MRL-SPL Team Description 2013
Standard Platform League

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Abstract. This article presents a brief explanation of research interests and team description of MRL SPL team intending to participate in RoboCup 2013 Standard Platform League. This team description includes various sub sections such as software structure, perception, global modeling and localization, behavior control and dynamic head motion, and locomotion control. Related published articles, future research topics, and research experiences are also provided here in this paper.

1. Introduction

MRL SPL is one of the research teams of the Mechatronics Research Laboratory (MRL) concentrating on biped robots. MRL (working under supervision of Qazvin Azad University) is an active participant in RoboCup's different leagues since 2002 and its main research topics are artificial intelligence and robotics. MRL SPL team participated in RoboCup 2012 competitions with 6 NAO v 3.2 robots (with upgraded head of v 4.0) and one NAO v 4.0 robot. This team ranked 1st in the international IranOpen2012 SPL competitions and planned several major improvements according to the league's objectives which include some modifications on previous image processing algorithms [1] such as robot detection, line extraction, and simultaneous image capturing from both cameras. MRL SPL continued its previous approach this year to develop biped robot's kick engine, obstacle avoidance and optimized path planning, multi-agent co-operative behavior strategy, shared world model, calibration free image processing and its implementation in robots configuration, on-line and timely optimized camera calibration as well. These new research subjects and major improvements in various sections of the MRL SPL will be described in the following paragraphs. One of the main MRL SPL team's aims is to develop a reliable co-operative game play this year by improving the available multi-agent behavior on the self-developed code structure namely "MRL SPL Base". Several improvements have been made on behavior base to complete hybrid automata with synchronized constraint for co-operation tasks. Active strategy based on game state is currently under development which yields to the increased rate of decision making. Moreover, further investigations have been made on optimized path planning and kick engine to enhance the precision of reaching and kicking the ball duties. Major modifications on debugging panel have been performed this year to handle path planning tasks and world modeling as well. This TDP is divided into 9 sections. Sections 1 to 3 provide software structures and team's various subgroups. Section 4 deals with the robot detection, perception procedures, modifications on camera calibration and simultaneous image capturing. Section 5 portrays improvements on particle filter-based localization, cooperative localization, and world modeling. Section 6 describes MRL SPL path planning, behavior control, multi-agent co-operation mechanisms, and behavior software architecture. Motion control and kick engine development are illustrated in section 7. MRL SPL published works and research contributions are also presented in section 8. Lastly, future works and planned activities are mentioned in section 9 which represents future research subjects to improve the current state till the international RoboCup competitions.

2. Team Structure

Main groups of the team are Perception and World Modeling, Behavior Control, and Motion Control. Related publications, research subjects, and team information are available on the team home page: www.mrl-spl.ir. Team members are: **Undergraduate Students**: Majid Lashgarian, Mohammad Shafiei R. N., Aref Moqadam Mehr, Mohammad Ali Sharpasand, Novin Shahroudi, Koosha Zarei, and

Mohammad R. Ghazeli; **Graduate Researchers**: Mostafa Yaghobi, Mohammad Ali Zakeri, Mohammad Reza Shahmohammadi; **Post Graduate Researchers**: Sepehr Tabatabaei, Maani Ghaffari Jadidi, and Ehsan Hashemi; **Team Leader**: Sepehr Tabatabaei**.**

3. Software Structure

Blackboard model of problem solving is being used in our self-developed code structure after comprehensive study of B-human's software architecture [2] which includes concurrent execution of three main processes namely "Motion", "Cognition", and "Communication". Cognition contains three main modules "Image Processing", "Modeling", and "Behavior Control"; a lateral module is also employed to communicate with Naoqi SDK which resembles B-human's Naoqi interface design. This lateral part is initiated to connect to DCM and transact data with that module. MRL SPL's self developed "Logging System" has been added as a module into the *SimRobot* to satisfy requirements of the behavior control and motion groups. The *SimRobot* [2] to which the above mentioned software framework could be connected is also employed as the simulator of MRL SPL team since last year. Previously prepared tools are planned to be merged into the *SimRobot* for more integration. Bhuman's and NorthernBites' valuable code release and descriptions are hereby gratefully acknowledged. In addition, team communication process is revised this year for better performance; unpredictable situations have been also taken into account in which communication may be lost during a game play since our team experienced this bad condition in RoboCup 2012 events. Further features for the current architecture are ongoing such as developing an advanced thread for a safe message queue on different levels of inner communication, constructing comprehensive open-source logging system, and adding some access policies for blackboard data.

