ROBOT SOCCER: INTEGRATED FRAMEWORK FOR MULTIDISCIPLINARY HI-TECH EDUCATION

G. Sen Gupta, Lim Y. S., C. H. Messom, S. Demidenko,
S. C. Mukhopadhyay, D. N. Pinder

ABSTRACT

Robot Soccer has become increasingly popular over the last decade as a platform for education and entertainment. It is a powerful vehicle for dissemination of scientific knowledge in a fun and exciting manner. It encompasses several technologies – embedded micro-controller based hardware, wireless radio-frequency data transmission, dynamics and kinematics of motion, motion control algorithms, real-time image capture and processing, multi-agent collaboration, programming and mechatronics in general. With very user-friendly Graphical Interfaces (GUI), different elements of scientific principles can be explored and experimented with by interacting with the system. The results of experiments are presented instantaneously. Since the systems from two teams perform in a competitive environment, there is tremendous excitement too. This itself is a great attraction for students, from primary schools to tertiary education level. The key features of the Robot Soccer Games and how it is used in learning mathematical, scientific and engineering concepts are presented in this paper.

KEYWORDS

Robot soccer game, vision theory, control algorithms, radio frequency transmission, programming, embedded systems, computer based learning, graphical user interface, interactive software

INTRODUCTION

Micro Robots are used in education and entertainment in many ways (Jong-Hwan Kim and Myung-Jin Jung, 2000). There are robots which navigate a maze, climb a wall, play a game of soccer, wrestle with another robot, run round a track, balance a pole, mow the lawn and vacuum clean the house. As shown in Figure 1, the robots vary in size, from as tiny as 4cm x 4cm x 4cm to those that reach human size. The popularity of Robot Soccer Games has been increasing in leaps and bounds. It is evident from the number of participants in the many keenly contested international competitions – Federation of International Robot Soccer Association Robot World Cup (FIRA, *online*), RoboCupSoccer (International RoboCup Association, *online*), International Robot Olympics (IROC, *online*) to name a few – which are held on a yearly basis, in different countries around the globe (Robotic Competitions List, *online*). National Robotic Competitions are held in practically every scientifically advanced country e.g. Singapore Robotic Games (SRG, *online*), Canada First Robotic Games (Canada FIRST, *online*) etc. In each competition there are various robotic categories, which are increasing every year.

The robotic games have enabled people and their robots from all over the world to come together to share and disseminate knowledge. As well as the hardware that makes up the physical aspects of the robots, there is also a large amount of software in the system.., When used as part of a suitable programme of study, is a powerful tool for learning not just programming techniques but large number of scientific principles - from image processing to motion control theory.

Figure 1. Various sizes of Robots for Soccer game

Entertainment Robots offer a proving ground where engineers in software, computers, sensors and communication - all things electrical and mechanical - can test, develop and apply their latest technology. In many tertiary institutes around the world, students engage in constructing robots for edutainment. Usually it is done as a major project which is a core element of the study program (Linda M. Head, Gay Canough and Ravi P. Ramachandran, 2002). In this paper we have introduced the robot soccer game as a powerful computer based learning tool, highlighting the various topics that students learn from the system and how the software is used to learn and apply concepts. Project based learning is increasingly becoming an essential aspect of many engineering courses. A project-based learning method is a comprehensive approach to instruction. Students participate in projects and practice an interdisciplinary array of skills from math, science and technology. Researchers are also keen to explore the use of simulation software and multi-media to enhance project-based learning (William R. Penuel and Barbara Means). When students use computers to apply higher order concepts and when teachers are knowledgeable about how to use computers as productivity tools, students show significant gains in mathematics achievement (Wenglinsky, 1998).

SYSTEM DESCRIPTION

Figure 2 shows the system components of a Robot Soccer System. It consists of a colour CCD camera which feeds the image to a Frame Grabber Card, which is plugged inside a PC. The Frame Grabber card digitises the picture. The software running on the PC is hierarchical in construction and is made of several layers. It first analyses the picture and locates the position of the ball and the position and orientation of the robots from both teams. The information from the Vision Processing software sub-system is passed to the Strategy Layer which decides the next move and what behaviour each robot must exhibit. The Control Layer generates the commands for the robots, which are sent on a wireless media using Radio Frequency (RF) wave. The software architecture is shown in Figure 3. The PC is the central controller and is the “brain” of the system. A transmitter is attached to the PC which transmits the control data to the robots. Each robot has its own RF receiver to receive the data sent to it. The system presented here has 3 robots in each team.

