Darmstadt Dribblers

Team Description for Humanoid KidSize League of RoboCup 2007

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Abstract. This paper describes the hardware and software design of the kidsize humanoid robot systems of the Darmstadt Dribblers in 2007. The robots are used as a vehicle for research in control of locomotion and behavior of autonomous humanoid robots and robot teams with many degrees of freedom and many actuated joints. The Humanoid League of RoboCup provides an ideal testbed for such aspects of dynamics in motion and autonomous behavior as the problem of generating and maintaining statically or dynamically stable bipedal locomotion is predominant for all types of vision guided motions during a soccer game. A modular software architecture as well as further technologies have been developed for efficient and effective implementation and test of modules for sensing, planning, behavior, and actions of humanoid robots.

1 Introduction

The RoboCup scenario of soccer playing legged robots represents an extraordinary challenge for the design, control and stability of bipedal and quadrupedal robots. In a game, fast motions must be planned autonomously and implemented online which preserve the robot's postural stability and can be adapted in real-time to the quickly changing environment.

The Darmstadt Dribblers participated in the Humanoid Robot League in 2004 for the first time and were the first German team to participate in the penalty kick competition. In RoboCup 2006 the joint Darmstadt Dribblers & Hajime Team achieved with a newly developed hardware and software in the three disciplines of the Humanoid KidSize League an excellent overall result in comparison with the 16 competing kidsize humanoid robot teams: 2nd place in the Technical Challenge, 3rd place in the 2-2 games, and 3rd place in the penalty kick competition. Our striker, the humanoid robot *Bruno*, scored 27 goals in total (16 in the 2-2 games and 11 in the penalty kick competition). Moreover, in each of the three competitions the team marked the best place of all kidsize teams which have been using directed vision and not circumferential vision with (almost) 360 degrees field of view at any time. Our robots cannot see ball, goal or opponents in their back! They have to coordinate their whole

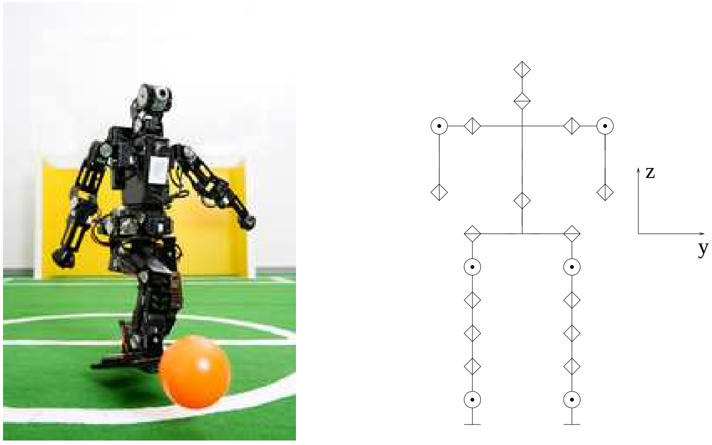

Fig. 1. Autonomous humanoid robot *Bruno* kicking a ball (left) and its kinematical structure (right).

body motions with the limited field of view of the directed cameras to recognize objects in their back, e.g., by turning around.

Although cameras with 360 degrees field of view or two wide angle cameras simultaneously looking forward and backward are still allowed in the Humanoid Robot League of RoboCup 2007, Darmstadt Dribblers decided to continue to focus on directed vision. This requires to develop a higher level of artificial intelligence[1] with active vision strategies in which the robot has to control its body parts to actively seek for objects of interest and to develop short- and long-term memory strategies to reconstruct a global view of the field of play. But also consumes much more of the precious computational resources available onboard of the humanoid robot than circumferential types of vision.

In RoboCup 2007 the Darmstadt Dribblers participate in the Humanoid Kid-Size League as an independent team with a further enhanced hardware and software based the achievements of previous years. The robots are equipped with onboard vision, perception and planning capabilities implemented on an embedded PC104 board as main onboard computer and two tailored, directed cameras. For postural stabilization control gyroscopes and accelerometers are used. The control architecture for autonomous behavior and high level functions is embedded in a software framework with exchangeable modules.

In the following sections a short overview of the specific research topics as well as of the hardware and software concepts of the Darmstadt Dribblers is given.

[1] R. Brooks: "Humanoid intelligence requires humanoid interactions with the world."

