the effectiveness of the simulator is discussed, and further studies are suggested.

AIM OF THE MBR-01 AND EDUCATIONAL FEATURES

The MBR-01 is designed as an education tool for the module 'Control and Robotics'. It is a 14-week and 70-hour experimental based course consisting of different sections. This tool is used for 5 weeks and 25 hours within the whole course.

The main goal of the tool is to develop an educational platform that allows students to improve their knowledge of control systems and a mobile robot. The following educational features and contributions have been taken into account in light of the module's learning features.

- The educational tool allows students to apply fundamental techniques to conventional and modern control systems.
- Students can design PID and FLC systems for speed and position control.
- Students can determine the effect of changing the parameter of FLC on MBR-01.
- It provides an introduction to image processing and use in control systems.
- Students can use the fuzzy system for edge detection in image processing.
- Students increase their knowledge of wireless communication systems, classification of RF communication systems, modulation/demodulation techniques, microcontroller based RF, and infrared transmitter and receiver design.
- Students have the opportunity to study on Internet base remote control systems.
- Users who have a homogeneous basic knowledge will adopt the system. In particular, these are students attending a course on electronic measurements and electric machinery.

The pedagogical setting of this course is based on simulation-oriented and collaborative learning. Any content and form of learning should require students to have an active role and help them to construct new ideas and concepts based on their previous knowledge and experiences. Likewise, the students who conducted experiments in groups over a period of time in this course have experienced some cognitive processes: acquiring the theoretical knowledge, understanding the reasons and conflicts lying beyond this knowledge, making decisions, constructing and structuring the decision made on the model, and performing and making new decisions or drawing new conclusions on each performance.

It is important that Bloom's taxonomy of the cognitive domain is taken into consideration in the use of this MBR-01 educational tool in a learning environment. The first five levels of knowledge, comprehension, application, analysis and synthesis are perfectly carried out in this simulation course study. The sixth level, evaluation, is usually based on the type of tool, and it does not necessarily serve our aim in this pedagogical method.

STIMULATION-BASED TEACHING AND COLLABORATIVE LEARNING IN ENGINEERING EDUCATION

The learning activity proposed here is based on two main methodological principles: collaborative learning and simulation-based teaching.

Collaborative learning

Collaborative learning is a highly preferred method that produces greater student learning and satisfaction in a variety of disciplines; this is essential in engineering education. It is increasingly a major component of engineering curriculum and practices. It is recognized as a high cognitive learning strategy. Murphy and Hennessy suggested that collaborative learning was not only a tool for learning but an object within the engineering curriculum. However, it is important to note that cooperative learning has positive outcomes only when the students function efficiently with good interpersonal skills within the group.

Within the scope and aims of our study, collaborative learning is one of the best pedagogical applications for MBR-01, being efficient in terms of teaching and engineering education in the following ways.

1. It requires social interaction between students and instructors in order to design the speed and position control of MBR-01 and to help learners build their knowledge as they express and defend their ideas. The share of core knowledge and the interaction between the learner's proximal zones of development enables learning through social interaction, which creates life-long learners.
2. It requires the learner to provide explanations for their thinking process and justify their problem-solving strategy, while using the designed FLC software to find the best parameters. This helps students to use higher-order thinking skills.
3. It encourages students to think in depth, and helps them to use the material more easily, to orient team decision and brainstorming and to make their own approaches.
4. The collaborative learning process gives students experience in using the skills that they will need in industry.

Simulation-based learning

Simulators are advantageous for engineers because they offer a real-world environment situation. They create a learning environment that supports experimental and reflective learning. They offer a good opportunity to validate the theoretical discussions held in the classes. Students are very involved in the practical scenario demonstrating the theories; they develop a better understanding of the system presented and become keen to do well. Therefore, the effectiveness of simulation training is greater than that of traditional training methods.

During this application, learning objectives are determined so as to teach students the various fundamental aspects of control processes, image processing, developing RF communication algorithms and remote control applications at the robotics and control system laboratory. By using this simulator in an academic area, students have the opportunity to control the speed and position of an autonomous mobile robot, experiencing a real environment situation. Most importantly, the developed software system enables students to cast a critical eye over the management of control systems and the challenges of control engineering. It also develops and stimulates the students' cognitive skills since, after each attempt to find the correct parameters, students are required to develop strategies. This accelerated learning gives students an invaluable understanding of the course in a short space of time, provides a safe environment for teaching and learning, makes team training possible, and reduces cost [31–33].