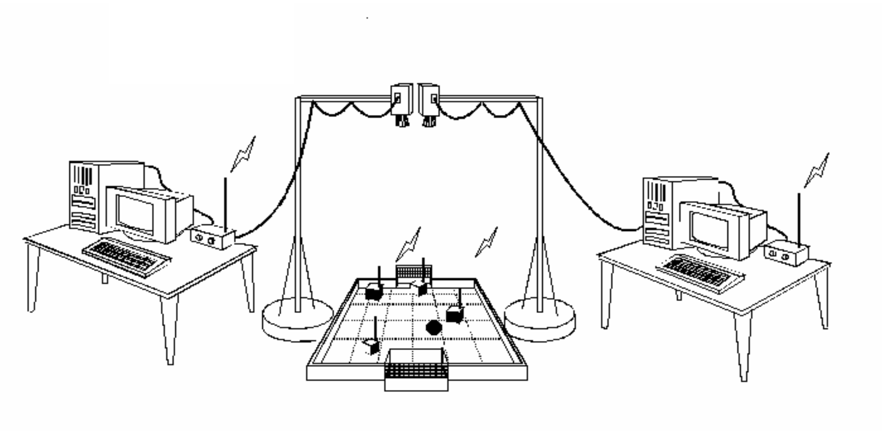


Figure 2. Global Vision Based Robot Soccer System

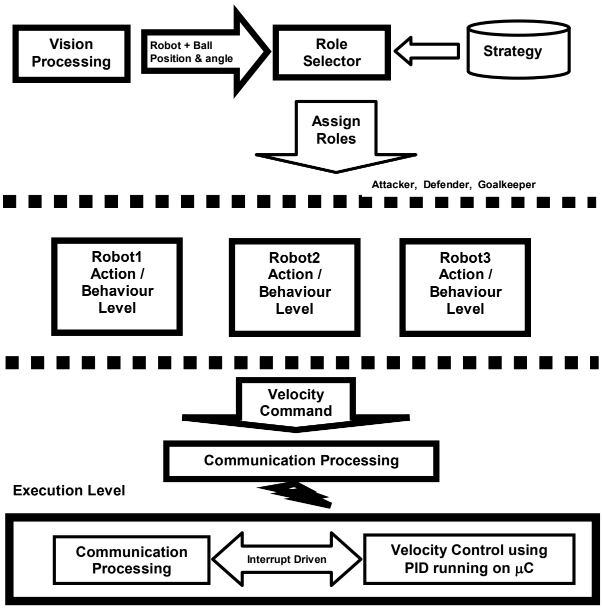


Figure 3. Hierarchical Software Architecture

COMPUTER BASED LEARNING OF SCIENCE

The robot soccer game incorporates many spheres of science. To plan the basic trajectory of a robot's movement, knowledge of trigonometry and geometry are required. The software system that has been developed allows experiments where various parameters can be changed and the effect observed.

Shooting the ball - Learning geometry

A case study of shooting a ball is presented in this section. After understanding the basic geometry, the students experiment with changing certain parameters using the Graphical User Interface (GUI) and observe the motion of the robot to shoot the ball. The geometry is briefly explained in Figure 4.

