

# BRocks 2016 Team Description

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**Abstract.** In this paper, robotic systems of the BRocks team, which is to participate in Small Size League (SSL) of RoboCup Germany 2016, are summarized. Brief descriptions of the robots' subsystems (mechanical, electrical, and AI systems) are given, and solutions along with modifications to various problems are explained.

## 1 Introduction

Due to having a centralized off-board vision system, Small Size League (SSL) is one of the most exciting competitions of RoboCup with its high pace involving sophisticated strategies. This feature of the league stems from the fact that the global vision system, which perceives all robots and the ball in the field, minimizes the effort on robot localisation and mapping; therefore, enabling the teams to dedicate their focus on developing more advanced software and hardware solutions for their robots [1].

In order to realize a team of robots that can compete in RoboCup SSL, there are several technical topics that must be considered and studied such as electronics, communication and control issues of robots. To do so, the BRocks team have been working within the Networked & Embedded Control Systems Laboratory at the Boğaziçi University since 2008. Our team participated in previous RoboCup SSL competitions 2009 (Graz), 2010 (Singapore), 2011 (Istanbul), 2012 (Mexico City), and 2013 (Eindhoven). However, our aim is not only to participate in RoboCup competitions, but also use our test bed to develop and test our hybrid, decentralized control, coordination algorithms while taking communication, networking, vision, electronics and mechanical constraints into account.

The rest of this paper is organized as follows. In sections 2 and 3, mechanical and electrical subsystems are described respectively. In section 4, we provide the details of vision based integrated control system. Finally, in section 5, low level control architecture is explained briefly.

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## 2 Mechanical Components and Systems

In this section, we will present the mechanical subsystems of the robots. The mechanical design of our robots is similar to other RoboCup designs [2–4] in that it is equipped with four custom-built omnidirectional wheels, a dribbler and a kicking system in front.

As listed in Table 1, our robots meet the mechanical criterion of the RoboCup SSL.

Height of the robot	142 mm
Maximum diameter of its projection onto the ground	175 mm
Percentage of ball coverage	< 19%

Table 1: BROCKS Team Robots: Mechanical Specifications.

After delineating the problems in the wheels, kicker and dribbling mechanism in our previous design, the mechanical system has been redesigned this year. The mechanical subsystem is composed of 3 main components (see Figs. 1– 3):

- Locomotion System
- Dribbler Mechanism
- Kicker

### 2.1 Locomotion System

As shown in Fig. 1, the locomotion system consists of a base and four omni-wheels driven by 30 W brushless DC motors with a gear ratio of 3.6:1. We have modified the omni-wheels to improve movement abilities and robustness. The wheel consists of 15 O-rings around the base wheel which is redesigned so that rollers can turn freely. In this way, bigger rollers can be adopted. Material of the wheel is aluminum 7000 series. Both the wheels and the base of the robot were manufactured precisely via CNC tools based on CAD designs.

In addition, there is an improvement (two bearings, a bolt, and a washer) in the wheel’s mounting system and rotating mechanism in order to dismantle and reassemble it easier. This also reduces the vibrations during robot’s movement. For this purpose, a new encoder and wheel mount has been developed, which brings more precise perpendicularity between the motor shaft and the wheel without any need for extra adjustments. This enhancement provides more reliable directional and rotational motion for the robot.

