

A Lego-Based Soccer-Playing Robot Competition For Teaching Design

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Abstract

Course Objectives in the ME382 Instrumentation Laboratory at Norwich University include 1.Design of systems involving both computer hardware and software. 2.Use of modern computer tools for data acquisition and control. By having the students use a Lego Mindstorms robot kit and Robolab graphical programming software as a rapid prototyping tool combination a beginning at achieving both outcomes can be efficiently accomplished. The problem to be solved during the first six laboratory sessions is to design, build, test and compete with a robot that plays soccer. This competition is patterned after the International RoboCup Junior competition. The kit has the necessary components to allow the students to be creative in their mechanical designs. Since the RoboLab software is realized as a National Instruments LabView Virtual Instrument, this experience naturally gives students the background to design their own custom data acquisition virtual instruments later in the semester using the National Instruments computer-based data acquisition equipment. The spirit of competition heightens the motivation for the engineering lessons. The Australian competition winner (2000) was used as a case study. Mechatronics is stressed from the beginning. The students model their robot dynamics and use a digital video camera to measure critical performance criteria. They redesign the suggested software to achieve a superior ball handling performance. Thrashing behavior detection is discussed and designed into the software to help the autonomous robots recover when they get stuck or grapple with another robot. Players used the touch sensor to communicate pre-kickoff information such as which goal to shoot toward. The software design needed to allow for timely attention to the sensors as well as resolve conflicts when two or more sensors were demanding a response at the same time. The most successful designs used a subsumption software architecture. The students genuinely enjoyed the competition while learning integrated hardware and software design strategies. Their later experience with LabView writing their own stripchart Virtual Instrument proceeded naturally from their RoboLab experience and they have the confidence to be able to realize custom industrial automation solutions in the future.

I. Introduction

The Norwich University ME382 is a one credit third year "Instrumentation Laboratory" course that meets for 3 hours per week. Educational goals for the course include students being

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able to develop computer-automated data acquisition and control software as well as to design and conduct an experiment to evaluate that design. The Lego Mindstorms Robotics Invention System kit¹ has been used as an inexpensive rapid prototyping tool to meet those goals. The RCX software is replaced with an equally inexpensive graphical programming tool called Robolab that is available from Lego Dacta. The Robolab tool is a graphical programming language developed by Tufts University using National Instruments' LabVIEW software². These hardware and software tools allow the students to efficiently prototype and test the effectiveness of their design strategy. The Trinity College "Home Fire Fighting Robot Competition" problem was used in the past as a competition challenge. In that problem the students were able to design reactive software solutions combined with an overall problem solution strategy. The RoboCup Junior³ robotic soccer problem presents a dynamic artificial intelligence challenge with a great range for learning about Mechatronics, the realizing of a superior design by considering the simultaneous application of mechanical, electronic and software methods for solving problems.

II. The Competition

The RoboCup Junior rules specify that the competition is played on a 48 by 72 inch playing field with a gray scale surface. The soccer field pictured in Figure 1 is constructed out of painted plywood. A paper gray scale is available but in humid weather the paper tended to buckle so that paper surface was replaced by painting the gray scale directly on the plywood surface.

