Team-NUST Description for RoboCup-SPL 2015 in Hefei, China.

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Abstract. *The paper discusses the current work done, software development and future work of Team-NUST for RoboCup. A brief overview of software architecture is discussed followed by detailed description of independent modules including vision, kinematics, localisation, communication and software architecture.*

Index Terms— *robocup*

1. Introduction

Robocup is an international platform to further research in robotics and artificial intelligence. The Robocup Standard Platform League (SPL) is a robotic soccer competition with teams of fully autonomous humanoid NAO robots competing against each other without any human intervention during gameplay.

Team-NUST was established formally in 2013 with the aim of carrying out research in the rapidly progressing field of humanoid robotics, artificial intelligence, machine vision, motion planning, kinematics and navigation; with the motivation to participate in RoboCup Standard Platform League. Work by the already established teams in Robocup SPL including, but not limited to, B-Humans, RunSwift, Kouretes, Nao-Devils, UPennalizers and Dutch Nao inspired TeamNUST to work for this exciting platform.

The focus of TeamNUST is to span all the relevant areas prerequisite of an autonomous soccer gameplay by a participating team. We are working on robust and predictable kicking motion, multi-agent cooperative behaviour, motion planning, situational awareness based on efficient perception and robust probabilistic multi-agent localisation.

The paper is divided as follows: Details of team members is discussed in section 2. The software architecture is discussed in section 3, the kick and kinematics is discussed in section 4. In section 5 algorithms of vision are explained. Robot localization is discussed in section 6 followed by Motion Planning (section 7), Artificial Intelligence (section 8) and conclusion.

2. Team

The team is working in RISE Research Center[1], part of SMME-NUST, with publications in the field of cognitive robotics, machine intelligence focused on design, control and motion planning for robotics systems including mobile robots, humanoid robots, multi legged robots, intelligent bionics and robotic manipulators

Team-NUST was established as a platform to open and explore research areas of Robotics, focusing on humanoids, under the Legged Robotics Group of RISE Research Center.

Participation in Robocup will help TeamNUST in technical knowledge advancement, as we learn from other teams approaching similar challenges as us. It will provide an opportunity to better contrast our research and ideas with fellow researchers across the globe. RISE Research Center is one of the very few robotics oriented research institutes in Pakistan. Qualification and participation will earn recognition for related research in our community, generating interest in robotics from other academic institutes of all level, thus increasing awareness of robotics in general.

Team-NUST was the first team from South Asia to compete for qualification in RoboCup SPL.

2.1 People

Team-NUST comprises students of NUST under supervision of Dr. Yasar Ayaz, Director RISE Research Center[1] and Head of Department Artificial Intelligence and Robotics in SMME-NUST. The students are from departments of Electrical Engineering, Computer Engineering and Mechanical Engineering. The team consists of:

- Muhammad Talha Imran – Team Leader (B.E Electrical Engineering)
- Maham Tanveer (B.E Electrical Engineering)
- Abdul Rehman (B.E Electrical Engineering)
- Shams ul Azeem (B.E Electrical Engineering)
- Abdul Haseeb Ayub (B.E Computer Engineering)
- Idrees Hussain (B.E Mechanical Engineering)
- Umair Hasan (B.E Mechanical Engineering)

The team's supervisor, Dr.Yasar Ayaz (PhD Tohoku University, Japan), is a seasoned researcher in the field of humanoid robotics. His papers on Humanoid Robotics span footstep planning, navigation and control; and have been cited by leading universities in more than 12 countries including USA, Japan, France, Germany, South Korea etc. He has also been included in Top 100 Educators of the world 2013 by IBC of Cambridge and has been featured in Marquis Who's Who in the World 2013 as a notable academician and researcher in the field of robotics. A list of selected relevant publications of Dr. Yasar Ayaz have been listed in Appendix-A.