STRUCTURE OF MBR-01

The vehicle that was developed is shown in Fig. 1. The vehicle has two electric motors: one is the steering motor, which gives the orientation of the driving wheel, and the other provides the driving torque. There is a wireless image transmitter unit with 2.4 GHz carrier frequency, which captures the trajectory information with a CCD camera and transfers image data to a computer. There is also a reciprocal RF data transmitter unit to control signals between the robot and the computer. On the mobile robot side, a fuzzy controller unit caries out position control by obtaining the angle of the steering wheel and deviation information from seven optical sensors.

Control implementations of the MBR-01 have been realized using an Intel Core 2 CPU (1024 MB RAM, Window Vista operating system) and PIC

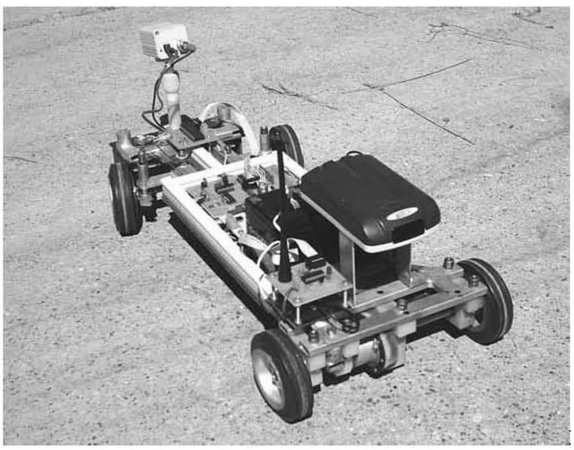

Fig. 1. Autonomous mobile robot.

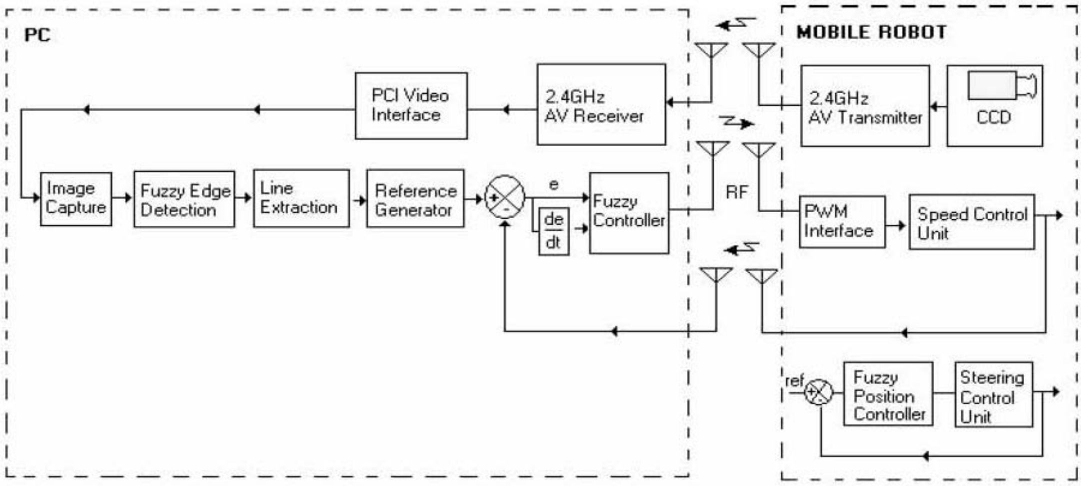

Fig. 2. Simplified control diagram of the MBR-01.

series microcontrollers. All algorithms processing on the PC have been developed using C++, assembler codes, and Windows API components. Figure 2 shows a simplified block diagram of the system.

EDUCATIONAL SOFTWARE

The tool works in the Windows environment. The drive system operation can be observed on a PC monitor and can be modified by choosing an appropriate user interface. The educational software has a main control user interface that is divided into four sections: namely, the main control, fuzzy edge detection, line extraction and speed control user interfaces.