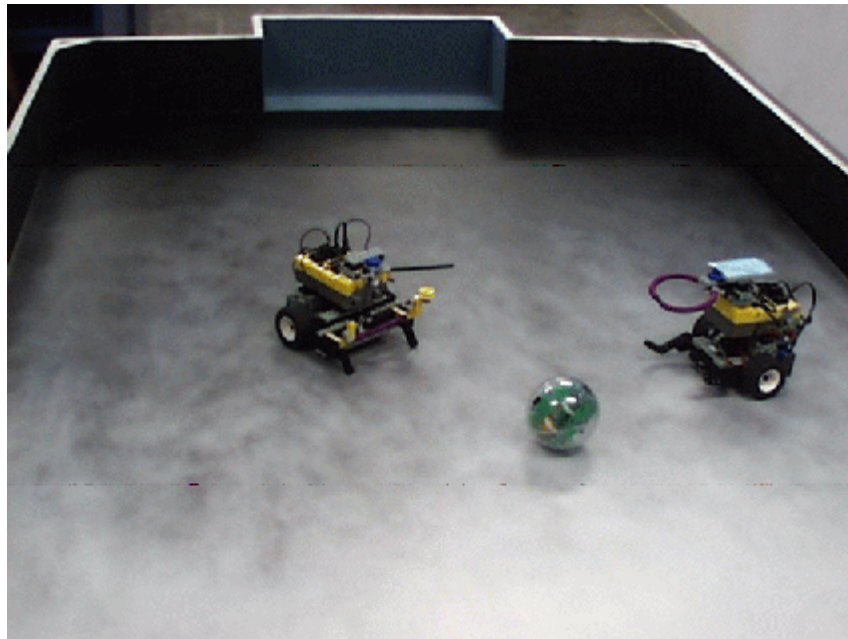


Figure 1. RoboCup Jr Soccer Field

The ball and special sensors to supplement the Lego Mindstorms kit are available from Wiltronics⁴. The construction plans for an example soccer-playing robot (robcon1.ppt, robcon2.ppt) as well as some example RoboLab graphical programming software (Programming.doc) are available from the Australian Web site. The RoboCup Junior League is designed for middle and high school education levels. The challenge to college students is how does their knowledge result in designing and building superior robot designs? The instructor maintaining one robot constructed to these Australian winner's plans helps to keep the challenge fresh in student minds.

There are four RoboCup⁵ international collegiate level competition leagues. The simulation league challenge is accomplished entirely on a computer display console and provides computer science students the ability to experiment with artificial intelligence problem solving techniques without worrying about the problems of designing, building and maintaining the mechanical or electronic aspects of the robots. The small robot competition league uses an overhead video system coupled to an off-field computer that analyzes the video and directs the robot teams by radio control.

The Lego "Vision Command" kit is designed to supplement the Mindstorms Robotics Invention System. With Vision Command hardware and RoboLab software, there is the potential to inexpensively realize a small robot RoboCup type competition using the Lego video camera overhead and using the InfraRed communications already built into the robot components in place of the radio control used in the international competition. This capability for use in Norwich University robotic soccer is currently under development.

The Norwich University intramural competition has been used in upper level mechanical and electrical engineering courses. It will be introduced into the new first year "Professional Projects" course next fall. In order to enhance the spirit of the competition, a trophy (Figure 2) is on display with name plates for all past winners. Plans are to also put this winner information on our WWW site.



Figure 2: The Norwich University RoboCup Soccer Trophy

III. Course Tasks

Solution of the soccer robot problem is divided into three parts each allowed two weeks. The first is design and testing of the mechanical structure. The second is design and test of the sensors. The third is realizing the design by building upon the test software to realize the design strategy for both producing a sufficiently reactive robot with an effective game strategy.

During the first two weeks, the robots are constructed using the parts in the Lego Mindstorms kit and constrained to fit within a 22 cm diameter cylinder. Student designs are not allowed to “trap” the ball. They are challenged to use the software to make best use of the electronic sensors and a good mechanical coefficient of restitution design and mobility for effective ball handling during the competition. After construction of the initial prototype, it is time for mechanical testing.

In the “one on one” version of the competition kick-off, the robot is not allowed contact with the ball for a period of one second after the initial contact. After measuring and modeling the dynamic response for different motor power settings, the teams design and demonstrate the ability to perform a basic kick-off maneuver. This maneuver is done using “dead-reckoning” although sensor input may very well be used for an improved “reactive” kickoff program task in the competition version of the software.

The second two-week task is to test the tactile and the light sensors using student-designed software. Supporting background information is available in books^{6,7} and on the Web⁸. The

tactile sensors are switches that are depressed when the mechanical antenna or bumper makes contact with the other robot or the wall. Software is designed to avoid getting stuck. The Lego light sensor is used to sense the reflectivity of the gray scale. This allows the robot to determine field position. The robot can compare successive sensor readings to estimate progress toward either the white or the black goal.

