Robo Soccer
- a real time platform for applying computational intelligence

Prof. Alok Kanti Deb
Department of Electrical Engg, IIT Kharagpur
alokkanti@ee.iitkgp.ernet.in
“Here in the place of that Hijli detention camp stands this fine monument of India, representing India’s urges, India’s future in the making”

---- Pandit Jawaharlal Nehru
IIT Kharagpur over the Decades

1950’s: Establishing the IIT Education System with 224 students and 42 teachers

1960’s: Growth in Engineering, Science, HSS, Vibrancy in Academic Research

1970’s: Capacity Growth, Sponsored Research & Consultancy

1980’s: CSE, Biotechnology, Industrial Engineering, SRIC

1990’s: Multi-disciplinary Centres, ATDC, Missions, Entrepreneurship Park, Business Management


2010: Medical Education, Engineering Design and Manufacturing, Entrepreneurship, Science Park, Fund Raising for the Institute

Vision 2020: World Class Technology based University
Global Partnership with Peer Institutions.
Be among top 20 tech Institutions in 20 years

1950’s: Establishing the IIT Education System with 224 students and 42 teachers
Introduction

Why RoboCup?

- International research and education initiative.
- Designing a team of fast moving autonomous robots in a dynamic soccer environment.
- Provides a standard platform where teams can compete and test their robot controllers, designs and algorithms.
- 40 countries around the world – yet to be an Indian SSL team.

The Small Sized Soccer League

- Arena: 6.05m X 4.05m
- Robots: Diameter 18 cm but less than 15 cm unless it has onboard vision.
- Height – 15cm
- Over head camera 4 m above the field
- One common server
- Wireless communication
- Maximum team size is 5
- Green carpeted field with an Orange ball.
Robocup 4 Wheel Robot Design

Omni wheels – plastic wheels with rubber rollers across the perimeter for lateral movement.

Motor – 12Vdc motor with 512 ticks/rev encoder and 27:1 spur gearhead.

Bottom view of robot chassis

Complete robot with shell

Omni wheels – plastic wheels with rubber rollers across the perimeter for lateral movement.

Kicker

Dribbler
FIRA-Federation of International Robot Soccer Association

- Arena: 2.2 m X 1.8 m
- Robots: 7.5 cm × 7.5 cm × 7.5 cm
- Over head camera 4 m above the field
- One common server
- Wireless communication
- Maximum team size is 5
- Black carpeted field with an Orange ball.
HuroCup

“By 2050, a team of fully autonomous humanoid robot soccer players shall win a soccer game, complying with the official FIFA rules against the winner of the most recent World Cup of Human Soccer”
Robo Soccer (http://www.fira.net/)

- **HuroCup** – Sprint / Obstacle Run / BasketBall / Weightlifting / Marathon / Soccer

- **AmireSot** – One robot & Two human members

- **MiroSot** – Five robots, one can be Goalkeeper

- **NaroSot** – Five robots; (Field-1.3m × 0.9m; Robot-4cm×4cm×5.5cm)

- **AndroSot** – (Field-4m × 6m; Robot dimensions- <50cm; Robot weight- 600gm; Remote control)

- **RoboSot** – (Field-2.6m × 2.2m; Robot-20cm×20cm×No height limit)

- **SimuroSot** - In simulation platform
Technology Requirements

- Mechanical
- Sensors
- Digital Control
- Power Electronics
- Image Processing
- Video Processing
- Communication
- Software
- Algorithms
- Artificial Intelligence
- Computational Intelligence (Fuzzy Logic, Neural Networks, Evolutionary Computation) \(\Rightarrow\) Intelligent Control
- Embedded Electronics
Chassis design for new FIRA robot

Design Features
- The design features 4 dribblers: 2 on each face of the robot.
- The dribblers have been designed such that the ball fits exactly into the groove. Hence, when the robot moves at a high speed, the ball is held in the groove.
- Not more than 30% of the ball should be inside the body of the robot at any time. This constraint has also been taken care of.

