STUDYING ELECTRICAL AND COMPUTER ENGINEERING THROUGH THE CONSTRUCTION OF ROBOTIC TEAMS AND SYSTEMS

Reinaldo A. C. Bianchi[1] and Alessandro La Neve[2]

Abstract *¾ The development of robots involves more than simple integration of Electrical and Mechanical Engineering techniques. It can be used as a basis for Electrical and Computer Engineering and Computer Science education based on practice, because of it's multidisciplinary domain that includes a large variety of fields. Besides this, it motivates a large number of students, due mainly to its challenging nature and because of the increasing public interest. At Centro Universitário UniFEI several strategies are being developed to help students in studying electrical and computer engineering subjects, through the design, construction and operation of robotic teams and systems. Students are involved in part time work on scientific initiation projects and final course projects, designing robots and implementing control and computational vision software. The result of these projects, such as Artificial Intelligence, Robotics, Computer Graphics and Programming related material, are successfully being used in the computer engineering course.*

Index Terms ¾ hands-on engineering education, final course projects, scientific initiation programs, university-industry joint programs.

1. INTRODUCTION

The development of robots involves more than a simple integration of Electrical and Mechanical Engineering techniques. It can be used as a basis for Electrical and Computer Engineering and Computer Science education based on practice, because of it's multidisciplinary domain: it includes, in fact, a large variety of fields, such as mechatronic devices, digital systems, customized hardware, wireless communications, operational systems, device drivers, control theory, simulation and several aspects of artificial intelligence (computational vision, sensor fusion, planning, genetic programming, neural networks and multiagent systems). Besides this, it motivates a large number of students, due mainly to its challenging nature and because of the increasing public interest.

At Centro Universitário UniFEI, former Faculdade de Engenharia Industrial, several strategies are being developed to help students in studying electrical and computer engineering subjects, through the design, construction and operation of robotic teams and systems.

The purpose of this paper is to present current projects in the robotics domain that were developed in engineering courses at Centro Universitário UniFEI, with the aim of integrating undergraduate students with research and providing an active and cooperative learning environment. Several approaches, such as scientific initiation, final term projects, curricula integration, and the current learning environment, which include simulated or building kits, robot platforms, team-based design, real-time programming paradigms and the educational impact of robot competitions, are being used and evaluated.

The Scientific Initiation projects involving robot competitions started in 1999, with a selection that attracted more than 40 students, who were enrolled the 4th year of the computer engineering course. There were several students involved in the project, on part time work basis, designing the robot and implementing control and computational vision software. As a result, we were able to build an autonomous mobile robot, with Genetic Algorithm based control software and Computer Vision hardware.

Several Final Term projects were developed in the robotics domain: some used educational robotic arms and others developed their own mobile robots. At the same time, the students acquired research techniques and learned how to work in a team. The robotics domain is a motivating work based on group activities that greatly improves the students' skills.

These different approaches are described in this paper, such as the related work in the use of robot building in education. Two Scientific Initiation projects at FEI and one Final Term Project using robots are also described, and finally the use of robotics related material, in the computer engineering course, is presented in section 5.

2. ROBOTS IN EDUCATION: RELATED WORK

The development of an integrated robot team can be used as basis for Electrical and Computer Engineering and Computer Science practice based education, as it is a multidisciplinary domain, which includes a variety of fields.

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It also motivates a large number of students, due to its challenging nature and arousing public interest.

Work on the use of Robotics for education - especially that involving the RoboCup competition [1] has been done in two fronts: as an introductory research program for undergraduate students and as a subject to be taken in Artificial Intelligence - AI courses.

Several features characterize the RoboCup Domain as a unique environment, as it was analyzed by Verner [2], including:

1. The learning subject comprises knowledge in hi-tech electrical, mechanical and computer engineering.
2. The learning method concentrates on practice in design, constructing and operating intelligent robot systems.
3. The training practice is a form of participation of the students in research and development of projects that aim at the implementation of a soccer game robot team.
4. The robot systems developed are discussed at RoboCup forums.
5. The domain reflects the state of the art in robotics and Artificial Intelligence.
6. It attracts wide professional and public interest. [2, p. 52]

On the other hand the RoboCup can be used in AI classes, as analyzed by Coradeschi & Malec [3]. They presented an AI Programming course organized around the RoboCup SoccerServer simulation system, aiming at the study of knowledge based software systems, multi-agent theory, and other AI techniques. As results, the students found stimulating to implement a real system and were enthusiastic until the end. Finally, one of the teams created during that year course has won vice-championship of Sweden for the year 2000, loosing only to a professional team. Two other teams took the 4th and 5th place.

