NimbRo TeenSize 2008 Team Description

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Abstract. This document describes the RoboCup Humanoid League team NimbRo TeenSize of Albert-Ludwigs-University Freiburg, Germany, as required by the qualification procedure for the competition to be held in Suzhou, China, in July 2008.

Our team uses self-constructed robots for playing soccer. The paper describes the mechanical and electrical design of the robots. It also covers the software used for perception, and behavior control.

1 Introduction

The project NimbRo – Learning Humanoid Robots – is running at Albert-Ludwigs-University of Freiburg, Germany, since 2004. Our TeenSize team participated with great success at last year's RoboCup Humanoid League competitions in Atlanta, USA. The striker Robotina and the goalie Bodo won the penalty kick tournament and came in second in the technical challenges.

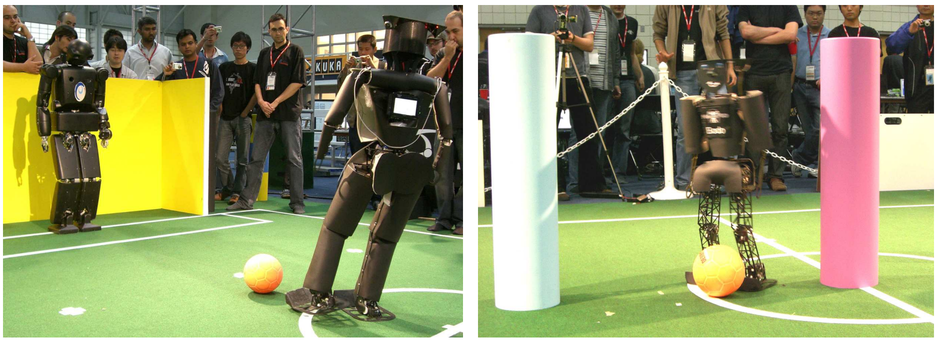

Fig. 1. Left: RoboCup 2007 TeenSize Penalty Kick final: NimbRo vs. Pal Technology (NimbRo won 5:4); Right: RoboCup 2007 dribbling challenge.

Robotina reliably kicked penalties into goal corners. She observed the goalie and decided late, which corner to kick the ball into. The goalie Bodo jumped quickly to the ground when the ball was approaching. He saved many goals. Figure 1 shows the final of the Penalty Kick tournament, where our robots met Pal Technology. The exciting game was open until the end. Our robots won the final 5:4. Bodo also did very well in the technical challenges, where he walked quickly across the field, performed the obstacle run with ease, and dribbled the ball in slalom around colored poles.

For the 2008 competition, we develop a new vision system for the NimbRo TeenSize 2007 robots, which has a limited field-of-view of 180°. This document describes the current state of the project as well as the intended development for the 2008 RoboCup competitions. It is organized as follows. In the next section, we describe the mechanical and electrical design of the robots. The perception of the internal robot state and the situation on the field is covered in Sec. 3. Behavior control in a hierarchy of agents and time-scales is explained in Sec. 4.

2 Mechanical and Electrical Design

Fig. 2 shows Robotina and Bodo, our TeenSize 2007 robots. As can be seen, the robots have human-like proportions. Their mechanical design focused on simplicity, robustness, and weight reduction. Robotina has a height of 122cm and weighs 9kg, including batteries. We extended Bodo and equipped him with a new camera head to comply with the 2008 rules. He is now 103cm tall and has a weight of about 4.5kg.

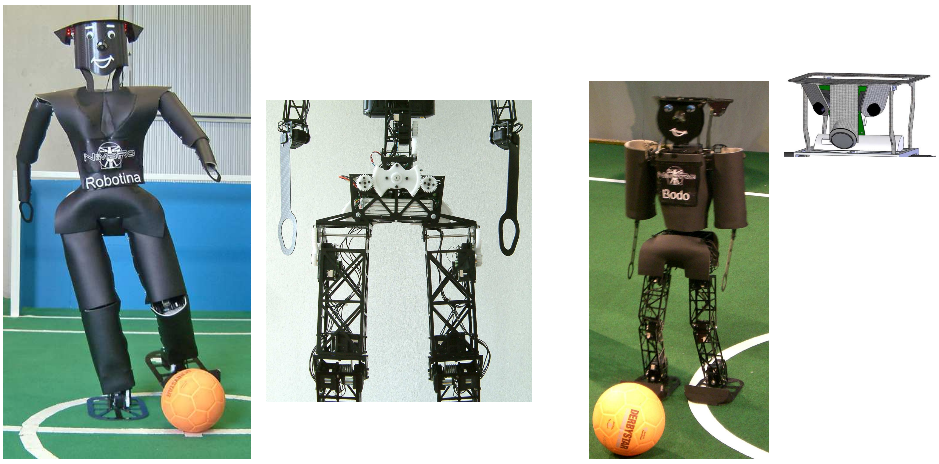

Fig. 2. NimbRo TeenSize 2007 robots Robotina (left, with mechanical detail) and Bodo (right, with drawing of new camera head)