2.2 Robots

TeamNUST has the following robots currently available for the competition

- Two (2) NAO v4
- One (1) NAO v5

Four (4) NAO v5 have been ordered were in shipment during the writing of this document.

Team NUST is willing to participate in all the 3 SPL competitions. Preference is team competition, drop-in player competition and other technical challenges respectively.

3. Software Architecture

An extensive and detailed architecture has been developed. It takes the information and interaction from the environment and translates it to motion in an efficient and organized manner. The design supports integration of debugging tools from the ground up.

3.1 Layered Design

The design is divided into layers, with selective synchronised information sharing between layers. The layers are as follows: perception layer which deals with vision, planning layer that deals with strategies, state machine that will control tasks and sequences of tasks, and actuation layer that sends commands of required actions.

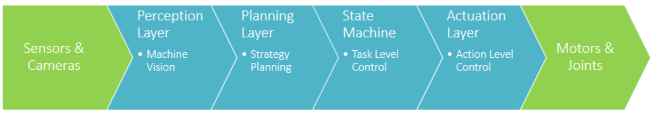

Fig. 1 Layers sequence

3.2 Components of a Module

A basic module is made up of local variables, a thread routine and an output connector. Control memory has ability to over write variables in module for debugging via control panel.

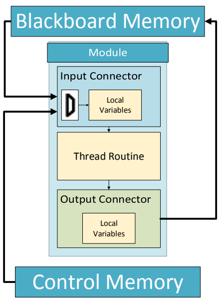

Fig. 2 Components of a basic module

3.3 State Machine Layer

Multiple levels deep state machine holding the relationship table of states controls task level activities of the system. It has an asynchronous connection to actuation layer.

3.4 Actuation Layer

Actuation layer schedules and executes movement commands, ensuring only valid sequence of movements are performed.

An action priority queue is maintained, containing one of two types of actions, iterative and one time. Actuation layer is responsible for stitching actions and producing a smooth output.

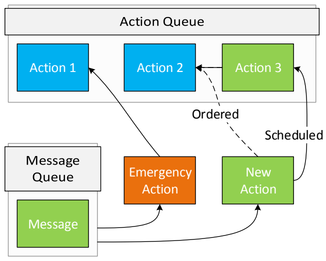

Fig. 4 Actuation layer structure

3.6 Planning Layer

It is responsible for making high level strategic decisions of game play. Intelligence at both individual level and team level are implemented in this layer. Both implied and implicit communication (as allowed by Robocup SPL rules) is used. This layer is currently under process of refinement.

3.3 Feedback Loops

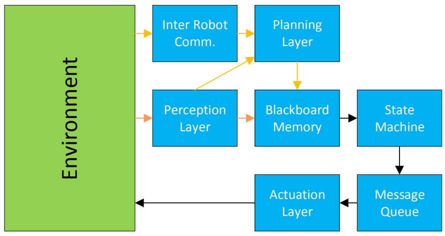

Fig.3 Structure of connection of layers

3.7 Graphical User Interface

A graphical user interface has been developed in Java. It is used for real time control and monitoring. It can change variables directly so targeted debugging can be done in real-time. The robot states can be changed remotely or the natural transition of states can be allowed.

A field view illustrates the real-time state of the field, with positions of robot, landmarks and balls shown; along with paths and footsteps planned by a robot. This significantly speeds up the development and debugging process.

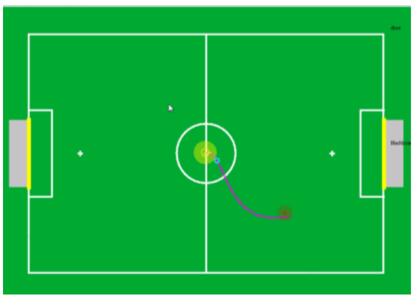

Fig. 4 GUI Field View

4. KICK

Kick developed is omni-directional with varying speeds. Its structure is key frame based. The Kick module is dependent on two main modules; trajectory generation and inverse kinematics.