3. Scientific Initiation Projects

Several students worked on these robotics projects, by designing robots and implementing control and computational vision software. At the same time, they got acquainted with research techniques and how to work in a team.

In the following subsections some of this scientific initiation work is presented, relating it to the main topic they students have studied.

A. Studying Programming and Control: Genetic Programming Based Control

Genetic Programming [4] has become a widespread technique in recent years. It is based on the implementation of programs that simulate the processes described on the evolution theory. In this approach, programs are treated as individuals, described as trees of defined functions. The fundamental process used to evolve programs can be described in the following steps:

1. Generate a random population of N processes, each one simulating an individual in a population;
2. Evaluate the fitness of each program;
3. Create a new population of individuals based on the reproduction, crossover or mutation of the best individuals of the current population and the removal of the most unfit;
4. If the current population has not reached a minimal pre-defined quality, or a pre-defined number of cycles has not bean reached, return to step 2.

Genetic Programming is usually applied in a wide range of problems, such as control or search applications. Our target is the use of Genetic Programming to evolve individuals, which are capable of playing soccer in the RoboCup domain.

As a first step in this study a wall following robot was built in a simulated environment, similar to the one described in [4]. Figure 1 presents the result of this study, showing the path of a robot following the wall.

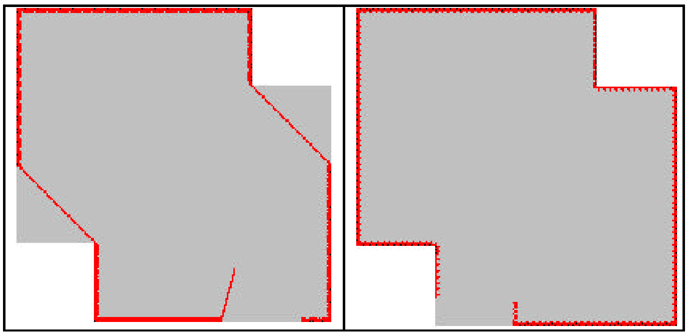

FIGURE. 1
RESULTS OF THE WALL FOLLOWING ROBOT IN2 DIFFERENT CONFIGURATIONS.

On left side of figure 1 there is the result of an early-adapted robot. It can be noted that the resulting robot is able to follow the wall and detect an obstacle, but is not capable of detecting the corners of the room. On the right side of the figure there is a well-adapted robot that has an excellent result.

The next step was to develop a ball following robot. This was done using a local vision paradigm, where the robot can only see what is in front of it, not knowing the location of the ball *a priori*. The results are presented in figure 2.

The image presents the path of one robot (the red line) following a ball (the green line). It can be seen that the robot follows the ball, touching it several times and also minimizing the movements of the robot, going to the place where the ball will be in a few moments.

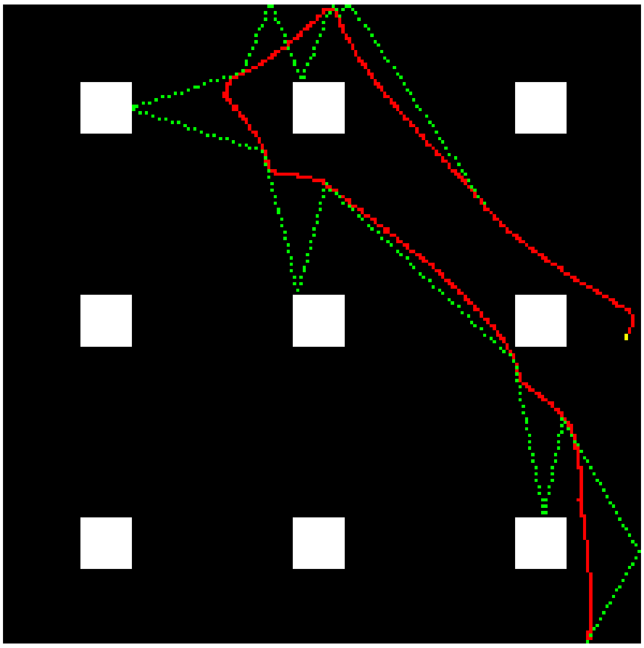

FIGURE. 2
RESULTS OF THE BALL FOLLOWING ROBOT. THE GREEN LINE IS THE PATH OF BALL AND THE RED LINE IS THE ROBOT'S PATH

B. Digital Systems: Hardware Based Vision

The most time-critical process of the Robotic Soccer is the discovery of the position of the robots in the game. A hardware was used to compute the position and speed of the robots in the game, which implemented Computational Vision – CV algorithms with an FPGA circuit.