2 Research

The research of the Darmstadt Dribblers in humanoid robotics focuses on

- fast and stable humanoid locomotion, e.g. [1–3],
- alternative humanoid arm and leg kinematics using bio-analogue, elastic kinematics [4, 5] or artificial muscles [6],
- modular, flexible and reusable software and control architectures for cooperating and possibly heterogeneous robot teams [7, 8],
- clocked, hierarchical finite state automata for programming high-level behavior of autonomous robots [1, 9],
- modeling, simulation and optimal control of the full nonlinear dynamics of motion of humanoid and four-legged robots [10, 2] and of humans [11],
- a real-time software- and hardware-in-the-loop environment simulating humanoid robot kinematics and dynamics as well as external and internal robot sensors for evaluating any onboard software used for image interpretation and perception, localization and control of a humanoid robot [8, 12],
- humanoid perception and localization using two cameras with directed views: the articulated pan-tilt head camera offers a monocular view angle of 45 degrees to percept small objects in a farther distance whereas the fixed camera in the chest gives a peripheral and more diffuse view of the environment with an angle of 95 degrees. In combination the two cameras offer a binocular, variable-resolution view of the robot's environment according a human-close embodiment. The wide angle camera incorporates some of the properties of the outer area of the human eye like a rather blurred recognition of shapes. where as the narrow angle head camera can localize objects like the ball much farther away, thus resembling the more focused inner area of a human eye.

3 Hardware

The basic robot kinematics and hardware is based on the improvement of the humanoid robot platform developed jointly with Hajime Robotics Ltd. in 2006 (Fig. 1). The hardware, software and sensor equipment of the three identical kidsize humanoid robots of the Darmstadt Dribblers is described in Table 1.

4 Software

4.1 Framework and architecture

The base of the robot control software is the object oriented and platform independent framework *RoboFrame*. It has been developed to match the special requirements in small sized light-weight robots, both legged and wheeled. The framework provides flexible communication connections between the data processing parts of the applications, the so called modules. Currently packet and

Height [cm]:	55	
Weight [kg]:	3.3	
Walking Speed [m/s] (max.):	0.4	
Actuators:	Servo Motor DX-117 resp. RX 64	
Torque [kg-cm]	33.0	63.7
Speed [sec/60°]	0.126	0.186
Degrees of freedom:	21 in total with 6 in each leg, 3 in each arm, 1 in the waist, 2 in the neck	
Sensors:		
Cameras	Philips SPC 900 NC (head and chest)	
Resolution	160 x 120	
Color space	YUV	
Frame rate [fps]	15 (head), 5 (chest)	
Angle [°]	45 resp. 95	
Joint Angle Encoder	21	
Accelerometer	Crossbow, CXL04LP3, 3 axes rate 10 ms	
Gyroscope	SSSJ, CRS03-04, 3 axes rate 10 ms	
Control frequency [Hz]	100	
Microcontroller Board:		
Manufacturer	Hajime Research Institute Ltd.	
Processor	32bit μC SH2/7145	
Speed	50 MHz	
Onboard PC:		
Manufacturer	DigitalLogic PC/104	
Processor	AMD Geode LX800	
Speed	500 MHz	
Operating system:	Windows CE 5.0	
Network:	Wireless LAN, LAN	
Batteries:	Li-Po 14.8 V (motor), Li-Po 7.4 V (controller)	

Table 1. Technical data of the kidsize humanoid robot Bruno.

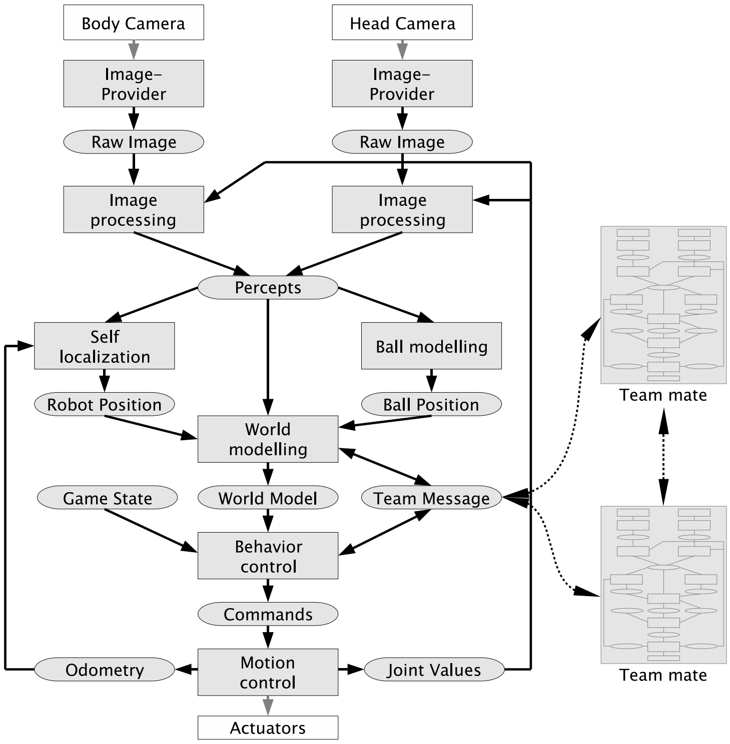

Fig. 2. Overview of modules (rectangles) and exchanged messages (ellipses) of the control software. White blocks are sensors or actuators, gray blocks are modules executed on the main onboard computer, a PC104.

shared memory based communication is possible. The connections are established during runtime with very little overhead, thus allowing to change the layout of the application very fast. Very different deliberative or reactive behavior control paradigms may be realized on the basis of RoboFrame.