Main control user interface

The main control screen of the educational vehicle software is shown in Fig. 3. On this screen, the mobile robot can be controlled remotely using the up/down and left/right arrow keys on the master PC, which is connected to the Internet network. For this operation, the IP address of the client PC is entered into the master screen monitor and the control processes is started by connecting to the client PC.

The MBR is controlled either manually or automatically on the variable trajectory. In

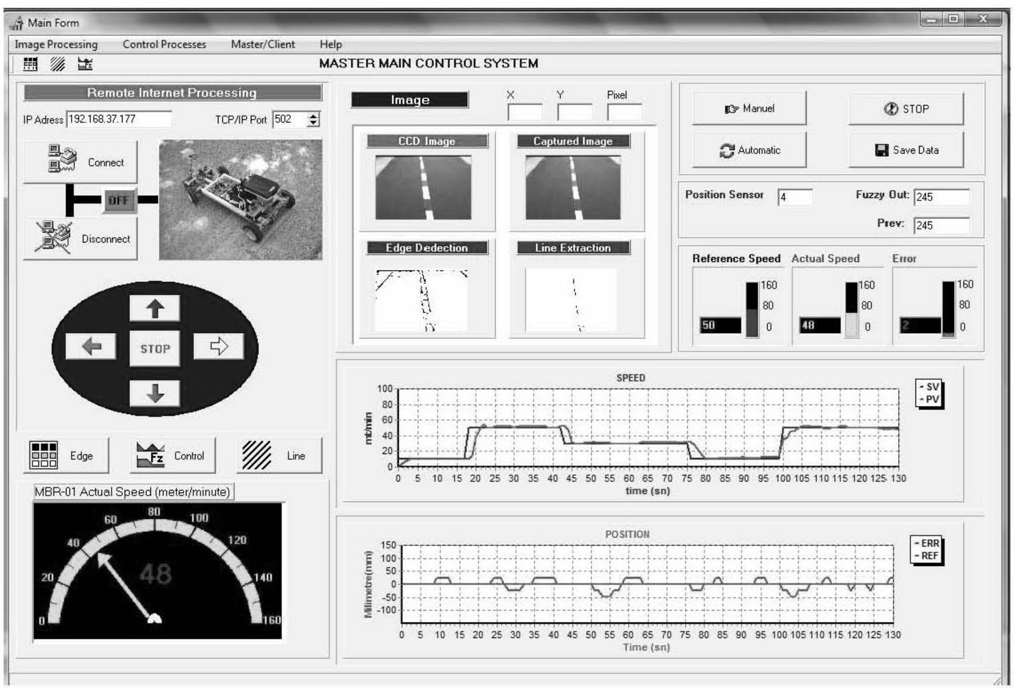

Fig. 3. Main control user interface.

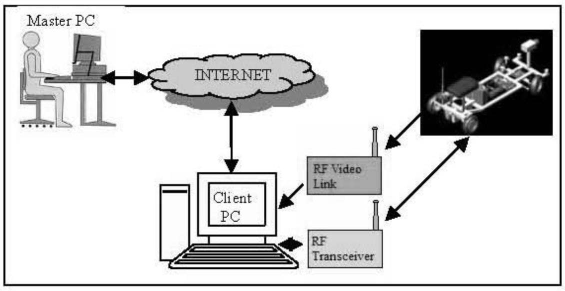

Fig. 4. Internet base remote control.

manual operation, the speed reference value is entered into the PC screen and position control can be achieved with constant speed on the selected trajectory. In auto mode, the mobile robot can be guided according to the curvature of the trajectory track calculated from the developed algorithms. During these operations, all data can be stored in the database software for graphical analysis and investigation by students.

Internet-based mobile robot navigation has a number of limitation and difficulties, such as a restricted bandwidth, image transmission delays, and packet loss or error, all of which influence the performance of Internet-based navigation systems. Although increasing the capacity of data transferring techniques through the Internet network, some problems in using the Internet networks [26] have been seen in real-time image processing. Image information is transferred in the form of compressed and small dimensions to improve the data transfer rate in the internet communication line. In this study, transferred image dimensions have been realized using 100*80 pixels and the speed limit is held to within 0–10 meter/minute. A block diagram of the system is shown in Fig. 4.