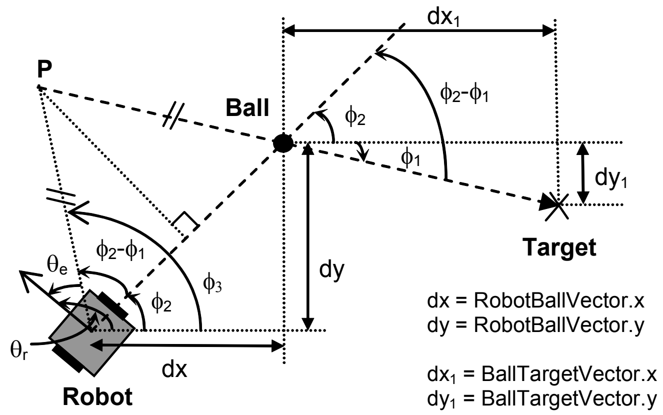


Figure 4. Calculating wheel velocities for shoot function

ϕ_1 **:** targetAngle
ϕ_2 **:** ballAngle
$\phi_2 - \phi_1$ **:** ballTargetAngle
θ_r **:** Robot Angle

Robot's desired angle, $\phi_3 = \phi_2 + (\phi_2 - \phi_1)$
$= 2\phi_2 - \phi_1$ ………………………………. Eqn (1a)
Angle Error, θ_e = Robot's desired angle – Robot angle
$= \phi_3 - \theta_r$ ………………………………. Eqn (1b)

The wheel velocities are calculated as -
$V_L = V_c - K_a * \theta_e$
$V_R = V_c + K_a * \theta_e$ ……………………………………………... Eqn (1c)

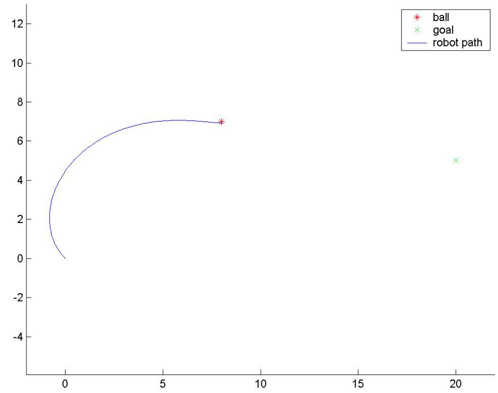
K_a is the constant proportional gain for the angle error. When the robot is in line with the target, the angle error, θ_e, will be zero and the robot will move straight towards the target with a constant velocity, V_c.

Practical Considerations

To make the robot turn faster towards the ball, the target position **P** (see Figure 4) was adjusted to be closer to the ball. This was achieved by adding a scale factor, *k*, to Eqn(1c) and the modified equations are as shown in Eqn (2).

$V_L = V_c - K_a * (\phi_2 + k*(\phi_2 - \phi_1) - \theta_r)$
$V_R = V_c + K_a * (\phi_2 + k*(\phi_2 - \phi_1) - \theta_r)$ ……………………... Eqn (2)

The experimental results using Eqn (1c) and Eqn (2) are shown in Figure 5 a & b. Students can generate the robot's trajectory by changing k, the scale factor, from 0.5 to 1.0. The trajectory is plotted using the data captured by the Vision Software.



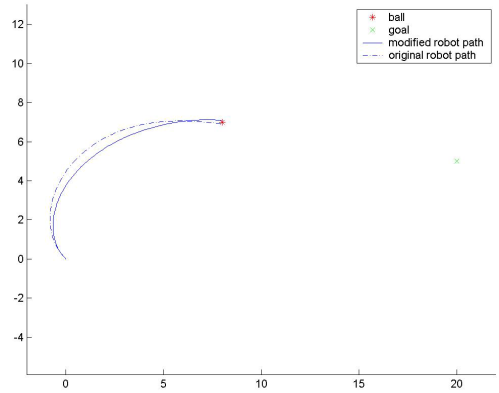


Figure 5a. Robot Path using Shoot Function 5b. Path using modified Shoot Function

Learning to see – Vision Theory
Each robot is identified by a "colour jacket". Students learn the basic theory behind image processing and object identification. The effects of various vision tuning parameters are experimented with. The software reports the position and angle of the objects - ball and robots - on the field, together with statistics of the reliability of the vision system.

A sample robot colour jacket is shown in Figure 6. Each jacket has two colour patches – a team patch, to differentiate between home and opponent team, and a unique robot colour patch to identify the robot within a team. The colours have to be tuned first using the GUI shown in Figure 7. Once the colours are tuned, the scanning can be tested. From the diagnostic data depicted on the screen, inference can be drawn on the accuracy of tuning and what parameters need to be altered to improve it.