Progress
- A wooden design was made and dribbling action was tested.
- Solidworks design has been sent to a manufacturer.
Solenoid Design Simulation in FEMM

Solenoid Circuit Simulation Result

Results
- Total current = 25 Amps
- Voltage Drop = 100.693 Volts
- Flux Linkage = 0.355456 Webers
- Flux/Current = 0.0142182 Henries
- Voltage/Current = 4.02774 Ohms
- Power = 2517.34 Watts

Plunger

Copper winding

Flux density plot for the solenoid

Variation of force profile of the plunger with the length of the plunger
Kicker Circuit

Power Electronics circuit for main kicker

Ratings of components used:
- Transformer ratings:
  - Primary: 50 turns
  - Secondary: 100 turns
- Capacitor: 2500uF, 100V
- Switch: IRF840
  - Voltage rating: 400V
  - Current rating: 8A
- Diode: 1A fast recovery diode
- Relay:
  - Switching voltage: 12V
  - Voltage Rating: 250V
  - Current Rating: 7A
- Battery: 12V, 2500mAh, Li-ion

Performance Characteristics:
- Output voltage = 100V
- Charging time ~2s
- Kicking Speed ~2m/s

Plunger for kicking

Kicker solenoid
Transformer Design using Area Product method

- Switching Frequency: 100kHz
- Power rating: 12Vx4A = 48W
- Ferrite core most suitable at 100kHz.
- Graph used to choose core
- Core 42510 is chosen for the design
Setup for testing the circuit

Blue: PWM signal at a duty ratio of 87%

Blue: PWM signal at a duty ratio of 87%

Pink: Diode Current (100mV/A)

Pink: Battery Current (100mV/A)

Blue: Capacitor Voltage

Pink: Capacitor charging current (100mV/A)

Pink: Capacitor Current (100mV/A)
Improvements in kicking circuit

Ratings of components used:

• Transformer ratings:
  – Primary: 30 turns
  – Secondary: 120 turns
• Capacitor: 2200uF, 200V
• Diode: 1A fast recovery diode (2 diodes in series)
• (rest of the circuit components are same as those used in the previous version of the circuit)

Performance Characteristics:

• Output voltage = 200V
• Charging time ≈ 5s
• Kicking Speed ≈ 5m/s

PCB Design for better reliability of circuit:

• All vacant areas have been connected to ground so that wire resistance can be minimized.
• All connectors have been placed on the periphery of the board for ease of access.
Automatic Dribbling mechanism

A TSOP proximity sensor is used to detect the approaching ball. The dribbler is turned ON when the distance of the ball from the robot is less than a calibrated threshold value.

TSOP binary o/p
0-ball in region
1-ball out of region

12V dc motor

Gear System

Dribbler bar

Diagram showing the circuit configuration with 5V power supply, TSOP sensor, MOSFET, and PWM signal.
Dribbler Testing

Performance Testing of dribbler

- Dribbler run at 7.5 Volts
- Robot placed at 45cm from the base of the ramp
- Length of ramp fixed at 50cm.
- Number of trials at each angle of the ramp is 30.

Experiment to find out optimal motor voltage

- Slope fixed at 25 degrees with the horizontal
- Robot placed at 45cm from the base of the ramp
- Length of the ramp fixed at 50cm.
- Number of trials at each voltage is 30.
Controller circuit

- PCB layout made in Eagle for fabrication of controller main board
- The board has been fabricated and tested
Chassis design for new FIRA robot

Design Features
- The design features 4 dribblers: 2 on each face of the robot.
- The dribblers have been designed such that the ball fits exactly into the groove. Hence, when the robot moves at a high speed, the ball is held in the groove.
- Not more than 30% of the ball should be inside the body of the robot at any time. This constraint has also been taken care of.