Fuzzy edge detection user interface

The fuzzy edge detection user interface is shown in Fig. 5. The camera image is transferred onto the fuzzy edge detection window and eight different edge rules are applied to the controller in order to determine the trajectory to be followed. The defined membership functions and fuzzy rules are shown in the window.

In fuzzy reasoning, classify a pixel in an image into a border region or a uniform region based on the differences in luminance between the pixel and its neighboring pixel. Detecting edges by fuzzy inference that classifies every pixel in an image into white or black is based on the following two strategies [20].

1. If a pixel points on the border region then make it black, else make it white.
2. If a pixel points to a uniform region then make it white, else make it black.

In order to decide whether a pixel belongs to a border or a uniform plane, luminance differences between the pixel and its neighboring pixels have to be computed. In the processed image, the computing starts from the upper left corner point (0, 0), moving to the bottom right corner point (X, Y). Going through the entire line, every U pixel and its neighboring luminance differences are calculated individually and then it is decided whether the pixel is an edge or not according to a defined fuzzy rule base.

The fuzzy edge detection user interface allows students:

- to have an overall understanding of fuzzy edge algorithms;
- to simulate and modify every phase of the operation at any time;

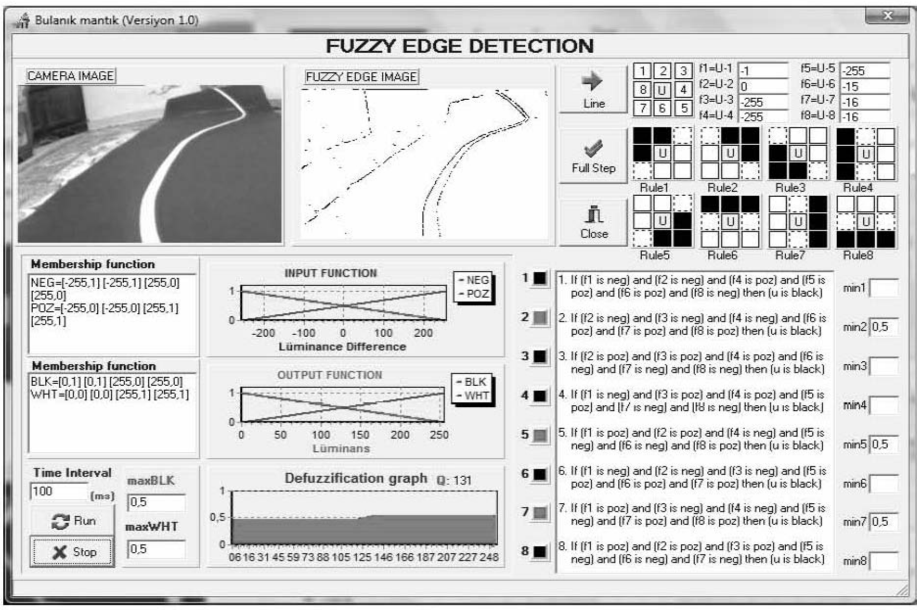

Fig. 5. Fuzzy edge detection user interface.