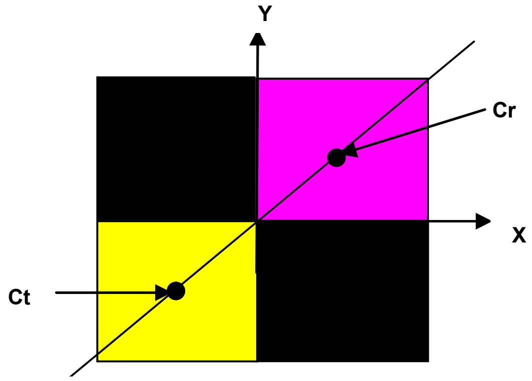


Figure 6. Robot's Colour Jacket

Students are exposed to the basic colour theory – how each pixel is represented by its RGB components and how the tuning can be improved by converting to YUV representation to segregate the light intensity component. The YUV range of the colours can be fine tuned using the GUI shown in Figure 8.

During the test phase of the colour tuning, students gain immediate feedback on the suitability of the YUV range values. Unsuitable YUV range values will result in a low number of pixels being identified from the required colour jacket itself and a large number being erroneously identified in the background and on other robots.

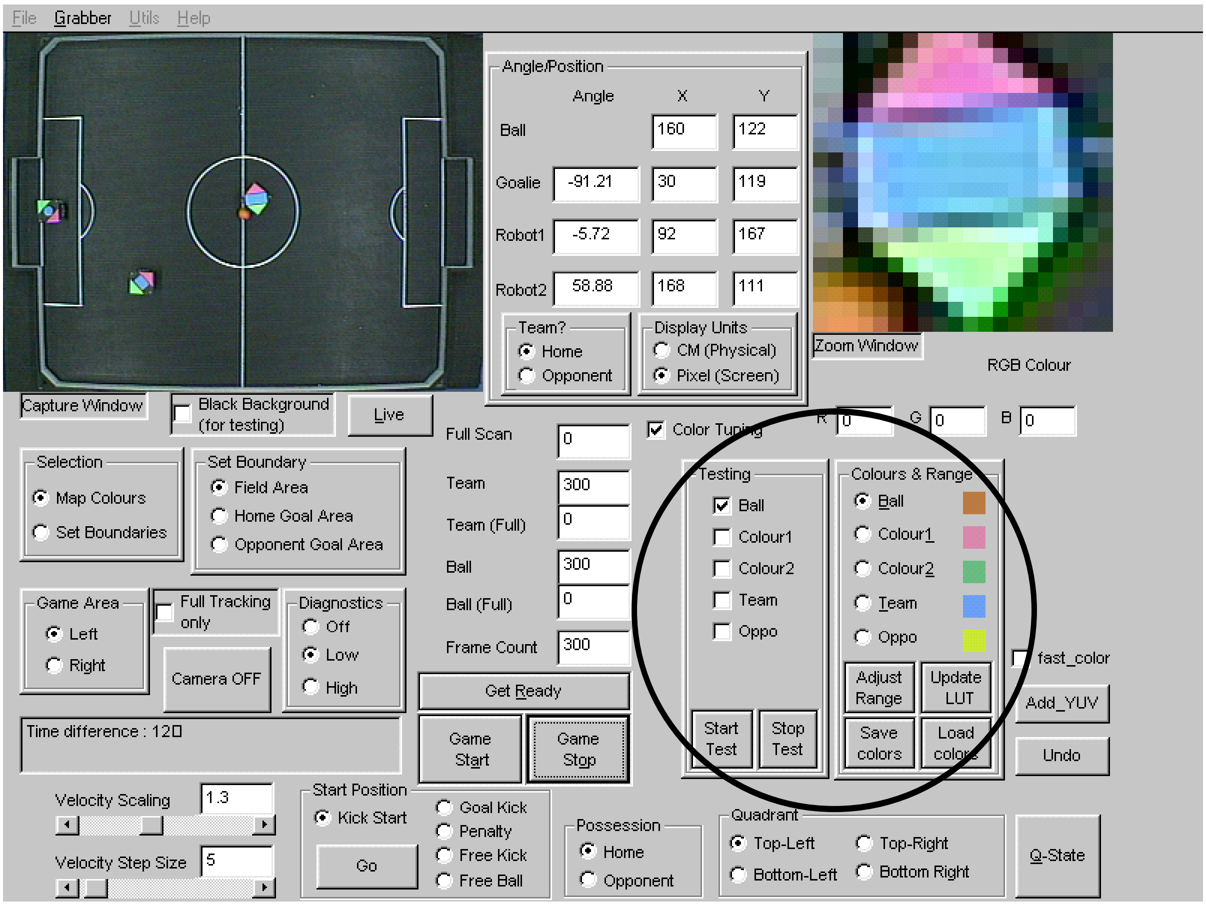


Figure 7. The application's GUI showing colour tuning buttons inside the circle

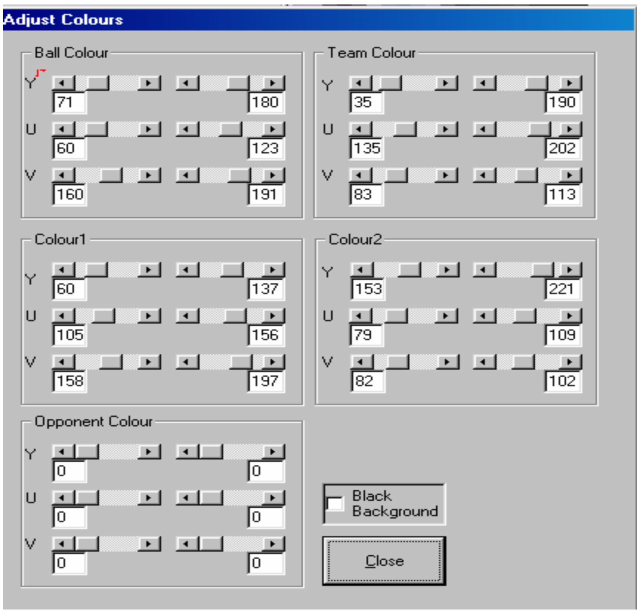


Figure 8. Tuning the YUV range of each colour

To improve the angle accuracy, students have to experiment with different colour patches and colour schemes. For the patch shown in Figure 6, the accuracy that can be achieved with good colour tuning is $\pm 5^0$. An alternate colour patch that is analysed and studied is shown in Figure 9. This patch improves the robot's angle accuracy to ±3^0. Students are required to comment on the reasons for the improvement thereby learning how the increased distance between the centres of gravity of the colour patches enhances accuracy.