Progress
- A wooden design was made and dribbling action was tested.
- Solidworks design has been sent to a manufacturer.

Advantages of new design
- Equal utilization of both faces of the robot was now possible.
- Dribbling was now possible. The robot can dribble with ball approach angles in the range -60 to +60 degrees.
- The chassis was lighter and hence, higher speeds can be achieved.
- The C.G. was lower and hence, the design was sturdy.
- **Reinforcement Learning**: System information is available as an evaluation signal from a ‘teacher’.
Control by Action Dependant Heuristic Dynamic Programming


Critic Element: SVM based Tree type NN (Jayadeva, A. K. Deb, S. Chandra, *IJCNN* 2002)


Desired Action element Mapping \[ A : \{x(t)\} \rightarrow \{0(t)\} \]
Reinforcement Learning Scenario

- Agent maps states to probability of selecting actions $\pi_t(s, a)$
- Agents goal is to maximize the total amount of reward it receives over the long run
- Value function indicates, while following policy $\pi$, the value of a state $V^\pi(s)$ or state-action pair $Q^\pi(s, a)$
Limitations of previous embedded systems design

- 1 ATmega 32 (the master controller) and 4 ATmega 88’s (slave controllers) used.
  - Each of these microcontrollers can operate at a maximum clock frequency of 20MHz.
  - This speed limitation has been a major barrier of design for faster and more accurate controllers.

- Parallel processing restricted.
  - A microcontroller was dedicated to processing each of the 4 motor shaft encoder readings.
  - More sensors like a digital compass, accelerometers and current sensors planned to be used.
  - Having dedicated microcontrollers to process the data from each of these sensors was impractical.

- Complicated signal processing tasks like Kalman filtering could not be implemented
New Embedded Systems Design

FPGA
- Processing Motor shaft Encoder data
- PID controller for motors
- PWM generation
  - Motor driver circuit
  - Kicker circuit (flyback converter)
  - Dribbler circuit (for controlled dribbling)
- Kalman filtering to combine accelerometer, shaft encoder and compass readings

ARM
- Interfacing accelerometers (3 Analog channels)
- Interfacing digital compass (I2C protocol)
- Wireless communication with computer using Xbee modules (RS-232 protocol)
- Logic for the master controller

![Spartan 3E development board](image1)
![ARM7 development board](image2)
Sensor Fusion using Kalman Filter

- Data from sensors like accelerometers, digital compass, shaft encoder and cameras needs to be combined and filtered to estimate the state of the robot.
- The state of a robot is defined as $\begin{pmatrix} x, y, \theta \end{pmatrix}$. 
## Game Strategies

### Current Implementation Problem

| Control System | Robot Motion Control Skill: Onboard PID control for velocity tracking Computer PD control for position tracking Eg. Move to point, follow path | • Deviation due to different wheel slip • Certain areas have changing slip |
| Robot Attack/Defense Tactics Manually designed skill state machines with parameters evaluated from heuristics Eg. Keep ball in possession, acquire ball | • Very little robustness and flexibility • Unforeseen scenarios and opponents • Very difficult to make accurate designs without proper experience |
Adaptive Critic for Antislip Control

Objective of the robot is to follow a velocity command as closely as possible. Hence primary utility function is

$$U(t) = \sigma_v\{v(t) - v_d(t)\}^2 + \sigma_\omega\{\omega(t) - \omega_d(t)\}^2$$

Where \((v, \omega)\) are the velocities, \((v_d, \omega_d)\) are the desired velocities and \((\sigma_v, \sigma_\omega)\) are the weights.

$$J(t) = \sum_{k=0}^{\infty} \gamma^k U(t + k) = U(t) + \gamma J(t + 1)$$

This is the secondary utility function, where \(\gamma\) is the discount factor.
Model of a Wheeled Robot

\[ M(q)\ddot{q} + C(q, \dot{q}) + F(\dot{q}) + G(q) + \tau_d = B(q)u + A^T(q)\lambda \]

\[ A(q)\dot{q} = 0 \]