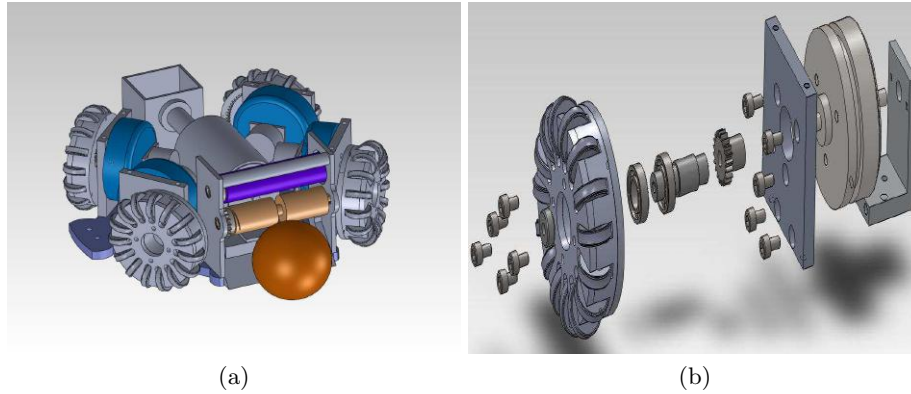


Fig. 1: (a) Technical drawing of BRocks robots , (b) The wheel's mounting system

## 2.2 Brushless DC Motors

Maxon EC-45 Flat 30 W brushless DC motors are used for the locomotion of our robots. The motors operate with 12V, at a maximum speed of 4400 rpm and can produce 59 mNm continuous nominal torque. 1:3.6 gear reduction ratio is used in order to increase the overall torque. Three Hall sensors with 120 degrees phase difference are available from the motors for speed measurement. The Hall sensors in the motor produce a feedback signal that help estimating wheel velocities. Hall sensors provide only 48 pulses per revolution; therefore encoders which have higher resolution (1440 pulses per revolution) are implemented.

## 2.3 Dribbler Mechanism

In the new dribbler mechanism, we use Maxon EC16 brushless motor with an embedded gearbox that has a gear ratio of 5.4:1. The gears between the shafts of the dribbler bar and motor are chosen to have a ratio of 1:1. The rotation speed is controlled via an actuator circuit whose input comes from the micro-controller, and it is activated once the robot has the possession of the ball. The dribbler is designed to have a ball coverage of less than 20%. The dribbler roller axel has been redesigned (see Fig. 2) to have better rotation. In the previous design, there was an abrasion between the roller and the dribbler arm which used to result in friction and termination in rotation. Additionally, the material of the dribbling roller has been changed to silicon.

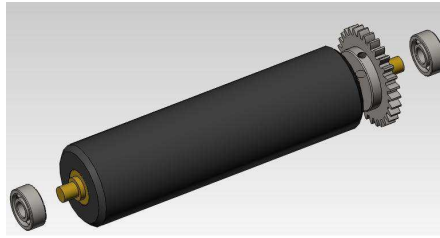


Fig. 2: The dribbler roller

## 2.4 Kicker

The kicker mechanism contains two 2200  $\mu\text{F}$ , 200V capacitors and two push type solenoid actuated by a kicker circuit. The associated kicker circuit is also controlled by the micro-controller which sends the kick signal and its duration. The robot has two different types of kicking system for direct and chip kicking.

We have changed our chip kick mechanism to a new one which has longer arms and is wider. Since one fourth length of its plunger is made of rigid compacted plastic, it applies more force to the ball. Moreover, the chip kick system contains a flat shape solenoid. With these specifications, it can kick the ball up to 6 meters.

The direct kicker contains a solenoid and a plunger which lead to kick the ball with the maximum speed set by SSL.

## 3 Electrical systems

Each of our robots relies on the following electronic circuits that receive commands from the software system in order to perform the desired tasks:

- Locomotion Motor Control Circuit
- Dribbler Circuit
- Kicker Circuit
- Main Board

### 3.1 Locomotion Motor Control Circuit

Our robots consist of four custom-built omni-wheels, each of which is driven by a 30 W, 4370 rpm brushless DC motor. The microcontroller is used to estimate the motor speeds and a controller logic is implemented on the microprocessor for precise speed control. Furthermore, a current sensing circuit is implemented to protect the system against unexpected errors by limiting the current flowing through the circuit. Fig. 3 shows the main board of the electrical system.

### 3.2 Dribbler Circuit

The dribbler consists of a 15 W brushless DC motor and it is driven by a simple H-bridge circuit that is controlled by the microprocessor.

### 3.3 Kicker Circuit

The design principle of our current kicker circuit is similar to other RoboCup designs [3] in the sense that it relies on charging a capacitor to 200 V and then releasing the solenoid once the controlling computer sends the "kick" command [2].

### 3.4 Main board

For proper implementation of the control strategies on the robots, it is critical that data be communicated to the robots in a wireless fashion that do not violate the rules of RoboCup SSL. To this end, we use Zigbee low power wireless communication modules. The control data generated by the main computer are sent to the robots using the wireless modules, which are then received and processed by the microprocessor to carry out the following tasks:

1. Measure and control the speeds of four brushless DC motors,
2. Activate the solenoid when required,
3. Activate and control the dribbler when required.