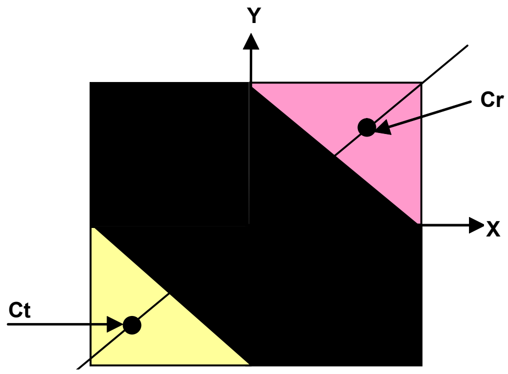


Figure 9. Colour patch to improve the angle accuracy

Learning the fundamentals of Wireless communication

Wireless transmission is another aspect which students learn about using the software. The effect of distance on the reliability of data transfer is learnt. The movement of individual robots can be remotely controlled. The path traced by a robot when fed with various velocities can also be experimented with. This eventually helps in programming the motion control functions.

The robots are remote controlled by the central PC using wireless Radio Frequency (RF) transmission of data. The fundamentals of RF transmission are covered in theory. Using the RF Link software, students experiment with how the RF data packet loss increases with distance of the robot from the transmitter and how the whip antenna's reception characteristics change when it comes in close proximity of another transmitting antenna. The RF Link software's GUI is shown in Figure 10.

Using the RF Link software, students can experiment with different communication ports and transmission baud rates. They experience first hand how the packet loss increases at higher baud rate while at a lower baud rate the transmission time increases.