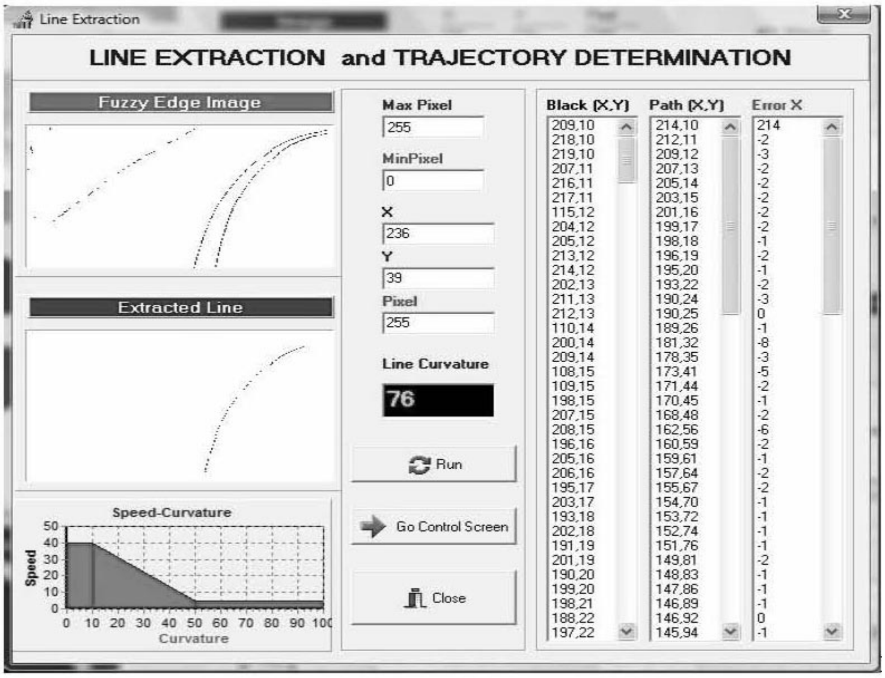

Fig. 6. Line extraction user interface.

- to observe the effects of a change in the membership functions on the control action;
- to observe each active rule and its output value and investigate its effects on the controller.

After the fuzzy edge detection process has been performed, the trajectory line extraction method must be applied to this image. The user presses the 'line' button to go to the line extraction window shown in Fig. 6. In this window, the user chooses the best trajectory to be followed and determines its curvature. The reference speed is determined according to this curvature.

Speed control user interface

In speed control, two controller types can be used. These are PID and fuzzy controllers. The fuzzy speed control user interface of the tool is shown in Fig. 7. Fuzzy logic parameters are defined by the user. Since FLC depends on the user's experience, a flexible rule base can be defined. Both count and limits of the membership function are defined when the user double clicks on the membership functions. During the control processing, the color of the fired rules turns to red.

The students gain the following educational capabilities from studying with the speed control window.

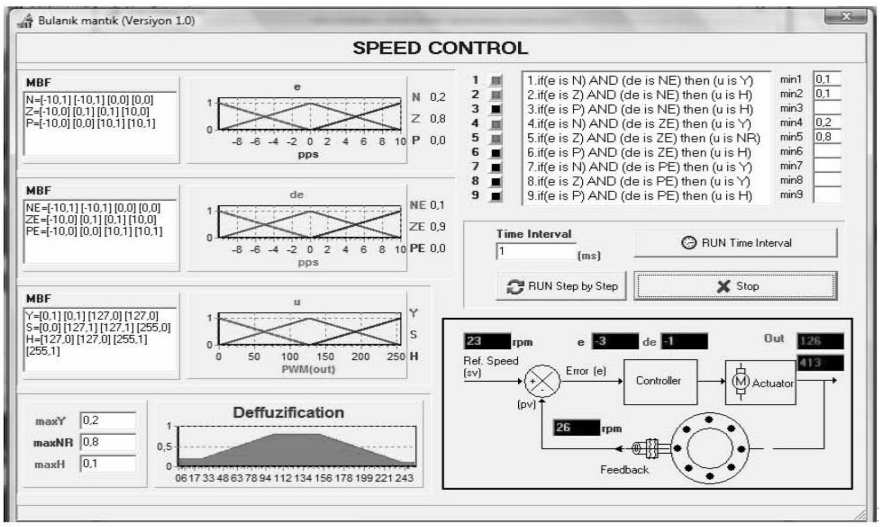

Fig. 7. Speed control user interface.

- They can make a connection between the system parameters and the system response.
- It improves their knowledge of fuzzy control.
- They can develop an appropriate fuzzy rule base for the speed control system.
- They can interpret and draw conclusions related to the system parameters.

CASE STUDY

The simulator was introduced during the 2007–2008 academic year in the Robotics and Control Systems Laboratory of the Technical Education Faculty at Marmara University, with 30 students in each term as a part of a 14 weeks course. During each 14 weeks, the course had 5 hours' lectures. Lectures are based on theoretical sessions, which are followed by the practicals. The course contents and learning activities applied are shown in Table 1.

All the data taken from the experiment could be saved to a database file by the students whilst running on-line. This database file can be used by the students off-line using an off-line simulator program. Students can visualize all the graphical data from the control and image processes algorithm outputs. At the same time, students are able to simulate the experiment step by step using this data file in the off-line program.