Choosing a matrix \( Z(q) \in \mathbb{R}^{n \times (n-m)} \) spanning the null space of \( A(q) \) and an auxiliary time vector \( R(t) \in \mathbb{R}^{n \times (n-m)} \)

\[ \dot{q} = Z(q)R(t) \]

\[
\bar{M}(q)\dot{\bar{R}} + \bar{C}(q, \dot{q})\bar{R} + \bar{F}(\dot{q}) + \bar{G}(q) + \bar{\tau}_d = \bar{B}(q)u
\]

where
- \( q \) – Coordinate vector
- \( M \) – Inertia matrix
- \( C \) – Coriolis and centrifugal matrix
- \( F \) – Surface friction
- \( G \) – Gravitational Vector
- \( \tau_d \) – Disturbance Matrix
- \( u \) – Input torques
- \( A \) – Constraint matrix
- \( \lambda \) – Lagrangian multiplier
Architecture

- **Action Network**: 4-3-2 MLP structure with \((v, \omega, v_d, \omega_d)\) as input and \((u_1, u_2)\) as output.

- **Verification Network**: 4-3-2 MLP structure with \((v, \omega, v_d, \omega_d)\) as input and \((\lambda_1, \lambda_2)\) as output, where
  \[
  \lambda_1 = \frac{\partial J}{\partial v}, \lambda_2 = \frac{\partial J}{\partial \omega}
  \]

- **Critic Network**: 4-3-2 MLP structure with \((v(t + 1), \omega(t + 1), v_d(t), \omega_d(t))\) as input and \((\lambda_1(t + 1), \lambda_2(t + 1))\) as output.

- **Vehicle Model** provides \(R(t + 1), \frac{\partial R(t + 1)}{\partial R(t)}, \frac{\partial R(t + 1)}{\partial u(t)}\)
Learning from scratch

Self Learning from scratch for values of $\sigma_\omega = 0.25$ and $\sigma_v = 0.25$. The figure shows that the adaptive critics adjust itself to the nominal values of weights by $t = 10s$. The learning rate is $1e^{-2}$. 
Track with changing slip

Robot has to follow a simultaneous square wave of both velocity and angular velocity. The 4-tuple (start time, end time, left slip, right slip):

(0, 20, 1, 1), (20, 40, 0.5, 0.5), (40, 60, 1, 0.6), (60, 80, 0.6, 1), (80, 100, 1, 1)
Choosing Action Space

• Usually action space is chosen as a set of all valid discretized actions
• Theoretical convergence to optimum policy is defined only if every state is visited infinitely often
• Objective: Learning a policy with a generally good performance, fast learning time and fast adaptation.
• Solution: Using domain specific knowledge in designing action space with restrictive set of actions.
Case I: Keepaway Tactic

Keepaway is a subtask of RoboCup soccer, in which one team, the keepers, tries to maintain possession of the ball within a limited region, while the opposing team, the takers, attempts to gain possession.
Action Space

\[
\text{Action Space} = \begin{cases} 
\text{Hold Ball() : the greedy option} \\
\text{Pass to 1() : pass to nearest keeper} \\
\text{Pass to 2() : pass to 2nd nearest keeper}
\end{cases}
\]

• A perfectly weak opponent cannot tackle ideally. Hence A is chosen as HoldBall()
• To construct A’, let there be a strong opponent who charges at the highest speed at the keeper having the ball.
• Hence A’ is PasstoK(). This action creates a state jump as the ball moves from player 1 to player k.
Defense tactics

Case II: The Aggressive Defense (AGD)

Case III: Thwarting Flanking Attacker (TFA)
Action Space

\[ \text{Action Space} = \begin{cases} 
\text{Intercept ball} & A \\
\text{Dash 5 m left of opponent} & A' \\
\text{Dash 5 m right of opponent} & A' \\
\text{Dash 5 m in front of opponent} & A'
\end{cases} \]

