MRL Team Description 2009

Maziar Ahmad Sharbafi, Alireza Haghshenas, Meysam Gorji, Ehsan Hashemi, Ali Azidehak

Islamic Azad University of Qazvin, Electrical Engineering and Computer Science
Department, Mechatronics Research Lab, Qazvin, Iran
m.sharbafi@ece.ut.ac.ir

Abstract. MRL Small Size Soccer Team is planning to participate in 2009 world games. The team has attended 2008 games and several modifications are made to improve its efficiency in the competitive environment. Our team’s activities including mechanics, electronics, software, vision and artificial intelligence are described in this paper. Innovative approaches in designing and manufacturing 4-wheeled robots especially locomotion plan and a newly developed two kicker mechanisms are described in mechanics. Basic amendments in electronics, mechanics and software architecture are devised to reinforce the robots abilities. The sliding mode controller is utilized for motion control. Pattern recognition methods in Bayer space was our attitude for image processing. An overall description of the team structure is presented here.

1 Introduction

The MRL-SSL team has re-collected with new members in 2007 after a participation in 2005 games and a two year of inactivity. It successfully attended 2008 games with team built from scratch, and is planning to attend 2009 games without major changes. Instead, we’ve planned a suit of improvements over the last year’s designs and implementations. Like other robotic teams, its activity areas can be mostly divided into Software, Mechanical, Electrical and Control activities. The members are mostly experienced in other robotic leagues or other teams in the same league. The robotic hardware, as well as vision subsystem has been re-implemented from ground up; but principal structures are retained from the 2008 team. Major changes are reported here, beside an overall description of the current team structure.

Considering the capabilities of our robots in the first year of participation and qualifying to go to the second stage of the competitions, the first step of our three-year program was admissible. MRL ranked 1st in Kharazmi robotic competitions after participating in RoboCup 2008 which shows a remarkable progress comparing with our team's last year recognitions which was the 3rd grade in IranOpen 2008 competitions. Redesigning the robot structure, from the mechanical scheme to electrical boards and vision mechanism increases our abilities to participate more powerful in the future games.

This paper is organized as follows: after introducing the team members and their roles in the team, software architecture will be described in section 3. A new electrical
design based on FPGA, making the structure of robots’ onboard brain, is explained in section 4 in addition to the wireless design. In section 5 description of the 4-wheeled configuration for the newly designed robot which elevates the capabilities of the robots’ smooth and reliable motion. This part contains many technical discussions about optimizing the structure and new ideas to generate some useful innovative behavior. A novel approach in motion control based on nonlinear control design and vision will be explained in section 6.

2 Team Members

Our team members and their contributions in team are as follows:
Maziar Ahmad Sharbafi: Team Leader and Control and AI advisor
Alireza Haghshenas : Software and Vision designer
Omid Bakhshandeh  : Software & AI team member
Danial Esmaeeli    : Vision team member
Maysam Gorji      : Mechanics Supervisor
Saeid Esmaeil Pourfard : Mechanics team member
Ehsan Hashemi     : Mechanics and Control team member
Ali Azidehak      : Electronics Supervisor
Mohammad Houshyari: Electronics team member
Amirreza Karimi   : Electronics team member
Vahid Shoeybi     : Electronics team member

3 Software

In this section our software structure with many improvements in different parts will be described. The software structure is a successor to the one used last year. Nevertheless, it has received slight architectural modifications, as well as a fundamental re-implementation. The platform of choice is Microsoft windows, and the development tool is the set of Microsoft Visual Studio Express editions. Its different parts having the main role in team promotion can be summarized as follows:
• Simulator and Interface
• Vision subsystem
• Prediction subsystem
• Game strategy
• Path planning

A brief description of each subsystem follows. Changes from the previous year are emphasized. More details about other sections are explained in our last year team description paper [1].
3.1 Simulator and Interface

To simplify testing robot qualities, finding wrong decisions and robot mistakes in matches, a simulator is required for each team. To get these goals a high level simulator is needed. In this simulator the robot characteristics such as position, direction, robot decision etc are displayed. Figure 1 shows the interface of our simulator.

Another simulator is required to test our codes before implementing on robots practically. This simulator should have a physics based engine and our choice was using Microsoft Robotics Studio. These two simulators are some part of interfaces and it includes all relation and communication between robots, vision results and decision making module and so on.

Fig. 1. User Interface of the simulator, showing the viewer and settings Box

3.2 Vision Subsystem

The visual input consists of three Bassler A311f cameras, covering overlapped areas of the field and configured to output Bayer data. One reason to choose Bayer format is to avoid the delay introduced while converting from native camera color space to other formats like RGB and YUV. The Bayer format contains only one of R, G or B component values for each of the pixels. During the conversion phases, other
component values are interpolated from neighboring pixels and a false implication of resolution will dominate the extraction of information from visual data. Avoiding such interpolations will enforce us to acknowledge the inherent imprecision in the algorithm development phases. As the system is still under improvement, a formal comparison of the described method relative to traditional ones is yet to be carried out, but current results at least meet some previous vision system qualities.