As compared to the NimbRo 2006 robots [2], which were controlled by a Pocket PC, the 2007 robots have a much stronger main computer and a high-bandwidth vision system. The new robots are controlled by a tiny PC, a Sony Vaio UX, which features an Intel 1.33GHz ULV Core Solo Processor, 1GB RAM, 32GB SSD, a 4.5" WSVGA touch-sensitive display, 802.11a/b/g WLAN, and a USB2.0 interface. The weight of the UX is only 486g. Three IDS uEye UI-1226LE industrial USB2.0 cameras provided omnidirectional sight. We will reduce the field-of-view of the robots to 180° in 2008. The cameras feature a 1/3" WVGA CMOS sensor, global shutter, and are equipped with ultra-wide angle lenses. Each camera has a $90^\circ \times 140^\circ$ field-of-view.

The NimbRo 2007 robots have also stronger actuators, compared to the NimbRo 2006 robots. Bodo is driven by 14 Dynamixel actuators: 6 per leg and 1 in each arm. For all leg joints, except hip yaw, we use large RX-64 actuators (116g, 64kg·cm). All other joints are driven by smaller DX-117 actuators (66g, 37kg·cm).

Robotina's 23 DOF are driven by a total of 35 Dynamixel actuators. She has 6DOF legs, 4DOF arms, and a 3DOF trunk. All joints in the legs and the trunk, except for the yaw axes, are driven by two parallel actuators. The actuators are coupled in a master-slave configuration. This doubles the torque and lowers operating temperatures. The master-slave pair of actuators has the same interface as the single actuators used for all other joints. Dynamixel RX-64 actuators are used in the legs and DX-117 actuators are used in the trunk and in the arms. The ankle, hip, and trunk yaw/roll axes are reinforced by external 2:1/3:1 spur gears, respectively, resulting in a holding torque of 384kg·cm (39Nm) in the ankle and hip roll joints. The knee is not reduced with an external spur gear, because it needs to move quickly. Instead, a torsional spring is added in parallel to the knee actuators. This spring supports stretching the knee. It is designed to compensate for the weight of the robot when it is standing with partially bent knees.

The skeleton of the robots is constructed from aluminum extrusions with rectangular tube cross section. In order to reduce weight, we removed all material not necessary for stability. The feet, the forearms, and the robot heads are made from sheets of carbon composite material. The upper part of Bodo and the entire body of Robotina is protected by a layer of foam and an outer shell of synthetic leather.

Our soccer robots are fully autonomous. They are powered by high-current Lithium-polymer rechargeable batteries, which are located in their hip. Five Kokam 1250mAh cells are used for the KidSize robots. Robotina has five Kokam 3200mAh cells. The batteries last for about 25 minutes of operation.

The Dynamixel actuators have a RS-485 differential half-duplex interface. Each robot is equipped with a CardS12X microcontroller board, which manages the detailed communication with all Dynamixels. These boards feature the Motorola MC9S12XDP512 chip, a 16-bit controller belonging to the popular HCS12X family. The controller has an I/O co-processor and many interfaces, including serial lines and A/D converters. The Dynamixel actuators have a flexible interface. Not only target positions are sent to the actuators, but also parameters of the control loop, such as the compliance. In the opposite direction, the current positions, speeds, loads, temperatures, and voltages are read back.

In addition to these joint sensors, the robots are equipped with an attitude sensor, located in the trunk. It consists of a dual-axis accelerometer (ADXL203, ±1.5g) and two gyroscopes (ADXRS, ±300 °/s). The four analog sensor signals are digitized with A/D converters of the HCS12X and are preprocessed by the microcontroller. The microcontroller communicates with the Dynamixels via RS-485 at 1MBaud and with a main computer via a RS-232 serial line at 115KBaud. Every 12ms, target positions and compliances for the actuators are sent from the main computer to the HCS12 board, which distributes them to the actuators. The microcontroller sends the preprocessed sensor readings back. This allows keeping track of the robot's state in the main computer.

3 Perception

Our robots need information about themselves and the situation on the soccer field to act successfully.

• **Proprioception:** The readings of accelerometers and gyros are fused to estimate the robot's tilt in roll and pitch direction. The gyro bias is automatically calibrated and the low-frequency components of the tilt estimated from the accelerometers are combined with the integrated turning rates to yield an estimate of the robot's attitude that is insensitive to short linear accelerations. As described above, joint angles, speeds, and loads are also available. Temperatures and voltages are monitored to notify the user in case of overheating or low batteries.