4.1 OVERVIEW OF KICK

The kick module takes a total of three points of kick foot, which are calculated by trajectory generator. The joint values of the kicking leg are then calculated using inverse kinematics algorithm and interpolated to generate the kicking motion. The kick is flexible in nature. Adjusting the points gives various directions including front kick, angle kick, side kick and back kick.

A basic stability algorithm is working in the background to ensure a smooth kicking motion.

4.2 PHASES OF KICK

The kick motion is divided into three phases. The pre-kick phase, where the robot shifts its Centre of Mass (CoM) on the support leg and initializes the balancer to maintain balance on single foot. The kick phase, in which the kicking foot is interpolated between the three points of trajectory. The final phase is independent of the nature of kick, it adjusts the kicking foot in the pre kick pose and shifts CoM back to both feet.

4.3 TRAJECTORY GENERATOR

The trajectory generator takes as input the location of ball and location of ball's ideal final location. If the goal is not a strict ending point (like goal post) the speed is set to maximum otherwise it is adjusted to the required distance. The trajectory generator provides three points as output, the back point (pointA), the final point (pointB) and a point to adjust the curve of kick (pointC).

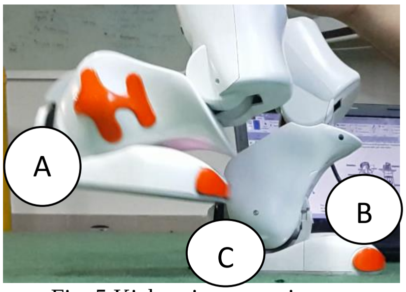

Fig. 5 Kick trajectory points

The three point path provides for variation in directions the ball can be propelled in.

Consideration is given to the allowed range of feet, and this is adjusted in the path planning stage before kick where the robot is aligned in a way that it can perform the kick.

4.4 INVERSE KINEMATICS

A DH parameter based model of the legs of NAO is developed. The model is based on the legs of NAO only, and is not effected by the upper body motion.

The module calculates leg joint values to achieve the required location of foot. The ankle angles are adjusted so the foot remains parallel to the floor to ensures a straight impact to the ball and avoid collisions with the floor.

The hip roll is adjusted first to get the foot in proper orientation. Then the hip pitch is then adjusted iteratively, followed by a trigonometric solution to get knee pitch. The algorithm gives results with error less than 0.1% average. If a point is outside the allowed workspace, the algorithm clips it to nearest allowed point.

We are focusing on developing an online dynamic kick, which will provide a better response in the fast paced environment of soccer.

5. VISION

Areas of vision covered are robot detection, goal post detection, field area extraction and corners detection on the image. All the visions algorithm were focused on their robustness, resistance to lighting variations and accuracy of results.

5.1 LANDMARKS EXTRACTION

Color features were taken as starting point for detecting different field features like field bounding edges, field lines, corners and objects such as robots and goal post. First of all the robots and goal post (yellow) are detected based on color, shape features and clustering of possible positive results. Finding the field bounding edges from an input image is a very crucial part because it gives us the area to do most of the image processing. After the field extraction and color classification, the ball is detected, considering the roundness heuristic. Corners are detected and classified (L, T, X) by using their shape features. After detecting these corners areas of field such as penalty area, kick-off area can be found. Following are the results of the vision module:

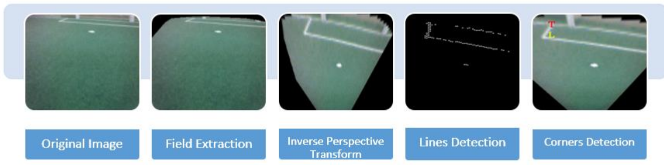

Fig. 6 Detection of field, lines and corners

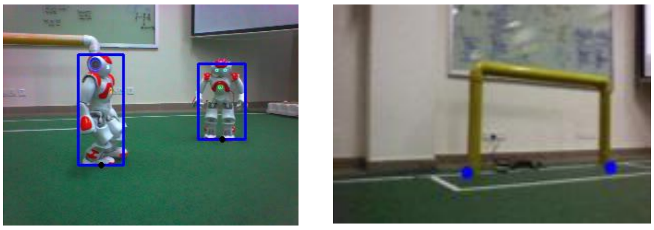
Fig. 7 Robot Detection (left); Yellow goal post base points (right)