4. Perception

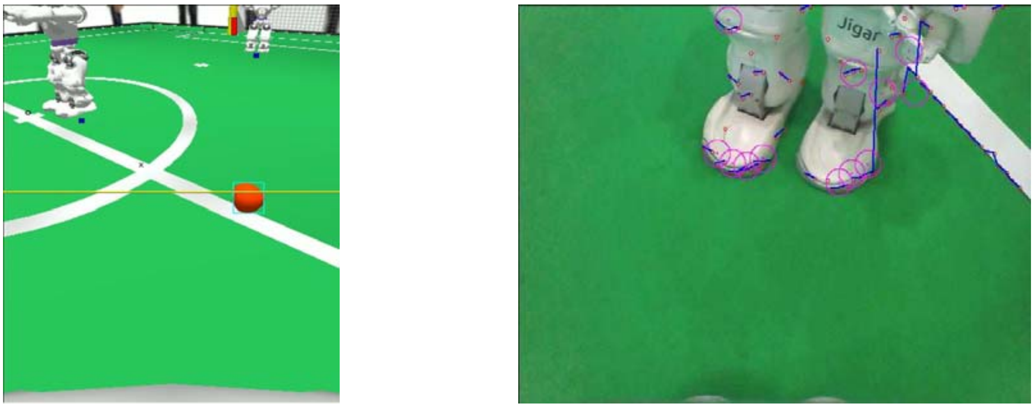
This section deals with MRL SPL perception group capabilities and improvements on the previous approaches. Since last year, some major modifications have been made to MRL SPL image processing scheme due to the increased size of images in NAO v4.0, and CPU frequency such as simultaneous image capturing from cameras, and modifications on the line extraction method. The new routine uses line direction feature while forming white regions [3] and would be run with a suitable time criteria consequently. Laying out procedure based on independence from color calibration would save lots of time to prepare robots for a game and therefore, became a main priority in the perception and vision group. On the other hand, team's previously optimized RANSAC line extraction [1] consumes a great amount of processing power due to complexity and large number of iterations. As a result, a novel method has been implemented based on scanning neighborhood together with their directions to cope with limitations of processing loads.

4.1 Simultaneous Image Acquisition

Simultaneous video streaming from both cameras together with improvements in NAO's processor provide great opportunity to increase perceived information from surroundings. Extracting objects from each image separately will cause lots of special cases for dimension and continuity of objects in the overlap position. Advantage of considering both images as a single one will remove the need of verifying special cases accordingly and results in robot's increased vertical field of view implicitly. Employing this capability as graphically illustrated in figure (1-a) leads to less motion blur and rolling shutter problem of CMOS camera sensors [3], and omitting of unnecessary head motions [1,4] which clearly simplifies behavior control decisions.

4.2 Camera and Torso Calibration

This task is performed with precise kinematic chain extraction and coordinate systems transformations [5] as employed in our last year's game plays [1]. As a result, a semi-automatic technique is employed which converts the problem to a nonlinear least-square optimization by exploiting Levenberg-Marquardt algorithms on two indispensible characteristics of mounted camera (disorientation and misalignment of the torso with the vertical axis). Target parameters in this optimization are torso orientation and camera pose together with robot's pose to compensate misalignment of the robot on the field. In practice, to compensate time delay in reading pitch angles' values (to compute camera pose from the base frame) a Kalman Filter is employed as an estimator in which the difference between current and previous command angle is defined as the estimator input and sensor data for joints' angles provide the observation. Even though the method is performed off-line and it is required to recalibrate the parameters before each performance, the convergence of the algorithms is quite fast and whole procedure can be done in a few minutes. There is a similar implementation in [2] in which Gauss-Newton optimization algorithm is used; other practical techniques perform online calibration as described in [6].