A simulator is designed to represent the ideal Bayer imaging process, in order to provide a ground truth for qualitative measurements of the vision system. Figure 2 display an image in our simulator in Bayer space.

A synchronizing signal is fed into the three cameras. The signal takes into account a concurrency with lighting changes imposed by the AC power supplies. It also eases and improves the precision of the information merging step. This concept will be described more in the next section.

![Bayer Sample Data](image1.png)

**Fig. 2.** Vision Simulator in Bayer space. The numbers on the top of the picture at the left show the position of the robots. The big circle shows the pixels more precisely in a zoomed view of two robots. Each pixel has only one of the Red, Green or Blue color components.

### 3.3 Prediction Subsystem

A formal prediction system was missing in the last year implementations. Therefore, simple extrapolations where used to predict object locations where required. This year, a Kalman filtering based approach is used, both to generate first derivatives including linear and rotational speeds and to predict object locations [2]. The KF is recursive, which brings the practical specifications that not all data is
needed to be set aside in storage and re-processed every time when for example a new measurement arrives.

The Kalman filter is fed with the information from last state estimations by the filter itself, the sensory information such as vision processing results, and PID controller parameters. The output is filtered and relatively reliable location information as well as linear and rotational speed estimates. Future location estimations are possible for any given time.

Several attempts have been performed during the last year for changing the nonlinear dynamic model of omni-directional models to linear models because of valuable advantages of these models including their reliable predictions and their simple computation and development. In linearization method, a linear behavior is simulated along several small intervals [3]. Therefore, nonlinear functions are divided into a specified nominal part and an indeterminate perturbation part. The mentioned simulation will result in values which are extrapolated to the general domain. Perturbation Kalman Filter, PKF, is implemented to carry out to approximate the state of nonlinear systems by linearizing its nonlinearities [4]. A nominal trajectory is defined then a first order Taylor series approximation is implemented to linearize the perturbations that occur around the nominal trajectory. Direction of the derivatives at a point on a surface will affect extrapolation.

We are trying to develop the Extended Kalman Filter, EKF, due to some disadvantages of using the same nominal trajectory all through the estimation process in PKF method which results into a large deviation of nominal state from the real state [5]. This would be attainable with estimating measurement functions at trajectories with the latest state estimates instead of estimation of the Taylor series expansions of the measurement functions at the nominal trajectories.

3.4 Game Strategy

Although in the last year competitions the strategy engine proved mainly useful, some factors limited its success, especially in providing adequate coordination abilities in multi-agent tasks, like pass-kick and cooperative defense. Also, for most of the implemented roles and skills, special circumstances were not considered explicitly and general implementations could not handle non-general situations well. On the other hand, the utilized design pattern facilitates the mentioned strategy for rapid role, skill development and updating.

Considering these factors, the strategy engine structure is principally retained; yet, implementation details changed to accommodate for better coordination and cooperation, such as the ability to assign and change roles for a group of robots as opposed to a single robot at each step.

Consequently, the Game strategy subsystem can be summarized as follows. The engine, that makes the actual decision and does the processing, is in the highest level. Plays are inspired from the CMDragons team in [6] but are generalized to be able to run simultaneously, and to include a subset of robots. In this generalized framework, team robots are partitioned between concurrent plays, which aim different goals. An example is defending with two robots and attacking with two other. Plays can specify the minimum number of robots they can work with, as well as to assign roles to extra
robots available to them. This way, plays can be defined as independent efforts happening in the team at any time. This definition and our implementation will account for inter-robot coordination, easier than the team-wide plays in [6], yet keeps another problem untouched, where a robot can perform some gestures that affect more than a single play. Creating a strategy engine that allows such multi-purpose gestures may be the subject of future developments.

Role repository which are the set of all roles, robots are able to perform is the next level. Each role is one robot’s contribution to the related play it belongs to, at any time. The roles use skills respectively, to perform lower-level tasks such as ball catching, dribbling, positioning, aiming, passing, kicking and blocking. Such low-level tasks use the control system either directly, or through some other modules, the most important of which, being Path Planner. The Play-Role-Skill hierarchy is inspired from some previous reports, notably [6].

3.5 Path Planner

Currently, we have two path planner systems implemented; one is based on graph based shortest paths algorithm and the other one is an implementation of ERRTs described in [5]. Both implementations are compatible and the currently used one could change without any need to alter other parts of the game engine. More suitable path planner will be selected in the future and combining these two ones to get a novel method is under investigation. A GPU based implementation of the path planner is under development, using NVIDIA CUDA.