The transistors in the “soccer ball” pictured in Figure 3 emit Infrared light. The light sensor in the Mindstorms kit can be used to detect the ball but is of very limited range. A more sensitive sensor also pictured in Figure 3 can be customized giving the robot greater detection range. During this period of the course, the concept of reactive software design is introduced. Timeline analysis is used to develop code that allows the robot to effectively search for the ball and keep it in view while dribbling down the field.

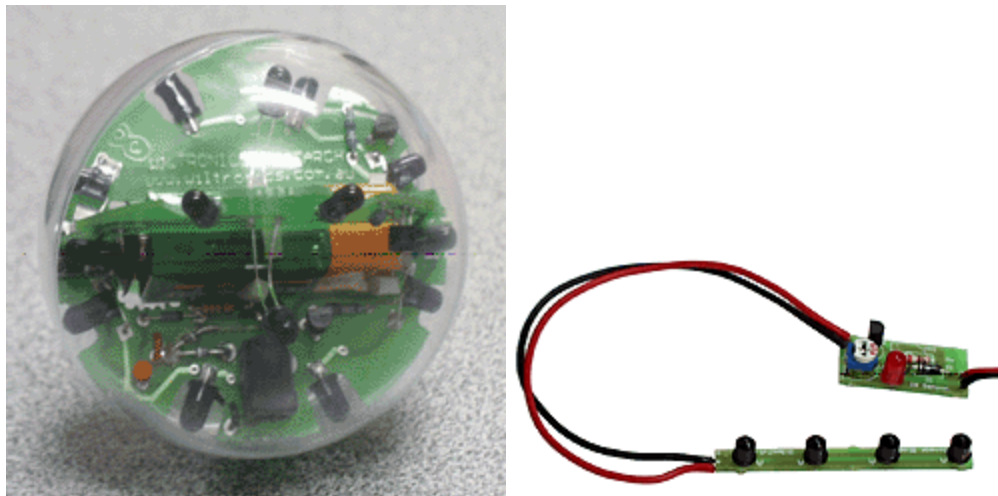


Figure 3. The Infrared Emitting Competition Soccer Ball and Infrared Sensors Available From Wiltronics⁴.

The third two weeks allow for development of the software to realize the game-playing strategy. Subsumption software architecture⁹ is suggested for realizing a multitasking reactive robot design. Students are coached to develop independent tasks for 1.Initialization (Kick-off) 2.Handling as well as searching for the ball. (Infrared Sensor) 3.Avoiding obstacles (touch sensor) 4.Arbitration among competing sensors for purposes of controlling the motors. The RoboLab graphical programming language allows for independent tasks just as well as the Not Quite C (NQC) code given in the literature on Subsumption architecture⁹. Timeline and state machine concepts of design need to be reinforced during this software development phase. The competition is run on the sixth week. Prior to the games, each team makes a presentation on their approach to design to allow the observers to better understand their robot's performance.

Adding vision sensing and control in the course now being taught inserts an additional two weeks after the second two weeks. Due to the physical and software constraints of the Mindstorms vision system and Infrared communications, the video information is available to only one robot at a time. Therefore, the competing robot has to be designed to rely entirely on the conventional Infrared sensor when vision control is not available. Therefore the suggested design approach is to use the robot and ball coordinates as determined by video analysis to assist in getting the robot close enough to use the Infrared ball sensor. Since the rules allow the referee to center the soccer ball in the field if no robot contact has occurred for 30 seconds, the unassisted robot might better focus its search at center field by using the gray scale and touch sensors to navigate to center field where the ball will most likely end up being placed by the referee.

IV. Results

Mechanical: Most of the American students come to the course with previous Lego experience so it is rare to get a team that does not assemble and modify their prototype rapidly. Student designs have effectively used mechanisms on the front of the robot for determining the best coefficient of restitution for collisions with the soccer ball. The motor voltage is Pulse Width Modulated (PWM). Currently, the “Power Level” software icon really refers to the PWM duty cycle. From studying the theory and gathering data from acceleration tests, students learn how to use gearing and “Power Level” to effectively control robot velocity.