(a) (b)

Fig 1. (a) ; Landmark and robot detection with simultaneous images captured by both cameras; (b) Robot detection

4.3 **Robot Detection**

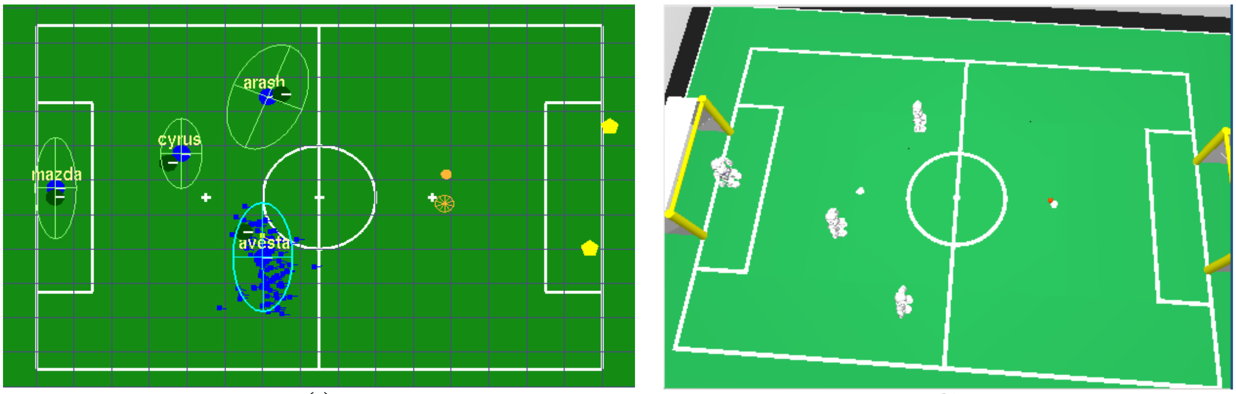
Detecting robots based on waistband color is already implemented and verified last year. Even though the routine performs well, it has already some weaknesses especially for close robots. Consequently, an alternative mechanism is implemented utilizing Nao's feet curves as provided in [7] and it is merely required to detect the feet especially front side of robot's foot in order to locate the robot. Whereas, the developed procedure by the MRL SPL perception group extracts the feet from every side just by locating curves below white region. This is achievable by calculating the standard deviation of foot edge points as exhibited in figure (1-b) in which circles are around the lines which make a significant standard deviation.

4.4 **Color Calibration**

Independence from the color calibration scenario before each game plays a key role in minimization of the required time for robots preparation and simplifies running a play. As a result, an automatic method is being implemented since earlier MRL SPL team's image processing mechanism needed color calibration. Some groups [8] consider the most part of images as the field color, thereafter it would be possible to exclude field objects within the field color. A more generic solution could be considering both objects' color values, and shapes and locations in order to decide about their types. This task could be done by utilizing Bayes Classifier to have more reliable object detection [9].

5. **Localization and Modeling**

This section is presented to lay out the practical aspects of localization and global modeling with presence of symmetrical fields in the MRL SPL team. A particle filter based approach [10], Monte Carlo Localization, MCL is selected for self localizing of agents like last year which offering many advantages over Kalman filtering based methods. The localization procedure of the team set out with the aim of augmented MCL technique and subsequent modifications particularly on the optimized re-sampling for the kidnapping circumstances as described in detail in [11] which is one of team's publications and substantiates this scheme. Several examinations were accomplished on MRL SPL real and simulated agents for various scenarios on the field to verify the selected augmented MCL practice as exhibited in figure 2 which represents a world model produced by co-operation between agents. The localization visualizer is built up with OpenGL last year under Linux and modified now to evaluate effectiveness of the augmented MCL by ideal and real sensory data, visualize movement of robots, sensor monitoring, and externally mounted positioning instruments. Moreover, enhancements to the general vision-based MCL algorithm on employing more robust negative information in presence of errors produced by imperceptible landmarks and utilizing line observations into the probability updates by the idea of identifying lines as atomic entities [12] are also studied and utilized in the team's localization group.