A Field Programmable Gate Arrays [5, 6] is an integrated circuit that can have its hardware designed by the user. It contains a large number of identical logic cells that can be seen as pre-defined components, which combine a few inputs to one or two outputs, according to Boolean logic functions specified by a user defined program. In its turn, individual cells are interconnected by a matrix of wires and programmable switches.

A user's design is implemented by specifying the logic function for each cell and selectively closing the switches in the interconnect matrix. This is done by means of a user program that defines the function of the circuit, usually written in VHDL (a high power Hardware Description Language).

The advantage of using an FPGA is that it gives hardware speed to user applications. As the computational power of these programmable logic devices is increasing (the maximum number of gates in an FPGA is currently around 500,000 and doubling every 18 months, while the price is dropping), complex applications are beginning to be feasible.

In this project, well known Computational Vision algorithms were translated to VHDL. The CV algorithms that were studied allow for the definition of objects position in an image and include images Binarization, Limiarization, Edge Detection and Chain-Code Segmentation [7].

These algorithms were tested on an ALTERA University Program Design Laboratory Package, which includes a MAX+PLUS II Development Software (Student Edition), one UP 1 Education Board and a ByteBlaster download cable.

The MAX+PLUS II software is a development system that includes design entry using graphical and hardware description languages, design compilation, design verification, and device programming. The UP 1 Education Board (figure 3) features two programmable and reconfigurable logic devices. Finally, the ByteBlaster allows the download of MAX+PLUS programs in the board.

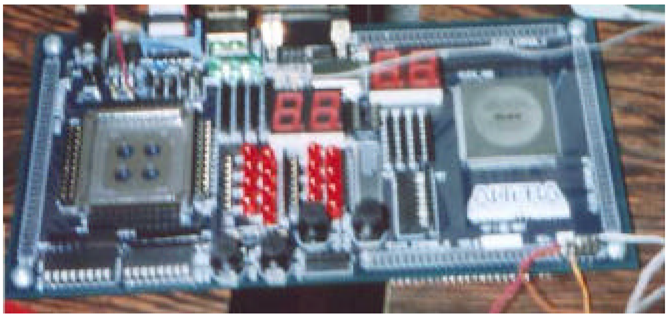

FIGURE. 3
THE ALTERA UP 1 EDUCATION BOARD.

The simulation results of a 100 MHz FPGA device implementing the vision algorithms, for a 320 x 240 pixels color image, are presented in the table below.

TABLE I
TIME NEEDED BY EACH MODULE TO PROCESS AN IMAGE WITH 320 X 240 PIXELS.

Module	Time
Thresholding	770µs
Edge Extraction	2,41µs
Chain-Code Segmentation	770µs
Total time	1,54ms

The table shows that the edge extraction is the fastest module. This happens because this implementation processes a line at each cycle time. As the other modules take one cycle to process each pixel their time is the same. Also, these results were obtained assuming that modules are working sequentially: the edge extraction starts when the image is binarized and the chain-code begins when the edge extraction finishes.

Finally, this table shows that the system can process 649 images (with 320 x 240 pixels) per second. A straightforward implementation of the same algorithms, written in C Language, run on a Pentium 200 computer with Linux OS, took 33ms to process each image (21,5 times slower than the FPGA version). As for the quality of the results, the images produced from the FPGA version were similar to the ones obtained with the implementation in software.

4. FINAL TERM PROJECT: BUILDING A WORKING ROBOT.

The construction of one robot was made as a Final Term Project. It was decided not to buy a robotic platform available in the market, in order to allow that the students developed their skills in digital and analog circuits, power electronics, control theory, and even mechatronic devices.