To determine the effectiveness of using mobile robot systems in laboratory studies, two different measurement methods were applied for 30 senior students in the Control and Robotics Laboratory. The first method involves measuring the learning level of the students. Therefore, pre-tests and post-tests were applied during the course. The improvements in the students' levels of learning were measured from the test results. In the second method, students were asked to participate in a questionnaire and interview at the end of the course. Before they work in the laboratory, students are required to attend a set of pre-laboratory classes that bring in the required fundamental knowledge and theories for practice. Each group was called for an appointment to practice the fuzzy system for two hours each week. Each group worked on the software system to realize the aims of the course described above. At the end of the course, students were asked to fill in a questionnaire, which was followed by a discussion and written feedback. In addition to the students' feedback, the feedback from the lecturers who used this tool was also collected.

Feedback from students

In the first measuring method, two tests were carried out by the students during the course, depending on the course contents. All of the tests consisted of theory and application examinations. The theory sections comprised memorizing, analyzing and problem solving questions. The results from the students in the four topics are shown in Table 2. The average percentage scores and standard deviation of the four different course topics are showed in the table.

Table scores show that an improvement in the students' learning can be seen across the whole research group. However, the most improvement in learning level was in the Application group. Figure 8 shows the average improvement in students' learning.

The second method of measuring the effectiveness of the simulator is the questionnaire filled in by the students. The questionnaire basically aims to assess the suitability of the tool for educational purposes, features and functionality of the MBR-01 and FLC software and any technical aspects of the simulator, such as malfunctions. It presents the quantitative data on the efficiency of the tool from an educational perspective under five main criteria: user friendliness, application specific self efficiency, the features and functionality of the tool, the suitability of the tool for educational require-

Table 1. Applied course description and learning activity.

Contents	Description	Activity
Basic concept of control systems	Control types, transfer functions, block diagrams, data acquisition systems, analog and digital controllers, automatic controllers (measuring elements, actuators and PID controllers), modern control techniques (fuzzy theory, sets and concepts. membership functions, fuzzy rule base, fuzzification and deffuzification processes)	Theory = 60% Presentation = 20% Lab = 20%
Design of control systems	Design and implementation of conventional and fuzzy controllers using microcontrollers and computers	Theory = 20% Presentation = 20% Lab = 60%
Image processing in control systems	Image processing technique, processing steps (image acquisition, pre-processing, segmentation, feature extraction, recognition), fuzzy edge detection, line extraction by using C++ software	Theory = 40% Presentation = 20% Lab = 40%
Using wireless communication techniques in control steps	Classification of RF communication systems, modulation and demodulation techniques, microcontroller-based RF and infra red transmitter and receiver design	Theory = 40% Presentation = 20% Lab = 40%
Internet base remote control systems	Definition of internet terms (ARP, CSMA, FTP, DNS, HTML, HTTP, ICMP, IP, IPX, ISO, LAN, MAC, SMTP, TCP, TCP/IP, UDP Router. . . .), problems of internet base remote control, design and application of remote control using C++	Theory = 50% Presentation = 20% Lab = 30%

Table 2. Pre-test and post-test scores on the student learning level in four course groups.

Contents	Test	Memorize mean s.d.	Analyzing mean s.d.	Problem solving mean s.d.	Application mean s.d.	Average score mean s.d.
Basic concept of control systems and design of control systems	Pre-test	67 19	68 15	62 16	56 19	63 17
	Post-test	76 13	74 9	70 11	85 12	76 11
Image processing in control systems.	Pre-test	54 10	45 16	52 14	47 9	50 12
	Post-test	72 14	65 12	74 12	66 16	69 14
Wireless communication systems	Pre-test	72 11	65 9	58 12	55 13	63 11
	Post-test	78 9	76 6	81 8	78 15	78 10
Internet-based remote control systems	Pre-test	42 8	33 18	34 21	38 9	37 14
	Post-test	75 12	69 14	54 17	65 17	66 15