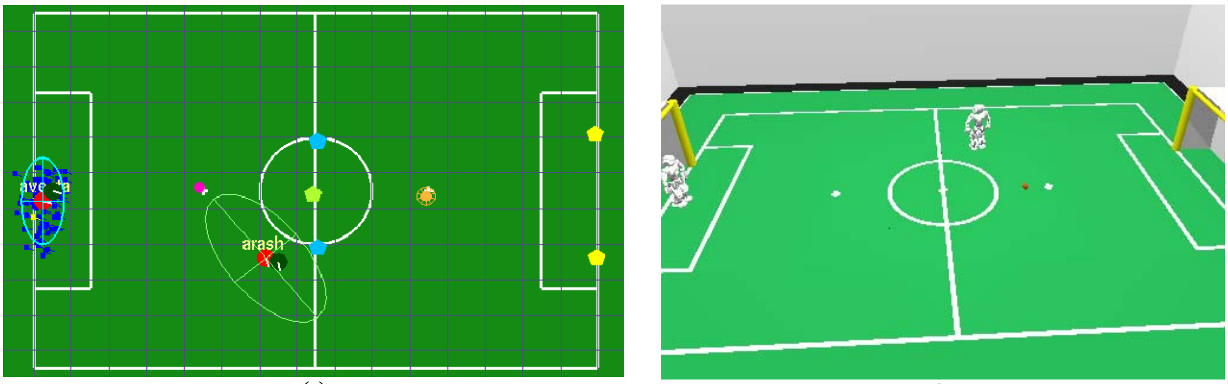


(a) (b)

Fig 2. (a) Percepted world model of Avesta agent (b) Agents' real situation in the *SimRobot*

5.1 **World modeling**

MRL SPL team has put effort to improve the world modeling division and focused on shared and central world model [14] since this capability is essential for game strategies, decision making, and reliable cooperation of agents. Each robot shares its status by communication with other agents and constructs its world model by gathering and combining the messages received from teammates as demonstrated in figure 2 in which unfilled orange circle illustrates the universal ball. In addition, sonar retrieved data are executed with a vision based sensor fusion process to detect an obstacle and its pose data are updated in the world model. MRL SPL "WorldModel" is also responsible to compute following criteria which are available and employed by other sections in the team's software structure: A) **Role probability** to roughly estimate the possibility of each robot's assigned roles according to robot position, time cost to reach the ball, etc. B) **Universal ball** is obtained by considering the availability of the ball visible by other robots. C) **Robot pose correction flag** which detects a condition by considering the position of the ball relative to goalie and another agent to correct and symmetries the robot pose.



(a) (b)

Fig 3. (a) Goalie's world model with a wrong symmetrized player position. b) Agents' real location in the *SimRobot*

5.2 **Coping with Symmetrical Environment**

Existence of two goal posts with identical colors was one of chief challenges in the SPL league in RoboCup 2012 events. It was also our team's major task in the localization and modeling group and the bellow described practice was carried out during the last events and revealed dependable results as well. The proposed key action to overcome this problem, which is somehow similar to the B-Human's [13], was tracking the robot pose and sharing the ball pose between the goalie and other robots in PLAYING mode to validate the pose of each robot. More specifically, if goalie and teammate observe the ball at different sides of field, the robot pose would be incorrect and it's in symmetrical position; otherwise, the robot pose is valid. This technique is also trustworthy when goalie and its teammate observe the ball simultaneously. The goalie was selected as a reference since its orientation is supposed to be marginally variable, self corrected and known most of the times. A central zone for the field is defined and clipped to have robust and reliable localization. As graphically represented in figure 3 the player, Arash, is not able to see the ball (ball is located behind him), but the outcome is the correct global position of the ball. In addition, if the player becomes able to look at the ball (purple circle illustrates imaginary and false ball position in player's world model), the ball in his world model is in different side of the filed in comparison to the goalie, thus it is likely to detect symmetrization of the player based on the fact that goal keeper and player must percept the ball in same side. Besides, some rules are considered for INITIAL, READY, SET, and PENALIZED modes. After PENALIZED status, the robot acts like INITIAL mode; for INITIAL and after PENALIZED, the robot stays at its position till it can distinguish self goal posts from opponent ones. There is also a new routine which is under development in the modeling group in which each robot can match its teammates' positions with detected teammates and assign positive or negative points to other mates. Continuous stream of robots' pose data during a game play leads to correctness of self localization data in symmetrical fields.