The electrical subsystems also include encoders, a gyroscope, an accelerometer and IR sensors as additional sensors in order to get the speed data more precisely. Sequential digital circuit is used to detect the rotational direction of wheels.

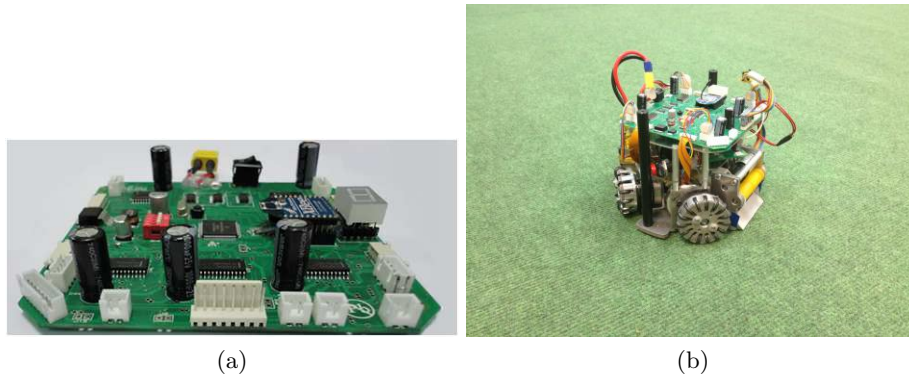


Fig. 3: (a) The main board, (b) BRocks robot

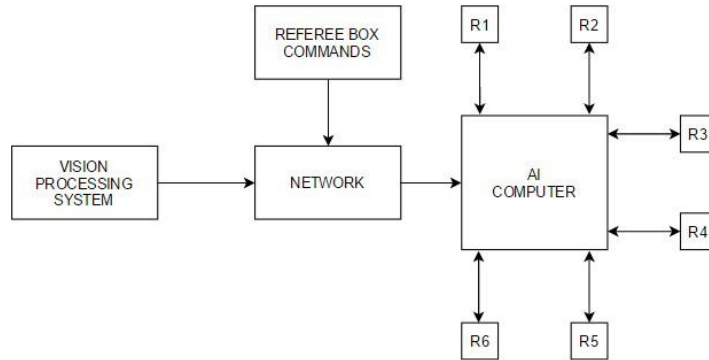


Fig. 4: Vision Based Control/Coordination Architecture

## 4 Vision Based Integrated Control System

In this part, we describe the complete feedback system composed of autonomous holonomic robots with wireless communication capability, two overhead cameras that can provide feedback on the robot and ball positions, and a host computer that acts as a supervisor (see Fig. 4). The host computer receives the vision data on the robots and ball positions and sends control commands to the robots according to strategy. There are two 60 fps digital cameras which provide the visual feedback to the controlling computer. The SSLVision software provides the positions of the robots and ball. The software must be properly calibrated based on the light intensity.

### 4.1 High-Level Control and Strategy Planner

High-level control of robots consists of two main modules:

1. Strategy planning and tactics: Strategy planning is crucial in multi-robot domains. The strategy planner assigns roles to each robot e.g., forward, defender or ball follower. Team Agent Behaviour Architecture (TABA) [5] is used for dynamic role assignment and tactics. In the architecture, there are four main section: agent leader selection, strategy selection, role assignment and tactic execution. Most important of them is role assignment, that is done according to the distance between robots and the ball. The primary attacker role is assigned to the nearest robot which goes to the ball position. We have four main roles which are primary attacker, offensive supporter, defensive supporter and the goal keeper.
2. Motion planning and navigation: One of the objectives is to arrive at the destination point from a given initial point by avoiding obstacles. Detailed

explanation of our strategy and motion planning explained in TDP written for 2013 [6].

## 4.2 Path Planning

The path planning system is based on well known RRT family of randomized path planners. The RRT planner searches for a path from an initial state to a goal state by expanding a search tree. Detailed explanation of our strategy and motion planning explained in our 2013 TDP [6].

