MRL Team Description Paper for Humanoid KidSize League of RoboCup 2020

Hamed Mahmudi[1][0000-0002-6790-5360], Amir Gholami [0000-0003-0125-3459], Mohammad Hossein Delavaran [0000-0002-0756-2642], Saeid Bazargan, Soheil Khatibi, Milad Moradi, Abolfazl Ashayeri, Arash Rahmani, Soroush Mehrtash, Kazem Firouzmandi Bandpey, Peyman Fallahzadeh, and Meisam Teimouri [0000-0003-0465-6528]

Mechatronics Research Lab, Dept. of Computer and Electrical Engineering,
Qazvin Islamic Azad University, Qazvin, Iran
`Email: mahmudihamed@qiau.ac.ir`

Abstract. RoboCup uses soccer competitions as a research area to promote robotics and artificial intelligence. The ultimate goal of the RoboCup is to develop a team of humanoid robots that can win against the human world champion soccer team in 2050. This paper presents the approach of the MRL KidSize humanoid team to participate in humanoid soccer competition in Bordeaux, France under the RoboCup 2020 rules. The team description paper presents the system characteristics of MRL KidSize humanoid robot which is containing system overview, robot vision and mechanical design.

Keywords: RoboCup, KidSize Humanoid League, Mechanical Design, Robot Vision

1 Introduction

The MRL project was started in 2003 in the Mechatronics Research Laboratory at Islamic Azad University, Qazvin branch looking onward to enhance the knowledge of robotics. The MRL humanoid soccer team is aimed to develop a humanoid platform for research and education. Our humanoid soccer-playing team has participated in the RoboCup Humanoid KidSize since 2011 [1-3].

In RoboCup 2019 which held in Sydney, Australia, the MRL humanoid robot team won the first place in the main competition. Also, the second place in technical challenges and first place in drop-in games was accomplished by MRL team. In addition, the MRL team of humanoid robots succeeded to achieve third place of best humanoid award.

The rest of this paper can be summarized in the following. In section 2 an overview of the system is described. The electronic parts are discussed in section 3. In section 4 and section 5 recent software development including methods of visual perception and lower body joint calibration are clarified respectively. Section 6 is about robot behavior algorithm and the mechanical design and dynamical analysis is introduced in section 7.

2 System Overview

The MRL humanoid robot platform with 20 degrees of freedom, 58 cm height and 4.4 kg weight is the our robot for participating in RoboCup 2020. All joints are equipped with Robotis Dynamixel MX series actuators which containing two Dynamixel MX-28 in neck and head, three Dynamixel MX-28 for each arm and six Dynamixel MX-64 for each leg. The main processing unit is an Intel NUC 7th generation and power management is done by MRL self-constructed controller board. The robot is powered by a 3-Cell, 3500mAH Li-Po battery.

Visual perception is accomplished by a Logitech C920 normal webcam with 78° field of view. All mechanical components of the robot are made of aluminum alloy 6061 which is manufactured by utilizing CNC milling in order to increase accuracy.

The software architecture is based on the UPennalizers RoboCup released code [4]. The vision, world model and behavior modules are completely rewritten and walk engine is enhanced to address disturbances more efficiently.

3 Electronic

3.1 Control Manager

Last year, we designed our control manager board (**Fig. 1** left) that was responsible for power supply, actuator communication and attitude estimation of the robot. In MRL-CM1, we divided the actuators lane into three separate lanes to reduce the load. So the transmission speed between the mainboard and actuators located in different chains increased. However, we need to read sensors data with a higher rate to get smoother motion controllers. Reading actuators and sensors data through the same BUS makes the rate of reading constrained by the speed of actuators reading that is considerably lower than sensors reading. Moreover adding extra measuring instruments to the system makes it even slower. To cope with this problem, a new control manager board (**Fig. 1** right) is designed that consists of two separated boards (actuators and sensors board). Each board is individually connected to the mainboard and transfers the data using the standard Dynamixel packets. The block diagram of the new system is demonstrated in **Fig. 2**.