6. Behavior Control

This section is contributed to MRL SPL team's works on the structure of behavior control and two recently modified approaches namely dynamic head motion and path planning. This year's main research topics and tasks in the behavior control group are cooperation among agents, fast and robust decision making, and running different strategies during a performance. As a result, a hybrid automata [15] has been developed and tested in this group and related constraints for synchronization between active agent skills during the game [16] are included as well.

To exploit all available players and reducing decision making time length, a strategic planning layer has been included which changes the strategy of the game dynamically. In order to have a consistent and cooperative behavior, a function would be utilized for selecting the roles which contains a matrix with rows representing active robots during a game and columns symbolizing roles. The indices of the matrix demonstrate probabilities of selecting roles for each robot and a role would be assigned to a robot that has the maximum probability. Robots' communication with strategic planning layer mechanism is employed in the behavior control section as presented in the MRL SPL 2013 qualification videos. The fully distributed coordination is used for multi agent localization purposes particularly for the symmetrical fields and is augmented for strategy planning such as multi robot co-ordination. In addition, logging system is now added to the simulator to simplify behavior debugging processes.

6.1 Path Planning

Concepts of previously selected path planning routines, "Potential Fields" and "Rapid-Exploring Random Trees", RRT [17], related modifications on these practices, and new features for obstacle avoidance were introduced in [1]. MRL SPL team conducted research on the above mentioned path planning methods last year as well as planning based on the Bezier curve formulation as provided in [18] and RRT was chosen [19] to be developed after careful investigation of practical results got from experimental and simulation data, processing loads during maneuvers of approaching to a point and obstacle avoidance as depicted in figure 4, and the local minima drawback of the Potential Fields scheme.

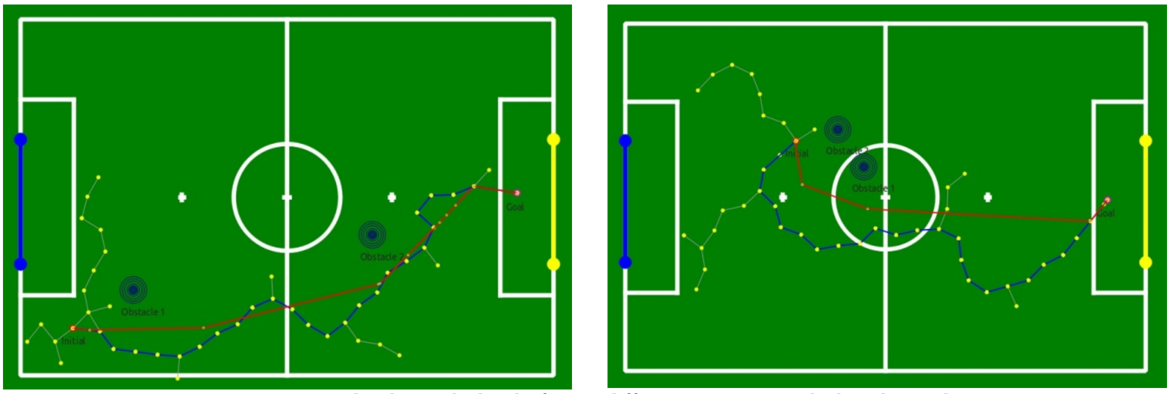
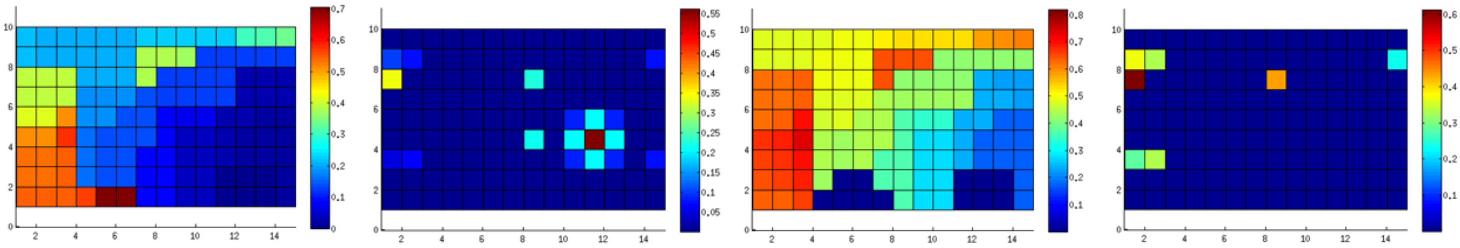