Students can also use the Link software to test the basic functionality of the robot using remote control commands. These low level remote control commands can be used to experiment how the robot's trajectory is affected by changing the velocity of the left and right wheel, what is the maximum speed at which the tyre slippage has a significant impact on the robot's trajectory.

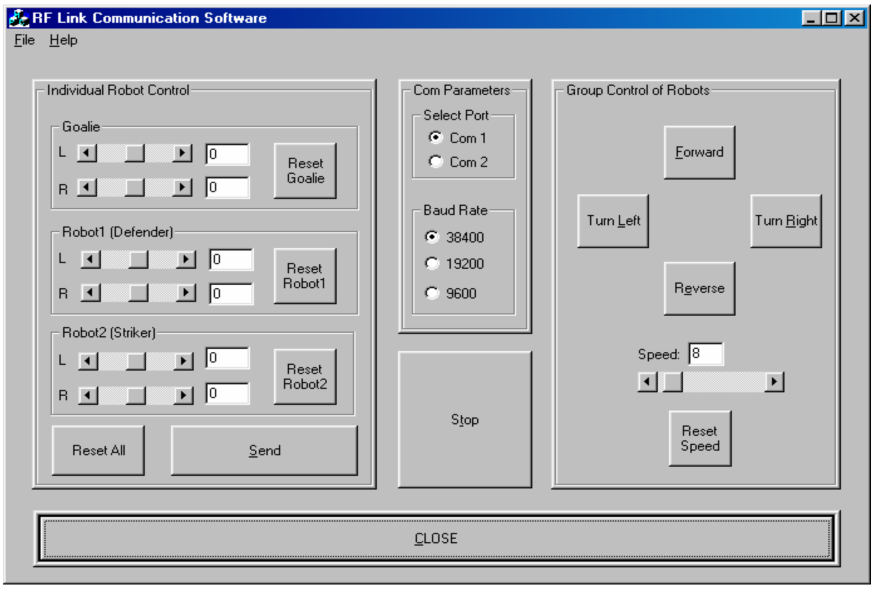


Figure 10. GUI of the RF Link Software

Control Algorithms and Strategy Planning – Tuning the game parameters

The strategy is planned using a State Transition Based Control. Students learn about these principals by interacting with the software system.

The robot soccer system is a very effective tool for learning how to program and implement game strategies. The students are taught the theory of the State Transition Based Control (STBC) methodology (G. Sen Gupta, C.H. Messom, Sng H.L, 2002). An example of selecting roles for the two robots, other than the Goalkeeper, is explained here. To implement the role selection, the field is physically divided as shown in Figure 11.

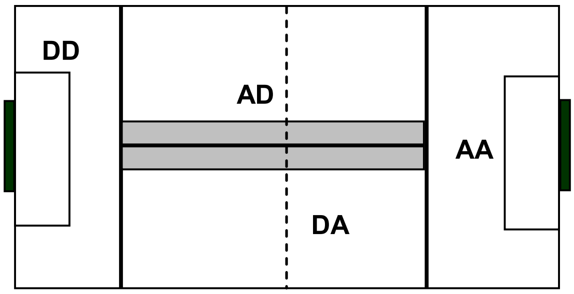


Figure 11. Boundaries for robot *Role Selection*

When the ball is in the region marked **DD**, two robots together exhibit defender behaviour. When the ball is in the regions marked **AD** and **DA**, one each is an attacker and a defender while the presence of the ball in the region marked **AA** makes both the robots take on the role of attacking the opponent goal. There is an overlap between **AD** and **DA** regions. The state transition diagram is shown in Figure 12.