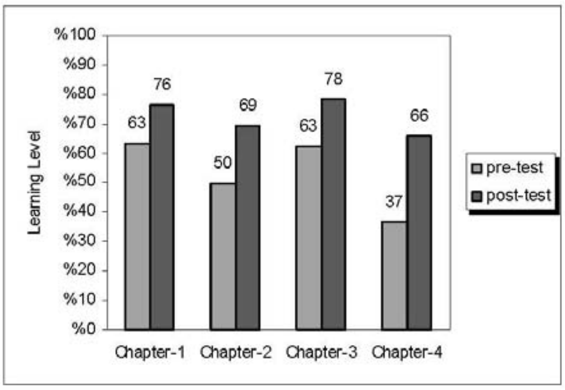

Fig. 8. The average learning improvement of the students in the four course topics.

ments, and learning and cognitive aspects. In the questionnaire the following questions were included, as shown in Table 3.

Obtaining feedback from the students is a priority task to verify the usefulness of the tool. The students' responses to the use of the educational tool have so far been very positive. They find the course easier to understand with the hands-on experience.

User-friendly: Most of the students found the MBR-01 educational tool easy to use and user-friendly, whereas only two students thought that it was difficult. As one of the students put it, 'I found the software quite easy to use, FLC was not complicated and was designed simple enough to manipulate the program. The directions were clear and there were not any unnecessary details that confused me at all.'

Application specific self efficiency: All the students agreed that the tool helped them learn how to design a rule base for the FLC. They said that they could adopt their theoretical knowledge to the tool and they could design the rule base of the FLC. According to the results of the questionnaire, the students aid that the tool gave them a chance to work with fuzzy edge algorithms and develop a better understanding of them. There were only four students who had difficulty in developing the RF communication protocols.

The features and functionality of the tool: All of the students commented that by working with the vehicle step by step, they could easily follow the varying control actions at different control values during the experiments and they could see the outcomes of the control actions both numerically and graphically. The color, design, plot data and the use of the graphs made the learning of concepts easier. A large proportion of the students were affected by the visuality of the program, which helped in learning and adopting the knowledge, and understanding each stage and the benefit of the experiment. They also increased their speed of gaining this understanding, besides acquiring a detailed perception of the model. Some of the students commented that visually supported tools save time, since they make learning easier and the incorporation of visual learning elements reinforced the visual nature of engineering.

The suitability of the tool for educational requirements: Since engineering concepts are being taught simultaneously with real world experience, many of the students reported that it has been an invaluable opportunity for them to take a close look to their future work and to relate it more directly with everyday life. They agreed with the idea that the implementation process and hands-on activity encouraged their constant participation in the course and enabled continuous learning.

Learning and cognitive aspect: Students generally accepted that working with the tool helped them to adopt their theoretical knowledge to the practical experiments. Most of them admitted that their existing knowledge was increased. None of the students preferred to study alone rather than in groups.

Students also submitted a written feedback to make further comments on the educational and professional aspects of the tool. The students' responses were sorted into several categories. These categories received a significant number of comments and all the students filled in the questionnaire and were involved in a discussion. When surveyed about their educational experience, the students indicated that most of the learning occurred after using the simulation.

Table 3. Questionnaire on tool efficiency.

Criteria	Sub-Criteria	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
User friendliness	I find it easy to get the MBR-01 tool to do what I want it to do.	26	3	1		
	My interaction with the MBR-01 tool is clear and understandable.	25	3	2		
	MBR-01 is not complicated to use	24	2	2	2	
	The tool has visual objects to ease the comprehension of control process.	28	3			
Application specific self efficiency	I have the ability to design rule base of FLC for speed control.	27	2	1		
	I have the ability to design rule base of FLC for position control.	28	2			
	I can observe the effects of changes in the action value of rules on the control action.	30				
	I can observe the effects of changes in the membership function on the control action.	30				
	I have an overall understanding of fuzzy edge algorithms.	28	2			
	I can find out the effect of each active rule on the controller output.	27	2	1		
	I have the ability to use fuzzy edge detection in image processing.	28	1	1		
	I can develop RF communication protocols.	24	2	2	2	
The features and functionality of the tool	I can observe the variables of the MBR-01 numerically.	30				
	I can see the variables of the MBR-01 graphically.	30				
	I can observe the all stages of control procedure graphically.	28	2			
	I can conduct the control system step by step.	25	3	2		
	I can observe each active rule while system is running.	30				
	I can easily record the control variables.	28	2			
The suitability of the tool for educational requirements	I liked working with MBR-01 in teams.	22	4	2	2	
	Working in groups with MBR-01 developed my interpersonal skills.	25	4	1		
	Working with MBR-01 enabled me to develop a better understanding of real experience.	25	4	1		
	It was beneficial to turn my theoretical knowledge into practice.	28	2			
	The simulator can help me to improve the quality of my vocational education.	28	2			
Learning and cognitive aspect	Working with the tool promoted my existing knowledge.	28	2			
	The simulation helped me to develop the ability to think deeply.	29	1			
	It helped me to evaluate my learning.	22	3	1	2	
	Rather than using the tool, I would prefer to read text and journals.					30
	Tools are an effective way for me to learn.	28	2			