Fig 4. RRT generated and smoothed paths for two different maneuvers with obstacle avoidance

Blue and red bold lines in figure 4 represent experimental data of followed path by the robot with presence of localization correction and smoothed RRT path correspondingly. On the other hand, gray path with yellow nodes shows RRT initially produced tree. RRT outcomes are also provided in figure (A1-a) for another circumstance of obstacle positions. Fuzzy-PI planner is also studied to reduce the pure dependency to global data and localization uncertainties. Furthermore, new planning skills such as multi agent path planning in "Ready" state which enables robots to reach desired locations without any collision during positioning and strategic planning during a game play are employed and examined in various conditions to play smoothly. Path planning with respect to concurrent minimization of localization uncertainty and maximization of behavior action gain is under study and is a challenge in turn due to low-level computational constraints.

6.2 **Dynamic Head Motion**

Dynamic head motion is studied [5,20], practically developed, and executed after RoboCup 2012 competitions in MRL SPL behavior control group to detect landmarks and tracking the ball in a most efficient and timely optimized manner. The following paragraphs focus on the proposed head motion with localization data feedback. To simplify the problem, a set of objects has been identified to be observed including landmarks and the ball and a 15*10 grid pattern over the field. The aim is to calculate a coefficient for each cell with respect to the probability of existence of an object inside the cell and its corresponding weight. Weights are computed from the time that an object has not been seen, constant bonus of the object, and self-localization feedbacks. Robot searches for a cell with the highest value to find the best focal point. Expected values are used as a combination of the probabilities with respect to weights of objects as graphically represented in figures (5-a) and (5-b).



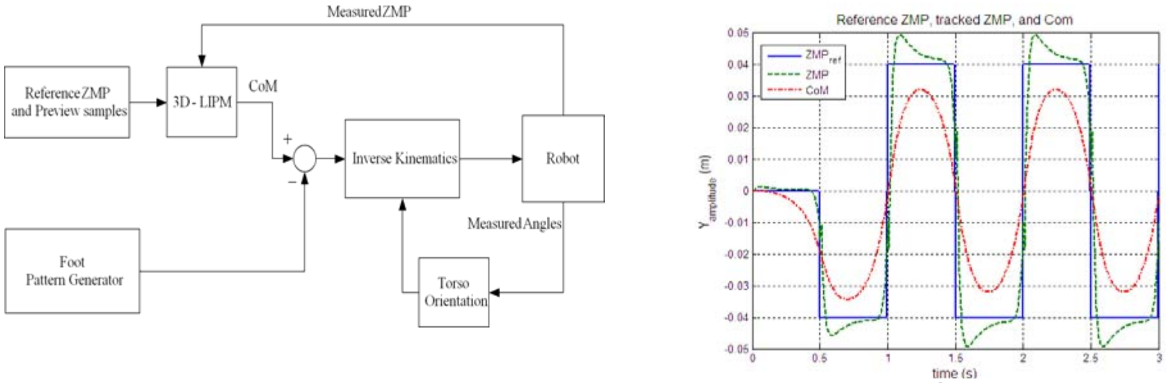
(a) (b) (c) (d)