• **Visual Object Detection:** The only source of information about the environment for our robots is their three cameras. Our computer vision software captures and interprets images with 752×480 pixels at an aggregated frame rate of about 32fps. The wide field-of-view of the central camera allows the robots to see their own feet and objects above the horizon at the same time. Two side-cameras have a narrower field-of-view of about 95°. They are heading ±40° away from the robot's central line. Our computer vision software detects the ball, the goals, the corner poles, and other players based on their color in YUV space. Using a look-up table, the colors of individual pixels are classified into color-classes that are described by ellipsoids in the UV-plane. In a multistage process we discard insignificant colored pixels and detect colored objects. We estimate their coordinates in an egocentric frame (distance to the robot and angle to its orientation), based on the inverted projective function of the camera. We correct first for the lens distortion and invert next the affine projection from the ground plane to the camera plane. Here, the objects detected by both cameras are fused in an egocentric view, based on their confidence. The objects are also merged with previous observations, which are adjusted by a motion model, if the robot is moving. This yields a robust egocentric world representation.

• **Self-Localization:** To keep track of non-visible goals, we need the robot coordinates in an allocentric frame ((x, y)-position on the field and orientation θ). We solve self-localization by triangulation over pairs of landmark observations, i.e. detected goals, goal posts, field markings, and the poles on the side lines. When observing more than two landmarks, the triangulation results are fused based on their confidence. The results of self-localization are integrated over time and a motion model is applied. As the field-of-view will be restricted to 180° in 2008, we also rely on the field lines for localization [4]. Oriented filters are applied to the green and the white images at two scales. Their responses are grouped to line segments. The center circle is detected and removed. The main orientation of the remaining line segments (modulo 90°) is estimated. For each of the two main orientations, up to two lines are detected in Hough space. The detected lines are matched to a model of the field lines for probabilistic localization.

4 Behavior Control

We control the robots using a framework that supports a hierarchy of reactive behaviors [1]. This framework allows for structured behavior engineering. Multiple layers that run on different time scales contain behaviors of different complexity. The framework forces the behavior engineers to define abstract sensors that are aggregated from faster, more basic sensors. One example for such an abstract sensor is the robot's attitude that is computed from the readings of accelerometers and gyros. Abstract actuators allow higher-level behaviors to configure lower layers in order to eventually influence the state of the world. One such abstract actuator is the desired walking direction, which configures the gait engine, described below, implemented in the lower control layers.

The framework also supports an agent hierarchy. For the TeenSize robots, we use three levels of this hierarchy: individual joint – body part – entire robot. This structure restricts interactions between the system variables and thus reduces the complexity of behavior engineering.

The lowest level of this hierarchy, the control loop within the Dynamixel actuators, has been implemented by Robotis. It runs at a high frequency. We monitor targets, actual positions, speeds, and loads. At the next layer, we generate target positions for the individual joints of a body part at a rate of 83.3Hz. We make sure that the joint angles vary smoothly. To abstract from the individual joints, we implemented here a kinematic interface for the body parts. It allows, for example, to independently change leg extension η, leg angle $\theta_{\mathbf{Leg}}$, and foot angle $\theta_{\mathbf{Foot}}$. On the next higher level, we use this leg interface to implement omnidirectional walking. Shifting the weight from one leg to the other, shortening of the leg not needed for support, and leg motion in walking direction are the key ingredients of this gait. The three basic walking directions can be smoothly combined. Our robots are able to walk in every direction and to change their heading direction at the same time. The gait target vector (v_x, v_y, v_θ) can be changed continuously while the robots are walking. This makes it possible to correct for deviations in the actual walking direction and to account for changes in the environment by using visual feedback. We used omnidirectional walking to implement basic soccer skills, like approaching the ball and dribbling. In addition to walking, we implemented kicking. More details on our hierarchical approach to reactive control can be found in [3].

5 Conclusion

At the time of writing, Jan 30th, 2008, we made good progress in preparation for the competition in Suzhou, China. In addition to the modified TeenSize 2007 robots, we intend to build a new TeenSize robot. We will play test games to select the best robot for RoboCup 2008.

The most recent information about our team (including videos) can be found on our web pages www.NimbRo.net.

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Team Members

Currently, the NimbRo soccer team has the following members:
- Team leader: Dr. Sven Behnke
- Staff: Michael Schreiber, Jörg Stückler
- Students: Martin Böhnert, Henrik Kretzschmar, Konrad Meier, and Hannes Schulz

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