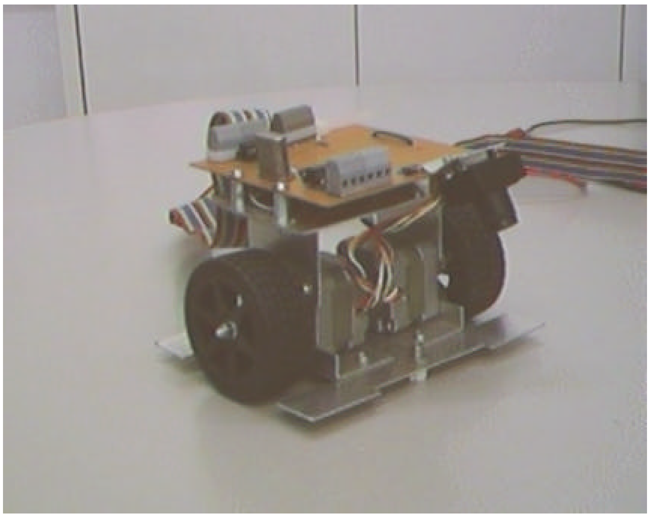

FIGURE. 4
THE ROBOT PROTOTYPE CREATED BY STUDENTS

The result was the design and the implementation of an autonomous mobile mini-robot capable of following a path, which had been previously drawn on the surface where it moves, based on visual information from an on-board camera. This mini robot prototype had its size based on the rules of the RoboCup F-180 (Small Size) league, and it consists of 2 step motors, a power module and a camera for acquisition of local images, all assembled on a metallic base. This robot sends the images to a microcomputer and receives command signals for the motors through a control hardware implemented in an Altera Max 7000 FPGA. The software system implemented in the microcomputer is composed of three basic modules: image acquisition, that captures the images using a standard Bt-878 videoconference board; path identification, that detects the center of the path that the robot must follow; and the control module, that implements a reactive behavior to follow the path and sends the information to the control hardware of the motor through a parallel port. The system was exhaustingly tested and the experimental results indicated that it is efficient, being capable of following any path drawn by a user. The robot is presented in figure 4.

5. ROBOTS IN THE CLASSROOM

Two courses (Artificial Intelligence and Computer Graphics) are using robots as class topics. In the first course the use of the Robocup Soccer Server [8] was tested as a study platform.

Figure 5 presents the simulator, a system that enables autonomous agents programs to play a soccer match against each other. A match is carried out in a client/server style: a server, SoccerServer, provides a virtual field and calculates the movements of the players and a ball. Each client is an autonomous agent that controls the movements of one player. Communication between the server and each client is done via TCP/IP sockets. Therefore the clients can be written in any kind of programming systems that have TCP/IP facilities, such as UNIX (SunOS, Solaris 2, DEC OSF/1, IRIX, Linux) or Microsoft Windows.

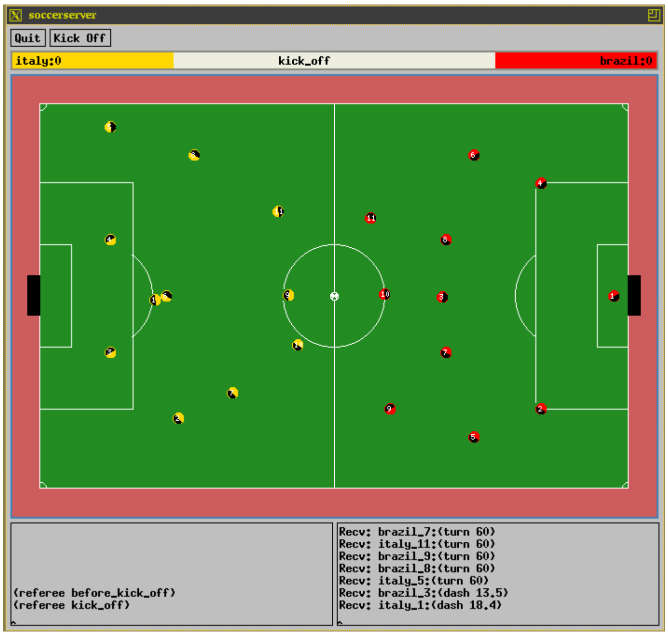

FIGURE. 5
THE ROBOCUP SOCCER SERVER - SCREENSHOT [8]

The SoccerServer consists of 2 programs: one is a server program, which simulates the movements of the players and the ball, communicates with clients, and controls a game according to the rules, and the other is a monitor program that displays the virtual field from the server on the monitor using the X window system.

The use of this server is still under evaluation: last term it was offered as a suggested activity - not as a compulsory task - due to difficulties aroused when installing and executing the server. The use of other kinds of robotic simulators, due to these difficulties, is under study.

Computer Vision and Genetic Algorithms used in the RoboCup domain are also being presented as AI examples in class.

In the Computer Graphics discipline the development of graphic simulations of the RoboCup domain by the students is being stimulated. Also, RoboCup is used as an example of Object Modeling.

6. CONCLUSION

As we have noticed undergraduate students have shown great interest in research projects and have been capable of defining and following both real research agendas and fulfill project system requirements.

The students used several methodologies in their studies, and they learned how to integrate different technologies and subjects, such as FPGA, VHDL, EDA, Digital Circuits, Step Motor Control, Artificial Intelligence, Computer Vision, Genetic Programming, Neural Networks, UNIX/Linux, C and C++ Programming Languages, TCP/IP Network programming and Wireless Data Communication.

As we can evaluate now the Robotics Domain has proved to be a very motivating practice, based on group activity that greatly improves the students' skills and provides a live, stimulating and cooperative learning environment, where everyone can discover and refine his own technical and social potential.

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