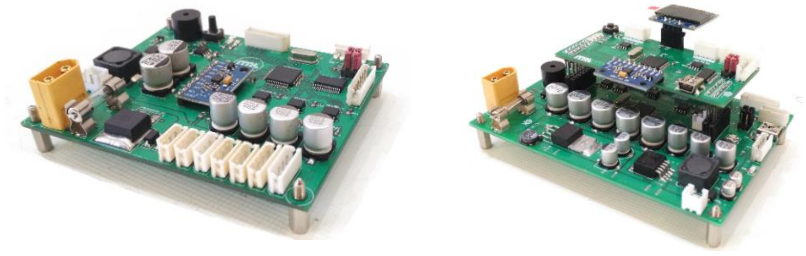

Fig. 1. Left: MRL-CM1. Right: Last version of control manager board (MRL-CM2)

Sensor Board. The processing unit of the actuators board is an ARM STM32F405VE microcontroller. The firmware is developed under standard HAL drivers [5]. This board is equipped with 2 inertial sensors (gyroscope and accelerometer). Also, it has a lane for communicating with strain gauges. Since its task is just to read data sensors and it has no communication with actuators, we can read data faster. An OLED display is attached for monitoring and debugging. In addition, it should be mentioned that another aim of this board is estimating roll, pitch, and yaw employing a complementary filter [6].

Actuator Board. The tasks of power management and actuators data streaming are accomplished by this board. The processing unit of the actuator board is the same as the sensor board. This board is designed to communicate with both TTL and RS-485 protocols simultaneously, but because of our available R series actuators of Dynamixel and efficiency of RS-485 over long distances between legs actuators, we used RS-485 protocol as our serial communication. Similar to MRL-CM1, to reduce the heavy load of data transfer, we have divided the communication lane into five independent lanes, each one has its own FIFO queue.

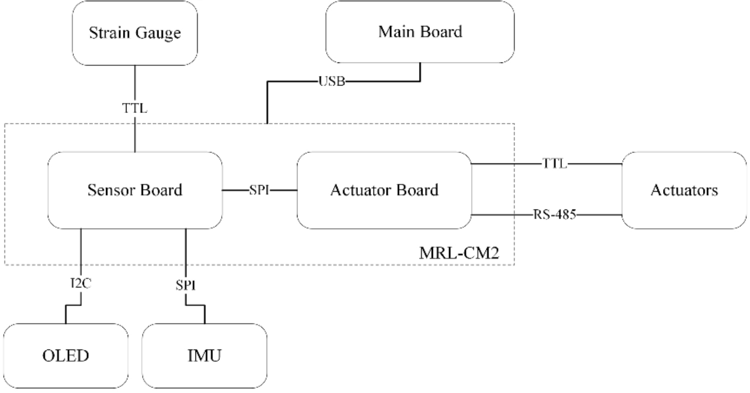

Fig. 2. MRL-CM2 Communications block diagram

As well, the actuator board is able to supply the required power for the entire robot. We used a DC-DC boost converter in MRL-CM1 which provided 18V-5A at a frequency of 350 kHz, but there were some problems. It was used only to supply mainboard voltage and we got the actuator voltage directly from the battery and we had no way to change and control it. So, in this version of the board, we used a DC-DC buck converter to supply the voltage and current needed for the mainboard and actuators, as explained below.

DC-DC Buck Converter. The battery is the main input power supplier of the robot and its voltage drops over time. By implementing this system, we can keep motors voltage constant and apply desired voltage to the motor in different situations, such as higher voltage than usual when the robot is kicking or when the robot is standing up. Moreover, the process of motion calibration of the robot becomes simpler.

Buck converters are switched-mode step-down DC-DC converters; the output voltage of buck converters is a function of the PWM duty cycle which controls the MOSFETs status. The output signal is an average of the PWM square wave [7].

4 Visual perception

Vision is the most important source of perception in a humanoid soccer playing robot. In this section, we briefly review the pipeline of our vision system and investigate the planned projects.