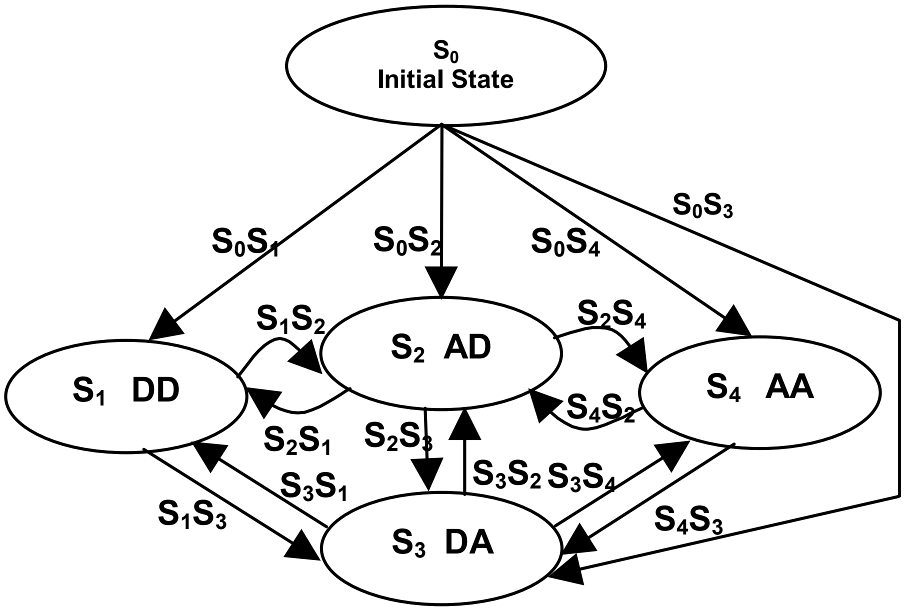


Figure 12. State transition diagram for R*ole Selection*

The software allows the user to change the overlapping region, the upper and lower limits for the attacker and the defender. The users interface for this shown in Figure 13.

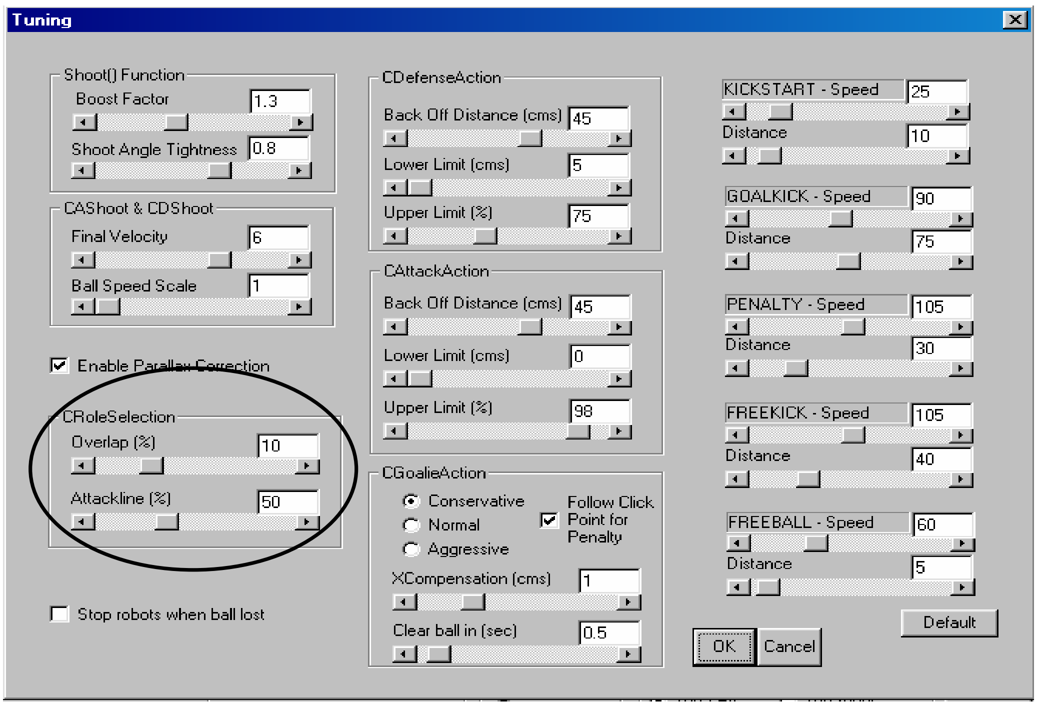


Figure 13. User Interface to alter state transition conditions for *Role Selection*

The concepts of the state transition based control are reinforced by experiments modifying the state transition boundaries.