Fig 5. Expected values when (a) the ball is lost (b) the ball is seen; Final coefficients when (c) the ball is lost (d) the ball is seen

Time cost has also been considered in this practice for looking at each grid and distance from the focal point which is usually ball position. This consideration has been conducted to increase the continuity and trustworthiness of head motions and optimize the motions to spend more time on looking at objects rather than moving the head. After omitting cells that are not observable for the robot, i.e. cells behind the agent and merging them with the "time cost" and "focus error" (distance from the focal point), the result will be a coefficient for each cell that is a proper criterion for choosing the best estimated point to look at as shown in figures (5-c) and (5-d). Further simplification on this procedure to one dimension (head yaw only) is possible through a fixed head pitch rather than moving the head in two directions by exploiting simultaneous image processing. With this improvement the robot may choose angles (select grids based on angles rather than Cartesian grids on the ground) at which it can see multiple objects instead of switching between grids. Additionally, global model data would help this especially with finding and tracking the ball. More appropriate techniques to address head motion requirements could be machine learning with Bayesian regression to learn a continuous map of the environment or utilizing a feed-forward control for the head yaw for preventing distraction of the robot in high speed turns.

7. Motion Study and Control

This section seeks to address research subjects and works done on motion control in the motion group. MRL SPL "Walk Engine" based on 3D Linear Inverted Pendulum Model [21,22] tested successfully on Nao with 12 cm/s walking speed, but it is decided to employ B-Human walk module for RoboCup competition to avoid excessive effort on this section and focus more on behavior section. Various experimental data of generated trajectories and controller responses will be published by MRL SPL code release and team report. Following paragraphs represent consecutive control and computational stages of the proposed walk engine. Figure 6 schematically illustrates the controller mechanism and results of CoM generated patterns. Reference Zero Moment Point pulse together with foot pattern generator provides input for walking. The core of the controller is a LIPM module which employs optimal preview control [23] of a discrete-time model of an inverted pendulum as a real-time pattern generator for robot’s center of mass. As graphically shown in figure (6-a), the difference between foot trajectory and robot's CoM leads to Cartesian space-based foot position. Afterwards, estimated foot position will be employed in the inverse kinematics equations presented in [24] for the Nao's first three joints angles (from ankle to hip) calculation.



(a) (b)

Fig 6. (a) MRL SPL walk engine and controller diagram; (b) ZMP and CoM position estimation

The feedback quantities include ZMP and torso's angles around x and y axis of the robot. In practice, the inertial unit of Nao provides noisy and undependable values for both accelerations and angles, thus sensor calibration and filtering on these values have been performed in the motion group as shown in figure (A1-b).

7.1 Dynamic Kick

Biped robots' ball kicking in an adaptable way is a crucial and important task in different groups of the RoboCup standard platform league. In order to achieve such an aim the swing foot should move along a path terminating the local position of the ball. The trajectory of such a motion must be generated online, since it has to be robust against any sudden changes in ball position. This change may be occurred in match field when the ball is hit by another robot or in the world model when vision has updated its output data. Besides, the robot shall maintain its stability throughout the kick. These two types of robustness enforce our motion group to design closed-loop kick with online generated trajectory. Firstly, an online trajectory based on Spline interpolation polynomials [25,26] is studied and generated to construct an open-loop kick, where prescribed trajectories are only restricted to satisfy kinematic constraints, i.e. tracking them doesn't ensure stability of robot. In order to reduce the computational cost with this method, the kicking motion is subdivided into five phases [27] known as Lift-off, Retreat, Strike, Return and Sit, among which two phases are executed online while trajectories of others are recorded offline. In each phase in addition to two predefined path end points, some intermediate control points are introduced to guarantee smoothness of trajectories. The swing foot is also confined to move along x-axis in Retreat and Return phases and along z-axis in Lift-off and Sit phases to simplify the problem.