4 Electrical Design

Our electronics and communications subsystem is built upon the last year’s experiences and has been upgraded in several ways, to eliminate observed drawbacks, and to improve overall efficiency. We can categorize our improvements as follows.

• Designing the main hardware core in an FPGA
• Using microprocessor for extra works
• Proposing an appropriate solution for charger related issues
• Redesigning the communication subsystem
• Construction of a board to synchronize the cameras
• Allocating some decision making algorithms to onboard processors

As an improvement to the last year configuration, we added an FPGA based section to the electronics subsystem and assigned the whole control and sensor reading loop to the mentioned FPGA. Figure 3 shows a picture of this board which is finalized after several tests. It was one of the most significant changes that we have made in electronic team.

A microprocessor based module is still retained for processing tasks related to communication tasks and higher level decisions. This change is also motivated by the usage of brushless motors, for which pure microprocessor control will be too computationally intensive and slow.
The kicker driver is improved over the one used last year, to accommodate for two separate solenoids: one for direct kicks and another for chip kicks. The aim includes improving charging curves, decreasing the resting time between successive kicks and resolving self damages frequently happened in the last year.

Another promotion was redesigning the communication subsystem. The newly developed system automatically searches for existing robots in the range and generates a list of robots, their identification tags, frequencies and delegates this mapping operation. This measure has been performed manually last year.

The layout is also changed, to simplify the robot packing/unpacking process, in case the robots need service during the matches.

The velocities of the robots are the primitive knowledge that we need to predict the robots’ positions. To compute it accurately cameras synchronization is the first step. Using an electrical board to synchronize three cameras was our selected method to gain two aims. The electricity voltage of power supply sinusoidal signal affects on the light of the field. If there exists a phase difference between camera shuttering and this sinusoidal signal, the images will have different lights that make working with them very difficult. Therefore to solve these problems together our synchronization circuits uses electricity voltage signal to generate a unique signal to synchronize the cameras.

Finally we moved some decision making processes from AI computers to onboard processors like kick when the ball is in front of you. We have added additional Infra red sensors to detect the ball location precisely too.

5 Mechanical Design and construction

Manufacturing, implementation of new optimized sketches and mechanical design improvement of different parts according to the motion control requirements are
considered in the new modified model. The major changes in the robot’s mechanical hardware from the last year model are described in the following paragraphs.

5.1 Wheels configuration

A four wheel configuration as the so called “butterfly configuration” is employed to achieve a smooth omni-directional motion and appropriate speed and acceleration regarding the specified strategy and motion planning together with enough space to install various components. This configuration is graphically illustrated in figure 4 in which front and rear wheel axis are positioned in 45 and 57 degrees relative to the vertical axis of robot. The chassis is a 2.5mm titanium alloy plate produced by wire-cut manufacturing method and provides a reliable base to install motor stands and driving system, kicking and spin back mechanisms, battery packs, and other mechanical and electrical hardware components.

Linear speed required is from 3 m/s to 3.5 m/s which could be attainable by implementation of the mentioned configuration. Additionally, performed tests show the linear speed about 3.2 m/s for the new model which properly satisfies the motion strategy requirements. The locomotion system powered by four brushless motors, EC 45 flat 45 mm, brushless, 50 Watt, provided by Maxon Motors Co. which meets design criteria including the power conditions and space limitations. Therefore, this model offers a much slimmer profile and leaves enough room in the robot to place two kicker solenoids. Required torque is to be provided by the brushless motors which is 0.53 N.m. This value is calculated regarding the robot’s weight, needed acceleration and some correction factors. A reduction transmission system is employed to achieve the required torque with two spur gears with transmission ratio of 4.4:1. This ratio satisfies the torque and rotational speed requirements.

Omni-wheels design and manufacturing process are completely changed. Assembled model of each wheel is depicted in figure 5. CNC and wire-cut manufacturing are executed to produce the wheels. In addition to this, some specific studies on wheels and the main gear materials have been performed in order to reduce the weight of wheels and Aluminum alloy.
The wheel arrangement consists of inner hubs, main transmission gear, ring, and aluminum alloy roller rings with Silicon Rubber O-rings stretched around roller rings. Silicon Rubber was selected for its high friction coefficient and acceptable durability. Silicon Rubbers are one of industrial rubbers with high tear strength at special performance. Tensile and tear strength, elongation and compression behaviors could be far superior rather than conventional rubbers. Previous O-rings were made of a low friction material on the carpet, which resulted in less traction and increasing slip, so yields to an acceleration decrease. Tear resistance at angular velocity and high static friction coefficient on the carpet are main factors affecting the O-rings material selection. A test platform is designed and produced as last year tests to reach a high static friction coefficient with measuring the driving voltage up to the wheel slip on the carpet for several materials proposed for O-rings including Viton, Polyurethane, NBR and silicon rubber. Suitable material with the above mentioned criteria will result in a quick movement with higher acceleration.