## 4.3 Multi-Agent Collaboration

The key issue in coordinating a team of robots during an SSL game is to decompose the complex task into simpler actions which might be referred to as modes and defining the transitions between these modes in some optimal way. As the constraints and the goals of SSL are known, it is a well-defined environment for developing multi-agent strategies. On the other hand, it is still a challenging test-bed since two teams of robots compete with each other to win the match.

The robots should work collaboratively in order to reach success. To this end, we intend to adapt a hybrid systems based formation in developing our multi-agent formation algorithms.

A hybrid system is a dynamical system whose behaviour develops as the result of a continuous state system interacting with a discrete event system. Towards achieving this goal, we have been working on developing consensus based algorithms in the context of switched systems [7–11]. In distributed control of multi-agent systems, agreement value can differ according to the tasks, working space or even time itself. For example, in the context of SSL, we might require a group of robots to have one orientation whereas a second group of robots has another orientation to deceive the opponents. We have examined the theoretical foundations of such multi-equilibria in [7]. Another important related problem is to reach consensus in the presence of misbehaving nodes as there exist several scenarios where some of the nodes of the system may malfunction due to various reasons. Hence, it is critical that the system adopts a fault-tolerant protocol so that faulty nodes do not prevent the achievement of consensus by non-faulty agents. As an example, consider a group of autonomous robots which intend to gather at one point in absence of any centralized controller. Suppose that each robot updates its position based on the information it receives from its neighbor robots while some robots are faulty and can/do not update their states using the predefined distributed algorithm. Furthermore, suppose that there are some robots that send conflicting information to their neighbors at any given time. In this setting, the objective of the fault-tolerant distributed algorithm is to ensure that all non-faulty robots are gathered at one point [11]. We intend to apply some of these techniques in our test bed in the near future.

## 5 Low Level Control

The schematic of our low level control architecture onboard each robot is shown in Fig. 5. The primary task of the low level control unit is to control the motor speeds.

The desired motor speeds are sent to the robot via wireless Zigbee trans-receiver module from the remote PC. The microprocessor gets the motor speed data from the Zigbee trans-receiver module onboard and activates the speed control loop.

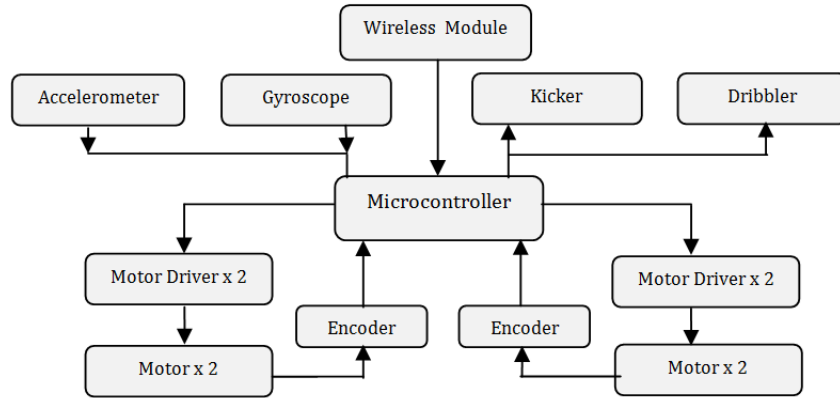


Fig. 5: The schematic of our low level control architecture.



### 5.1 Speed Control

The speed regulation for each wheel is achieved using a digital controller that takes the reference and the estimated speeds as inputs, and adjusts the set point into the actuator [2]. The complete block-diagram of the digital controller is shown in Fig. 6 with the variables defined in Table 2 [12].

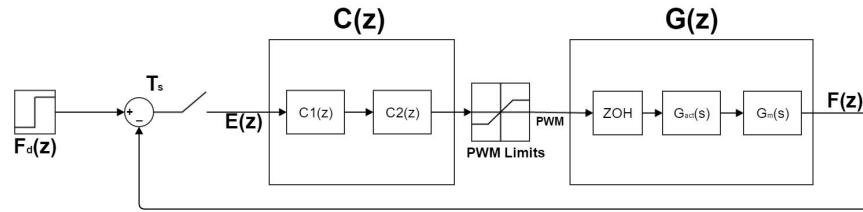


Fig. 6: Digital speed controller

$F_d(z)$	$z$ -transform of the desired wheel frequency
$F(z)$	$z$ -transform of the estimated wheel frequency
$C(z)$	Digital PI controller
ZOH	Zero-order-Hold
$G_{act}(s)$	Transfer function of the driver circuit
$G_m(s)$	Transfer function of the motor
$T_s$	Sampling period

Table 2: Descriptions of the variables in Fig. 6.