Most of the comments suggested that collaborative work had been helpful in improving interpersonal skills and developing interdependence in a social learning environment. It also created a discussion platform for the students. Five of the students asked for more frequent group work, particularly if they are required to use educational tools or robots like the MBR-01

Feedback from instructors

A discussion was also held among the instructors who used this tool as a part of a robotic and control laboratory. With respect to the learning experience and the proposed methodology, they recognized that the students showed a deeper understanding, higher level of motivation and better positive attitudes towards the course.

As an outcome of our teaching experience, it can be stated that the simulator has been efficient as a pedagogical tool for students to master control systems as compared with the students of previous years who did not use this device. The tool was very effective in the development of skills and approaches to the decision-making process. It has proved itself as a good skill tool for skill developments in students who are ready to obtain their degrees. The benefits that students obtained from the use of this educational tool go beyond electrical and electronic engineering; it helps them to improve their skills in interdisciplinary areas such as mechanical domains. It gives sufficient support to the achievement of the goals stated in the introduction, that students gained a high level of achievement and realized the educational goals. The instructors are therefore enthusiastic about participating in similar implementations.

MBR-01 has also been perceived as a valuable tool for cooperative learning. This educational tool and the collaborative learning proposed here offer a good opportunity to experiment with the students in terms of making the course into a real life experience. The proposed flexible methodology helped students to develop a flexible way to control the robot elements.

Regarding the lab discussed in this paper, its design replaces face to face physical experiments using a computer session with either a simulation or the remote real system, which makes learning more personalized. Students can immediately observe the resulting changes of parameters and become aware of some physical phenomena that are difficult to explain theoretically. When sufficient teaching environments have been developed, students could understand and value the self-learning processes and become aware of their increase in theoretical knowledge.

It is essential that we train students not only by giving them the theoretical knowledge but also to help them to become competent in practice, so that they can carry it on into life-long learning. As the results show, almost all students were able to integrate these two skills and analyze the efficacy of the model. It is of significant that the professor is important as well: the instructor should be the advisor or guide, rather than being a dominant factor in the learning process. Finally, the use of these tools has also led to a discussion in the department on the use of active learning and teaching strategies. It has contributed considerably to the faculty teaching.

CONCLUSION

In this paper, a new teaching tool used by undergraduate students in the Robotic and Control laboratories was introduced. The main objective of the tool is to improve the students' knowledge of control systems and robotics. The proposed methodology used in laboratory sessions, the structure of the mobile robot, and the technical and educational aspects of the tool as aids to teaching have been discussed in detail.

For the students, the tool has increased their knowledge and helped them to develop an understanding of the subject. The active involvement of the students in analyzing and finding the logic beyond the software has established their autonomy in learning. Moreover, repeatedly trying out different parameters to find the best control points of the system helped them to see the effects of the different controllers. Students have gained considerable experience of the performance and process of the system by this trial-and-error method. This implementation provided students with an enjoyable and beneficial way of participating in the process, and prevented them from being passive observers.

A discussion held with the students about their experience in this module shows that they obtained the quality and durability in practical skills and knowledge in using the fuzzy logic controller. They have also requested that the same system be used in Communication Systems Laboratory classes to give them more competence in the course.

Considering the great interest from the students and the positive indications from the results, the educational tool proposed here will be extended to the design of other theoretical-procedure activities and the tool will be used by instructors for curriculum development.

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