![Fig. 5. Omni-wheels and main drive gear exploded view](image)

5.2 Odometry system:

A separate shaft encoder, Usdigital-S4, is mounted on the motor stands which are different from the last year arrangement in which feedback of each wheel rotation was produced by encoders mounted inside DC motors. One of main advantages of this encoder is its miniature size which could be located inside the motor stand. It converts real-time shaft angle, speed, and direction into TTL-compatible quadrature outputs without index and provide 400 to 1440 pulses per revolution. The mentioned encoders are connected to the wheel gears and then to the motor with a couple of gears.

5.3 Kicking mechanisms:

Two electro-magnetic solenoids are executed for direct and chip kick as it is shown in figure 6. The optimized installation arrangement for direct and chip kick is one of the changes in comparison with the last year design. Kickers are mounted between four motor stands. Chip kick mechanism performs like direct kick by pushing the kick rod which actuates a swinger mechanism to rotate and then impose an inclined force to the ball. This force results in a ball movement with inclination of about 42 degrees in vertical plane. Kicking power and ball path improvement and also ball speed regulation could be achieved by using a suitable solenoid core. Various core materials were
investigated and experimentally tested as it was done last year. In addition several tests are under consideration to reach a more suitable selection of cores.

![Direct and chip kick mechanism](image)

**Fig. 6. Direct and chip kick mechanism**

### 5.4 Local ball positioning system:

A local ball positioning system in the ball capturing zone of robot is used to appropriately detect the location of ball. Advantage of this method is that the motions of robots approximately in 15 cm of the ball to catch it will be optimized in case of cooperate with other robots and passing. This device produces feedback to the main control and decision making unit to manage the rotation of robots in the passing and shooting situations.

Different arrangements including locomotion and driving system, direct and chip kick mechanisms, ball control and local ball positioning system, battery packs, electronic boards, and control unit are installed in different elevations.

### 6 Motion Control

The control subsystem is in charge of two tasks. First duty is fine tuning the robot trajectory, according to the information received from higher levels, such as the robot path, its priorities such as speed, precision, avoiding losing the ball and etc. Secondly, it decides on desired speed value of designated robot to achieve these trajectories.

In this section we present a brief review of our previous approach in motion control and the new method will be described. To reach a standard module to work on the robot control, a user friendly UI is designed to easily achieve any required control parameter. This user interface is depicted in figure 7. In this figure the motor speeds are drawn in the left part and the robot motion in planar space is illustrated in top right. User can change different control parameters such as motor PID controllers’ coefficients desirably [7].
6.1 Previous approach

To control the robot motion with the lowest possible wheels our previous robots, an admissible Emotional Reinforcement Learning controllers named BELBIC was selected to cope with uncertainties of the environment. The applications of this method is extended widely recently [8, 9]. Asymmetry of the robot, from the geometrical characteristics to mechanical specifications of the motors inherited from the aging and etc were generating many deficiencies in motion control. Therefore we try to use fast learning approach to train parameters online.

This attitude was not the best one but had some advantages that were sufficient for our first year experience. Most of the control methods which other teams use were not applicable to our three wheeled robot. The results of this method were satisfying for our previous participation in RoboCup competitions. The details of our approach are explained completely in [10].

![Control User Interface](image_url)

**Fig. 7. Control User Interface**

6.2 Sliding mode Control

With four wheels one degree of freedom allows the controller to reduce the control cost which relates to the robot slippage. Various techniques are applied in the literature [6, 11]. Our selected method is inspired from nonlinear control approaches which are utilized to control of two wheels robot in [12]. A brief review of the
mechanism which is described in [12] is as follows: “The posture of a mobile robot is represented by polar coordinates and the dynamic equation of the robot is feedback-linearized by the computed-torque method. A novel sliding mode control law is proposed for asymptotically stabilizing the mobile robot to a desired trajectory”.

Indeed, improvement of this approach to fit to our four wheels robot is inevitable. Using nonlinear control with more complexities regarded to linear ones has many advantages such as robustness, lower energy consuming, larger domain of convergence and etc. One of the most popular nonlinear control design method is sliding mode control which is robust in a wide range of uncertainties. More details of our results and fully described mechanism will be presented in future in our paper which is under construction.

References

1. Bakhshandeh, O., Azidehak, A., Gorji, M., Sharbafi, M. A., MRL 2008 Team Description