EXPERIMENTAL SETUP FOR COMPUTER BASED LEARNING

The experimental setup, shown in Figure 14, consists of a Pulnix 7EX NTSC camera and a Flashbus MV Pro image capture card.

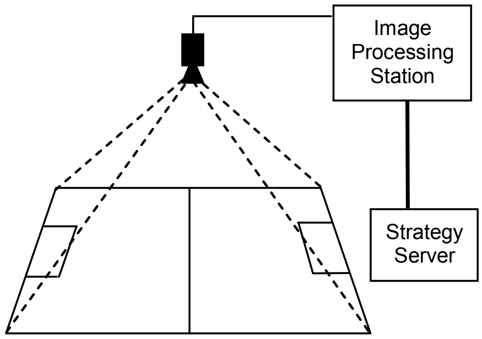


Figure 14. Experimental Setup

The image can be captured at a resolution ranging from 80x120 to 480x640 at a sampling rate of 30Hz. The students can experiment with the different resolutions and observe the accuracy of the system as well as the processing time. Processing the odd and even fields of the interlace camera separately captured at a resolution of 320x480 results in an effective image resolution of 320x240 delivered at a sampling rate of 60Hz. The image captured is processed on a 450MHz Pentium II PC with 128MB RAM. The data from the vision processing is passed to the strategy server running on the same PC. The image capture card was configured for off-screen capture, as shown in Figure 15. Onscreen capture allows the video image to be displayed on the screen, but experiments show that processing the image from VGA RAM has problems due to memory contention.

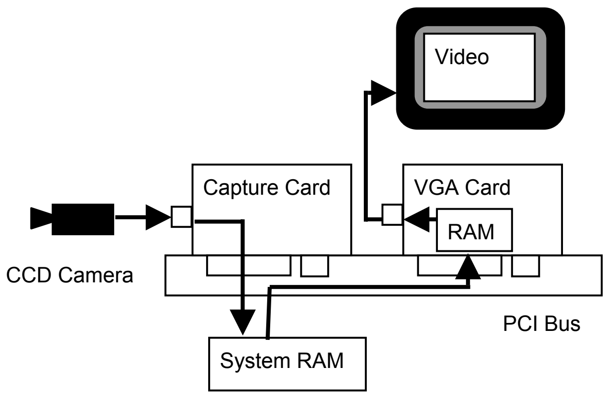


Figure 15. Image capture in off-screen capture mode

CONCLUSION

In this paper we have presented a Robot Soccer System as an effective and exciting computer based learning tool. Through this system and its software, students learn geometric principles, basic colour representation theory, control strategy and principles of wireless communication using Radio Frequency. The entertainment coupled with the robot soccer game is a great attraction for students and it helps to keep their interest in science and maths alive. The system has been used in Robotic Science Camps, which have been conducted in Singapore Polytechnic for students of primary schools, secondary schools and tertiary institutions. The science camps have been very successful and attracted enormous participation. A group of excited students is shown in Figure 16. At the end of the training sessions in the Science Camps, friendly games were held. All students where motivated by the camps and have learnt a lot about science and the application of mathematics and geometry in robotic applications. Informal feedback showed that they would definitely look forward to more such sessions in the future.

Figure 16. Students at a Robot Soccer Game

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G. Sen Gupta, Assoc. Prof. S. Demidenko and Dr. S. C. Mukhopadhyay
Institute of Information Sciences and Technology
Massey University, Turitea Campus
Palmerston North 5301
New Zealand
Email: G.SenGupta@massey.ac.nz, S.Demidenko@massey.ac.nz, S.C.Mukhopadhyay@massey.ac.nz

Dr. D. N. Pinder
Institute of Fundamental Sciences
Massey University, Turitea Campus
Palmerston North 5301
New Zealand
Email: D.N.Pinder@massey.ac.nz

Dr. C. H. Messom
Institute of Information and Mathematical Sciences
Massey University, Albany Campus
Auckland
New Zealand
Email: C.H.Messom@massey.ac.nz

Lim Y. S.
School of Electrical & Electronic Engineering
Singapore Polytechnic
500, Dover Road
Singapore
Email: LimYS@sp.edu.sg