The design of the digital controller  $C(z)$  depends on identification of the actuator and motor dynamics, i.e.,  $G_{act}(s)$  and  $G_m(s)$ , respectively. The speed regulation is realized using a digital PI controller whose parameters are chosen such that the closed loop pulse-transfer-function is stable, and certain transient performance specifications are satisfied. For more details, see [12].

## 6 Future Improvements

There are several improvements that are being carried out in terms of electrical and mechanical structure of the robot in order to make robot more stable and controllable.

### 6.1 Mechanical Improvements

In the new robots, Maxon EC-45 Flat 30 W brushless DC motors are to be replaced with Maxon EC-45 Flat 50 W brushless DC motors in order to provide high performance speed and position control. The 50 W brushless motors operate with 24V, at a maximum speed of 6710 rpm and can produce 82.7 mNm continuous nominal torque. Additionally, the mechanical structure of the dribbler has been modified as depicted in Fig. 7 to improve the ball control ability. Finally, the shooting mechanism is stabilized by changing the solenoidal structure.

### 6.2 Electrical Improvements

In the new main board, MC56F84789 Freescale microcontroller unit is used instead of MC9S08DZ128 model for 50 W brushless DC motors. MC56F84789 provides us tower development platform. Tower system is modular, scalable, flexible, and sensing. Therefore, structure of circuit has been changed in order to be more pluggable and be controlled more easily (Fig. 8).

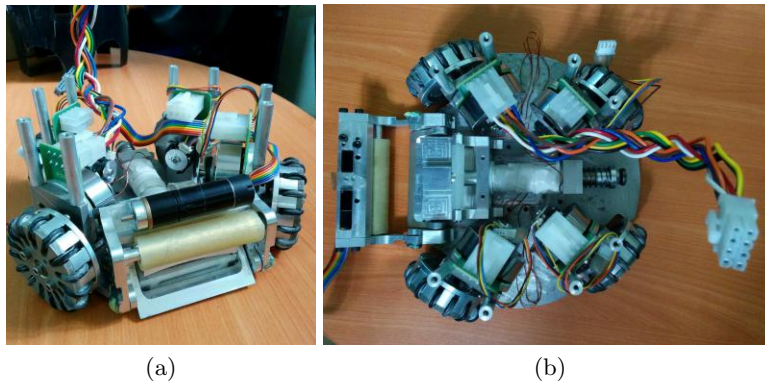


Fig. 7: (a) Front view of new robot , (b) Top view of new robot

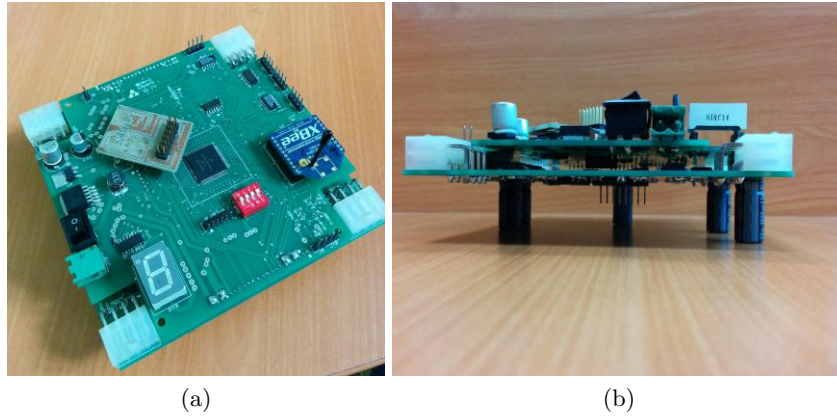


Fig. 8: (a) Top view of new circuit, (b) Front view of new circuit

## 7 Concluding Remarks

This paper provides an overview of BRocks 2016, covering the developments of robot hardware and the software architectures. Since our first participation in RoboCup 2009, our team has continuously improved. We are looking forward to competing in Germany 2016.

## Acknowledgements

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