5.2 INVERSE PERSPECTIVE TRANSFORM

A pinhole camera model for NAO is determined using calibration techniques. A camera model projection test bench is developed to tune parameters including the focal length.

The camera model is used along with forward kinematics to determine distance information of landmarks in scene. Each frame is converted to birds eye view using inverse perspective transformation which is again derived from camera model and forward kinematics. This bird's eye view makes it easier to detect field corners and to distinguish goal post from field lines.

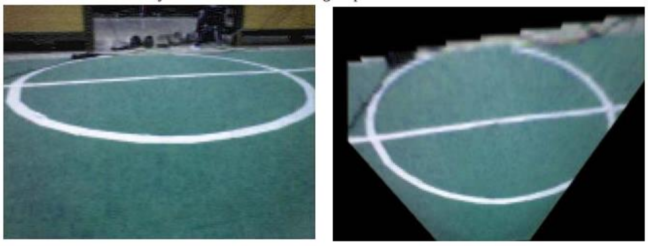

Fig. 8 Inverse perspective transform view of field

6. Localization

Mapping each feature point to landmark in the field is done using detailed heuristics. The determined landmarks are used by the sensor models for Kalman filter and Particle filter. An odometric model is used for both filters.
Particle filter is used to solve kidnap problem. Once a unimodal distribution is established Kalman filter is used to track the estimate with extra states to estimate slippage and odometric errors.

Localizing dynamic objects and adding them to world belief which is shared among all players at run time is our current focus. Later on this can also be used for improving localization.

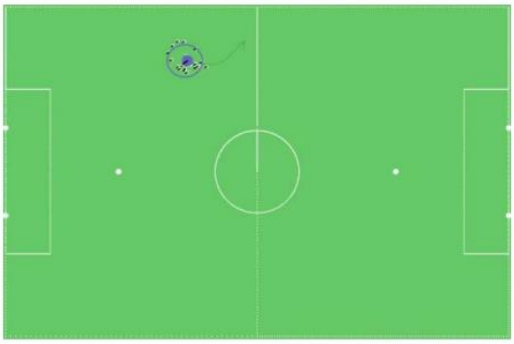

Fig. 9 Localization in field

7. Motion Planning

Robot motion in the field was planned using different methods. Trajectory generator plans an estimated path for longer distances. Motion of the robot while approaching the ball at close proximity has been experimented using potential fields as well as footstep planning.

7.1 Trajectory Generator

A Bezier curve is generated towards the ball, considering robot direction towards the target. A higher order curve will be used later for planning in populated field.

7.2 Footstep Planning

Close approach to ball required precise footstep planning in the pivot foot frame. Bezier curve is used to generate trajectory of the kicking foot, used to plan the footsteps.

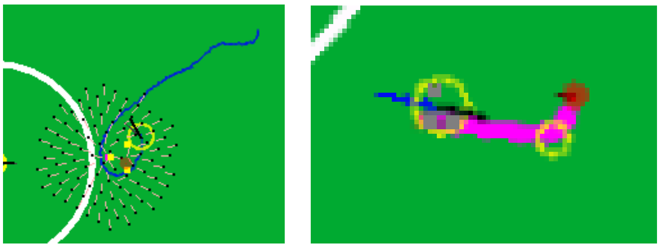

Fig. 10 Motion: Potential Field (left); Footstep Planning (right)

8. Artificial Intelligence

Intelligence exhibited by robot comprises its intelligent awareness of the environment and predictive planning of its actions to support the team as a whole.