Like most of the participating teams, we use a monocular vision system. The captured image at first is fed to a segmentation module [8] to perform semantic segmentation. Based on this segmented image the boundary of the field is determined. Then all object detection algorithms are applied only on the pixels located in the field boundary. The field lines and their intersections are detected using the Hough Transform [2]. For ball detection, first, some coarse regions of interest that may contain a ball are extracted using the segmentation map and camera matrix. Then each region is fed to a deep convolutional neural network to predict whether the region contains a ball or not and estimate the exact location of the ball in that region. The details of our ball detection approach are described in [9].

A detailed explanation of our segmentation module is provided in [8]. During RoboCup 2019 we had taken an important step toward coping with natural light condition, but there are struggles with direct reflection of sunlight and reflective objects. Some predicted masks by the network are shown in **Fig. 3**.

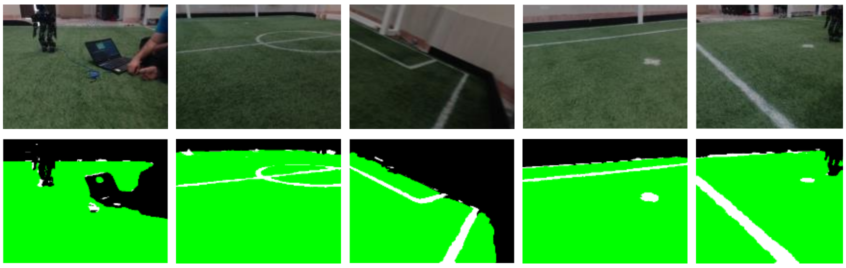

Fig. 3. The segmentation results on a few samples captured in MRL Labs at different times of a day.

5 Lower Body Joint Calibration

For accurate kinematic modeling of the robot joints calibration, offsets are required. A fairly accurate calibration can be achieved manually by hand and eye. Regarding to experiences during RoboCup competitions every collision of a robot shifts offsets slightly that should be recalibrated. Therefore repeated manual calibration of joint offsets can be very time consuming. In the following we present set-up and two potential solutions for this concern.

For the set-up, we constructed a stand equipped with a fixed camera to measure the position of a marker attached to a predetermined position on each foot of the robot, as shown in **Fig. 4**.

5.1 Calibration with genetic algorithm

One solution is to follow the procedure of manual calibration. As a first step, we set up the robot in a fixed predetermined position on the stand and set the pose of all 12 servos in the lower body of the robot to zero (lower body servos include hip yaw, hip pitch, hip roll, knee pitch, ankle pitch and ankle roll for each leg). Then we expect to observe the marker points in a desired position relative to the camera. Using a genetic search algorithm, we can actively search for a set of offsets that minimizes the Euclidean distance between the desired position of the markers and the observations measured by the camera.

5.2 Forward kinematics and gradient descent

The second approach is to take aid from forward kinematic modeling. Using kinematic modeling, we can estimate the position of marker points relative to the fixed external camera. The algorithm contains two steps: sample collection and optimization. For the first step we set all the offset parameters to zero and with an iterative process we move the robot legs to a number of positions that the marker points are visible and then for each foot position we measure the real position of the marker points using the fixed external camera. Each sample in this system is represented as a pair of all servo positions and the measured positions of marker points.

Using this samples and the forward kinematic model of the robot legs we can optimize for a set of offsets minimizing the mean squared error between the output of the model and the measured position of the marker points.

For the second step, we plan to use gradient descent to optimize the offsets in a way to minimize the following cost.

$$cost = \frac{1}{2n}\sum_{i=1}^{n}\sum_{j=1}^{m}(\boldsymbol{p}_i^j - \boldsymbol{o}_i^j)^2 + R \tag{1}$$

$$\boldsymbol{p}_i^j = \kappa_j(\boldsymbol{s}_i + \boldsymbol{b}) \tag{2}$$

In the above equations, $\boldsymbol{p}_i^j$ stands for the estimated position of the marker point j in sample i and κ_j is the forward kinematic model for marker point j which takes the addition of $\boldsymbol{s}_i$ (joint positions) and current offsets $\boldsymbol{b}$ as an input. In the defined cost function n is the number of samples and m is the number of marker points. Also, R can be regularization terms to prevent overfitting. For example, good regularization terms can be constraints on the upper bound and lower bound of offset values and the error between the estimated and observed rotation of the foot. Note that these methods are still some ideas that not completely implemented yet.