Action Space for AGD

\[ \text{ActionSpace} = \begin{cases} 
\text{Intercept Ball} & A \\
\text{Dash to midpoint between attacker 1 and 2} & A' \\
\text{Dash to midpoint of attacker 2 and target} & A'
\end{cases} \]

Action Space for TFA
FIRA 2013, Aug 24-29, Malaysia

• Mirosot
  – Round 1: Pools of 4 teams each. Opponents in our Pool: Ganebots (Indonesia), Electrosot PPD (Malaysia), PSP Ultra (Malaysia).
  – Match 1: 21-1 Lost against Electrosot PPD
  – Match 2: 12-2 Lost against PSP Ultra
  – Match 3: 0-11 Won against Ganebots

• Simurosot
  – Round 1: Pool of 4 teams. Opponents in our Pool: HUE-RSA (China), PSIS METAL WARRIORS (Malaysia), CYBERNATICS PMK (Malaysia)
  – Match 1: 0-18 Lost against HUE-RSA
  – Match 2: 0-25 Lost against PSIS METAL WARRIOR
  – Match 3: 0-15 Lost against CYBERNATICS PMK
FIRA 2014, Nov 5-10, Beizing

- **Mirosot**
  - Match 1: 27-1 Lost against Malaysia
  - Match 2: 13-0 Lost against China

- **Simurosot**
  Teams from Egypt, China, Taiwan & Korea
  - Match 1: 31-0 LOST
  - Match 2: 25-0 LOST
  - Match 3: 13-0 LOST
  - Match 4: 1-1 DRAW
  - Match 5: 8-2 WON
FIRA 2015, Aug 4-9, Daejeon, Korea

• Mirosot
  – Match 1: 15-0 Lost against UKM, Malaysia
  – Match 2: 7-3 Won against KAIST, S Korea
  – Match 3: 10-1 Lost against Malaysia Polytechnic, Malaysia
RESULT: 3rd Position (BRONZE)

• Simurosot
  Teams from Egypt, China, Malaysia
  – Match 1: 9-2 WON vs Egypt
  – Match 2: 13-0 LOST vs Whuan Univ., China
  – Match 3: 3-1 LOST vs Malaysia Polytechnic, Malaysia
  – Match 4: 3-0 LOST vs UKM, Malaysia
RESULT: 4th position
Faculty Mentors
Prof. Jayanta Mukhopadhyay (Dept of Computer Science)
Prof. Alok Kanti Deb (Dept of Electrical Engg.)
Prof. Dilip Kumar Pratihar (Dept of Mechanical Engg.)
Prof. Sudeshna Sarkar (Dept of Computer Science)

Results
FIRA 2010, Bangalore- Lost ALL 3 matches
FIRA 2013, Malaysia- Won 1 of 3 matches
FIRA 2014, Beizing - Lost ALL 2 matches
FIRA 2015, S Korea - Bronze medal
Comparison with other Teams

• **Structure**: Opponent teams did not employ a full metal body design. A *skeletal structure* was observed on almost all the robots.

• **Component positions**: Motors were placed in a single line. This helped place the battery in the same plane and compensate for the *weight distribution* maintaining a geometrically centric *center of gravity*.

• **Wheels**: Wheel casings mostly made of aluminum/steel. Gears were made of more wear resistant materials such as *brass*. The *traction material* provided as a outer covering of the wheel was made of *natural rubber*.

• **Auxiliary points of contact**: The front and back sides of the robots used ball bearings, fitted on a horizontal axle.
Past Students

[Supervisors: Prof. A. K. Deb (EE), Prof. J. Mukhopadhyay (CSE)]

[Supervisors: Prof. A. K. Deb (EE), Prof. J. Mukhopadhyay (CSE)]

Other Graduated Students


Present Students

Thank You