Sensors: Students learn how to read and optimize the sensor’s effectiveness by walking the robot through the expected motions and observing the readings on the robot LCD output. The most difficult art to master is how to write software that reads the sensors often enough while effectively controlling the motors. Not reading the sensors often enough is the greatest weakness in the student RoboCup competition designs. Many contestant robots move rapidly around the soccer field and often pass closely to the ball without stopping to read the sensor and detect the ball. The ball sensor has a visible LED indicator so the observer can determine when the reading exceeds the detection threshold. Often student robot programs do not read this sensor value and therefore do not respond in as timely a manner as the observer expects. If the robot is pointed directly at the ball and the battery on the ball is nearly fully charged, the ball detection range can be up to 9 inches. Under other conditions, the range can drop to just a few inches. For this reason, competing robots seem to be encountering the ball and scoring almost by chance. It is for this reason that the vision command feature is being developed. The vision command can locate the coordinates of the robot and the ball. This information is then broadcast to one robot using the built-in Infrared communication link. The robot software uses this information to vector closely enough to the ball so that the IR sensor will be in range. If the RoboLab software didn’t require a robot response as a condition to continue broadcasting, then more than one robot could use the Infrared video broadcast. Possible hardware and software modifications are being considered.

Software: Software design must be flexible. The robot might be going for either the white or the black goal. The robot may be kicking off or defending. The robot may or may not be allowed to use vision information to assist in getting to the ball. RoboLab allows for up to 5 programs to be stored in the robot simultaneously. Also, an on-board multitasking language feature allows for options to be turned on or off. Students sometimes communicate to the robot through the tactile sensors immediately after power-up to have the robot set “state control variables”. Once underway, the robot is designed to run autonomously. A good design uses sensors to detect when it gets stuck. Appropriate motor control should set it free. If it gets stuck and cannot get free on its own, the referee can authorize a team member to free the robot. While the robot is stuck, the other robot of course is free to score without interference. Another more challenging problem is when the robot gets stuck in an unproductive repetitive pattern of motion. This is called “thrashing behavior” and is more difficult to detect. This involves effective use of variables that in RoboLab are designated by “container” icons. Having the competition on the sixth week did not give students enough time to test and develop all aspects of their software designs. Extending the experience an additional week is likely justified. During the sixth week, the robots should demonstrate playing skills such as finding the ball and shooting it at the goal.

V. Conclusions

Competition heightens the educational experience. The problem with this is that the students sometimes spend more time on this one credit course to the detriment of other courses. Student course assessments overwhelmingly cite the Lego competition as the most enjoyable part of their laboratory experience. In the process, they naturally add to their mechanical educational outcomes. They 1.Develop their knowledge of fundamental methods of measurement used in mechanical engineering. 2.Increase their knowledge of computer-aided design and computer integrated manufacturing. 3.Formulate and solve engineering problems. 4.Design and conduct their own experiments as well as analyze and interpret data. 5.Improve their skill in using modern tools necessary for mechanical engineering practice. 6.Demonstrate an ability to design a system that meets speed and reliability requirements. 7.Develop their ability to communicate effectively and work in teams. These are current mechanical engineering program curricular educational outcomes.

The specific knowledge of DC motor PWM control, vehicle and ball interaction dynamics, mechanical and electrical characteristics of sensors, and robotic vision as used to control motion will likely have wide application in their later careers. After the competition, later laboratory experience requires the students to develop virtual instrumentation using National Instruments’ LabVIEW software. Since their RoboLab software is itself a LabVIEW virtual instrument, this occurs efficiently and naturally. The RoboLab and Mindstorms combination is even capable of projects that do data acquisition and control from a remote location. This could be done over a radio link, a telephone modem or in the case of RoboLab also over the World Wide Web. This World Wide Web capability also is a feature of the LabVIEW software they will like encounter

later in their careers.

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