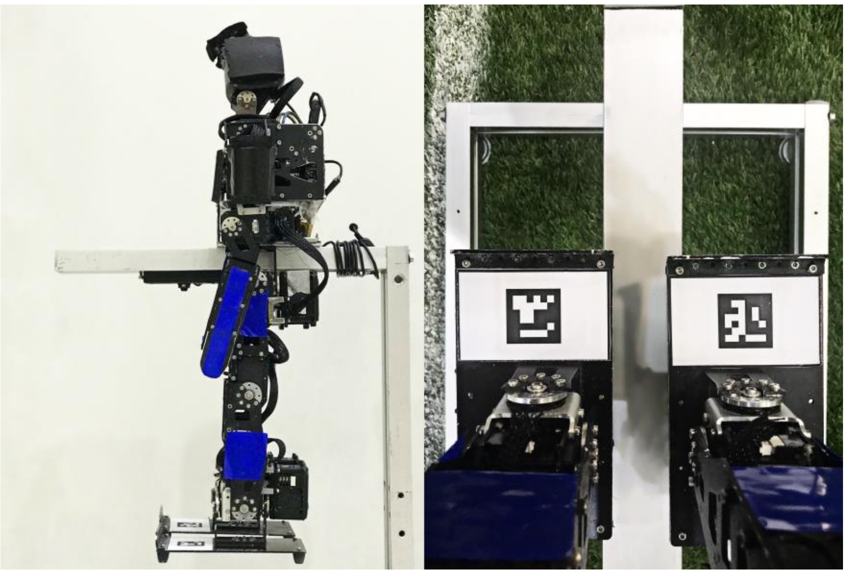

Fig. 4. Set-up for lower body calibration

6 Behavior

6.1 Active Head Control

Last year we introduced the Active Head action selector module which controls the viewpoint of the robot in order to improve localization and modeling the surrounding objects i.e. other robots or landmarks. The module, however, faced some problems main of which is the localization error because the robot chooses the action that minimizes the entropy based on current localization data [3]. This year we are looking forward to using a deep reinforcement learning algorithm in which the robot learns to move its head in the direction that will have the most observations from raw input image. The network is a CNN that can either be trained from scratch or use the first layers of a pre-trained network like our ball detector network and be fine-tuned to reach the purpose of maximizing total reward. Han et al. did similar and nice work to improve object detection quality [10]. This will explicitly decrease localization error which directly implies the quality of team play.

6.2 Strategy and Team Play

Last year we developed a supporter role which helps the Attacker when playing aggressively and helps Defender when playing defensively. We have four roles including Goalkeeper, Attacker, Defender, and Supporter that are assigned to robots based on the cost of reaching the ball and the distance to their own goal. The robot that has the lowest cost will be the Attacker that goes to kick the ball and the robot having the lowest distance to the own goal will be Defender. The goalkeeper is a static role and does not change and the last one will be Supporter [8]. This year we are working on better positioning of each role in the field in order to better blocking the way of ball to the own goal and more convenient reaching to opponent goal using the information shared by other robots and perceptions observed by the robot itself.

7 Mechanical design and dynamical analysis

Due to the new rules of RoboCup 2020 and integration of KidSize and TeenSize into one league, we decided to design a new platform of the humanoid robot. The previous platform was made by entirely aluminum which makes the weight of the robot heavy. For this reason, we're going to use a combination of carbon composite, 3D printer filament and aluminum for the robot's body structure. The specifications of material which will be used for manufacturing the new platform including TPU and PLA 3D printer filaments with 1.75mm diameter, Zoltek panex 33 carbon with 4mm thickness composite and aluminum alloy 7075 with 4mm thickness. In order to increase accuracy, the CNC Milling and CNC Laser cutting will be used. Besides being lightweight, carbon composite has an extreme strength which is a great advantage. Also, using 3D printer filaments make the manufacturing easier, because it can be made in any shape.