8. Research Contributions and Publications

A brief description of MRL SPL team's published works and research contributions are provided in this part. MRL SPL team will release its code (**MRL SPL Code Release**) with comprehensive team report soon which contains this team's research approaches on perception, localization, and motion control of Nao biped robots. Related publications of this team since 2010 on forward and inverse kinematics, five degrees of freedom dynamic modeling, optimization of the robot's hip trajectory parameters by employing Genetic Algorithm and Particle Swarm Optimization (in which PSO exhibited more appropriate outcome), simulated model of an optimal biped trajectory for the Nao robot, and path planning based on the Bezier curve formulation to eliminate undesired errors was mentioned in the team description paper 2012 [1]. Besides, several practical investigations have been carried out on the self developed walk engine with the optimal preview control of an inverted pendulum discrete-time model as a real-time pattern generator to reach a stable walk with the speed of 12 cm/sec.

Three-dimensional dynamic modeling of Nao robots with the assumption of motion decomposition in Sagittal and Frontal Planes has been comprehensively studied and published in [28]. In addition, studies on self-localization with particle filter routine and several examinations in diverse situations brought about this team's publication on particle filter based localization in [11]. This research group has also an investigation on linear quadratic tracking controller merged with a Fuzzy one as high level controller to follow diverse paths in [29] which is helpful for the group's studies on Fuzzy path planning controller. There is also an under review papers shortly titled "Bezier-based biped robots path planning" which probes several path and velocity requirements and their incorporation in path generation.

9. Planned Activities and Future Works

The following paragraphs are contributed to this team's planned activities and future research subjects. MRL SPL behavior group's research is concentrated on A) development of an unfailing multi agent planning to use role base selection with a range of procedures such as ad-hoc role selection and matrix cost, B) enhancements of the available dynamic head motion to be adaptive with different world model data such as predicted universal ball and obstacle models, and C) improvements in the combined path planning practice which implements both global and relative positioning data in diverse maneuvers. Moreover, active strategy selection and planning during the game accompanied by rapid decision making with the assistance of shared world model is under examination and construction.

Perception group will also focus on calibration free image processing, online camera calibration, and tracking opponent robots (to have more agents' co-operative behavior) which are currently under progress and planned to be carried out before IranOpen 2013 international events. Previous Nao CPU's capabilities such as MMX instruction set are utilized in many teams code base, specially image processing section [30,31]. The new robot's CPU has new capabilities such as hyper-threading and SSSE3 and MRL SPL team plans to employ such capabilities in order to reduce modules cycle time. The available world model also requires more improvements to predict passive objects such as the ball and achieve trustworthy shared data as depicted in [14].

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Appendix I

Additional Figures:

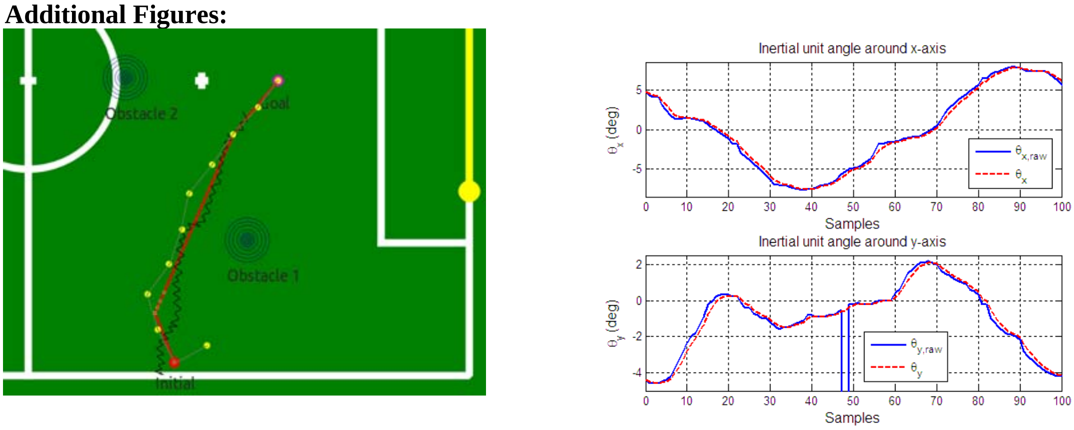

Fig A1. (a) Robot's experimental data on the RRT smoothed path; (b) filtered data of the inertial units for the walk engine