8.1 Landmark Processing

A probabilistic processing algorithm applied on landmarks detected provides a reliable stream of input to the system, filtering out anomalous detections and providing probabilistic locations of landmarks now lost from vision.

8.2 Cooperative behaviour

Robots cooperate to decide between attacking or defensive behavior depending on location of robots and the ball. Individually planned actions are shared among the team to bring about cooperation. Heuristics have been developed for role negotiation to enable multi-agent cooperation.

9. Conclusion

Team-NUST is a new team in RoboCup-SPL, and the only SPL-team from Pakistan. The project is an immense inspiration and we are hoping to learn a lot from this experience which will serve as a very strong foundation for our future research work.

With exception of a few instances, the work by TeamNUST is original and will provide a fresh perspective to the currently faced challenges in RoboCup SPL. Participation of Team-NUST will also generate awareness in the region regarding RoboCup.

Team-NUST is eagerly looking forward to participating in RoboCup-2015.

Sponsorship

We are thankful to National University of Sciences and Technology (NUST), Pakistan for sponsoring our Robocup SPL research and providing with funds for four new NAO robots this year.

TeamNUST qualified for Robocup SPL last year and was fully prepared to attend. Our external sponsor, however, refused funding due to high travelling cost to Brazil. This year, sponsors have expressed hope for funding, given the competition is in the neighbour country, subject to qualification.

ACKNOWLEDGMENT

We would like to thank National University of Sciences and Technology (NUST), Pakistan for sponsoring our RoboCup SPL research.

Forward kinematics module (by Kouretes) is used for IPT and image pixel to Robot Frame coordinates conversion. We thank them for their code release.

NaoQi Framework API provided by Aldebaran Robotics for NAO was used for interfacing our software with the robot.

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APPENDIX A

Selected Papers of Dr. Yasar Ayaz

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2. **Yasar Ayaz**, Atsushi Konno, Khalid Munawar, Teppei Tsujita, Shunsuke Komizunai and Masaru Uchiyama, "A Human-Like Approach Towards Humanoid Robot Footstep Planning", International Journal of Advanced Robotic Systems (IJARS), Vol. 8, No. 4, pp. 98-109, 2011.

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7. **Yasar Ayaz**, "Footstep Planning Among Obstacles for Humanoid Robots", Doctoral Thesis (Robotics and Machine Intelligence), Graduate School of Engineering, Tohoku University, Japan.

8. Teppei Tsujita, Atsushi Konno, Shunsuke Komizunai, Yuki Nomura, Takuya Owa, Tomoya Myojin, **Yasar Ayaz** and Masaru Uchiyama, "Analysis of Nailing Task Motion for a Humanoid Robot," Proceedings of IEEE/RSJ

International Conference on Intelligent Robots and Systems (IROS), pp. 1570-1575, France, September 2008.

9. Teppei Tsujita, Atsushi Konno, Shunsuke Komizunai, Yuki Nomura, Takuya Owa, Tomoya Myojin, **Yasar Ayaz** and Masaru Uchiyama, "Humanoid Robot Motion Generation for Nailing Task," Proceedings of IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), pp. 1024-1029, China, July 2008.

10. **Yasar Ayaz**, Atsushi Konno, Teppei Tsujita, Masaru Uchiyama and Khalid Munawar, "Obstacle Stepping Over Strategy for Humanoid Robots," Proceedings of SICE System Integration Division Annual International Conference (SI), pp. 533-534, Hiroshima, December 2007.

11. **Yasar Ayaz**, Khalid Munawar, Muhammad Bilal Malik, Atsushi Konno and Masaru Uchiyama, "A Human-like Approach towards Humanoid Robot Footstep Planning," Proceedings of JSME International Conference on Robotics and Mechatronics (RoboMec), 1A1-B02, Akita, May 2007.

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