The head and the hand will be 3D printed using PLA and TPU filament respectively. The arms and legs will be made by carbon composite sheets. The torso should be as light as possible, so the carbon composite is needed for it. But, due to the limitation of the carbon composite in term of drilling on the thickness, aluminum will be used for some parts of the torso. Since the aluminum alloy 7075 is more stress-tolerant than the aluminum alloy 6061 used in the previous robot, so it will be used in the manufacturing of the new robot. Also, to prevent damage to the robot when it falls, a TPU filament mesh will be used in front of the chest to reduce the impact on the robot.

The dynamical analysis before manufacturing of the robot is needed to reduce costs and errors [11]. Since the new platform of MRL humanoid robot is being designed, the use of simulator for dynamical analysis purposes is required. MRL-HSL real-time simulator [12] is a virtual humanoid robot which helps to dynamical analysis with considering forces on mechanical parts.

References

1. Teimouri, M., Salimi, A., Farhadi, A., Fatehi, A., Mahmoudi, H., Sharifi, H., Sefat, M.H.: MRL Team Description Paper for Humanoid KidSize League of RoboCup

2017. Mechatronics Research Lab, Dept. of Computer and Electrical Engineering, Qazvin Islamic Azad University, Qazvin, Iran (2017)

2. Teimouri, M., Fatehi, A., Mahmoudi, H., Ha, P.S., Gholami, A., Delavaran, M.H., Movafegh, F., Rahmani, G., Fathi, E.: MRL Team Description Paper for Humanoid KidSize League of RoboCup 2018. Mechatronics Research Lab, Dept. of Computer and Electrical Engineering, Qazvin Islamic Azad University, Qazvin, Iran (2018)
3. Mahmoudi, H., Fatehi, A., Gholami, A., Delavaran, M.H., Khatibi, S., Alaee, B., Tafazol, S., Abbasi, M., Doust, M.Y., Jafari, A.: MRL Team Description Paper for Humanoid KidSize League of RoboCup 2019. Mechatronics Research Lab, Dept. of Computer and Electrical Engineering, Qazvin Islamic Azad University, Qazvin, Iran (2019)
4. https://github.com/UPenn-RoboCup/UPennalizers
5. Microelectronics, S.: RM0090 Reference manual STM32F405xx. STM32F407xx, STM32F415xx and STM32F417xx advanced ARM-based
6. Allgeuer, P., Behnke, S.: Robust sensor fusion for robot attitude estimation. In: 2014 IEEE-RAS International Conference on Humanoid Robots, pp. 218-224. IEEE, (2014)
7. Kazimierczuk, M.K.: Pulse-width modulated DC-DC power converters. John Wiley & Sons (2015)
8. Mahmudi, H., Gholami, A., Delavaran, M.H., Khatibi, S., Bazargan, S., Moradi, M., Alaee, B., Rahmani, A., Firouzmandi Bandpey, K., Fallahzadeh, P., Teimouri, M.: MRL Champion Team Paper in Humanoid TeenSize League of RoboCup 2019. In: Proceedings of 23rd RoboCup International Symposium. Sydney, Australia (2019)
9. Teimouri, M., Delavaran, M.H., Rezaei, M.: A Real-Time Ball Detection Approach Using Convolutional Neural Networks. In: proceedings of 23rd RoboCup International Symposium. Sydney, Australia (2019)
10. Han, X., Liu, H., Sun, F., Zhang, X.: Active object detection with multi-step action prediction using deep q-network. IEEE Transactions on Industrial Informatics (2019)
11. Mahmudi, H., Fatehi, A., Gholami, A., Moradi, M., Fathi, E., Sani, A.G., Rahmani, G., Mohafezatkar, A., Karimi, A., Rahmani, A.: MRL Team Description Paper for Humanoid TeenSize League of RoboCup 2019. Mechatronics Research Lab, Dept. of Computer and Electrical Engineering, Qazvin Islamic Azad University, Qazvin, Iran (2019)
12. Gholami, A., Moradi, M., Majidi, M.: A simulation platform design and kinematics analysis of MRL-HSL humanoid robot. In: Proceedings of 23rd RoboCup International Symposium. Sydney, Australia (2019)