For debugging and monitoring of the software, a graphical user interface based on the platform independent GUI toolkit QT is available. With the GUI it is possible to visualize any kind of data by extending the provided API. TCP based data connections to multiple robots are possible. For further details on the architecture, the framework and the modules see, e.g. [7, 8].

4.2 Current modules

At the moment mainly four interacting modules developed with the framework described above are used: vision, (world) model, behavior and motion (cf. Fig. 2).

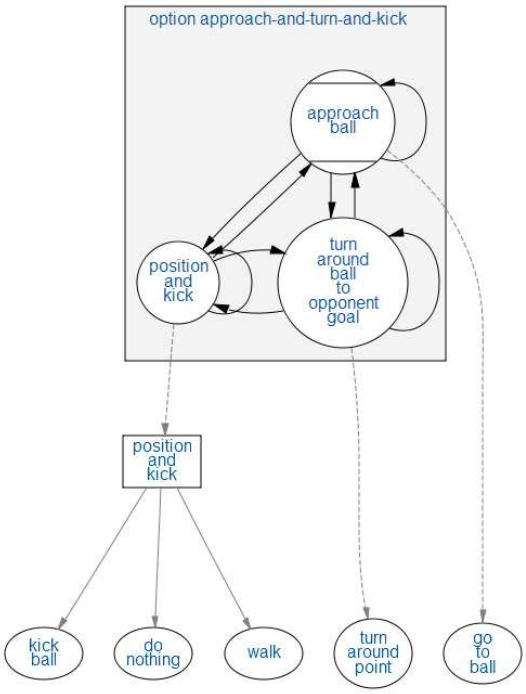

Fig. 3. A XABSL hierarchical state machine (gray) describing the behavior for approaching the ball and positioning towards the opponent's goal. When needed, basic behaviors (oval) or other state machines (rectangles) are activated.

Vision. To achieve a modular and extendable vision system for different camera types, the vision module can process images in different color spaces with different resolutions by choosing a highly object oriented approach which allows rapid prototyping of new image processors while providing the possibility for code optimizations for high computational efficiency. Image processing is split into two parts: a common pre-processing stage and several exchangeable modules for object recognition. Object recognition, done by so called perceptors, can work with multiple image types, such as pre-processed segmented or gray scale images, or the unprocessed raw image. This way, depending on the object and underlying recognition algorithms, the proper level of abstraction can be used by each perceptor while keeping the pre-processing efforts at the required minimum. The perceptors developed up to now detect field lines, line crossings, the ball, goals and poles.

(World) Model. The model uses the detected percepts from the vision module to update a world model. One part of the world model is a self localization, which is accomplished by Markov localization with particle filtering [13] tailored to the specific humanoid locomotion and perception using two different, directed camera views. All percepts calculated by the world model are used not only on the robot, but also exchanged between all robots in the scenario via wireless LAN. For inter-robot communication a fast, but less reliable UDP broadcast is used.

Behavior. The data provided by the model module is used to plan a more complex behavior such as it is required for playing soccer autonomously. The main task is separated into subtasks until they can be described as a set of atomic actions which can be executed by the humanoid robot. This is done by a hierarchical state machine described in XABSL [9], see Fig. 3 for an example. The basic motion actions are transferred to and interpreted by the motion module, other basic actions are processed in further modules.

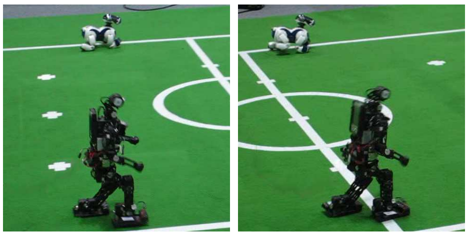

Fig. 4. Being the fastest walkin ghumanoid robot at the RoboCup 2006 Bruno was able to keep up with the optimized walking speed of an AIBO ERS-7.

Motion. The current motion module is mainly used to calculate walking trajectories using an inverse kinematics model and to control the neck joints with two DOF depending on the robot type. The control of the other joints in the arms is also possible, but used mainly for balancing aspects during walking or kicking. For walking the inverse kinematics engine takes three 6-dimensional reference points for pose (one in each foot, one in the hip) at a given time and calculates a 6-dimensional vector of joint angles for each leg. The inverse kinematics computation as well as the postural stabilization control are performed on the microcontroller board of the robot. The walking engine has been optimized by several parameters (e.g. different length and time variations during one stride) which can be altered at runtime [3]. Based on these methods a maximum walking speed of 40 cm/sec in permanent operation was achieved (cf. Fig. 4). From the accelerometer the robot detects if it has fallen down and to which side. The robot can stand up autonomously from lying on its back or its front side.

4.3 Team cooperation

Communication between the robots is used for modeling and behavior planning. If no ball is seen by a robot, it uses the ball position communicated by its team players to start its own ball search. In a similar way, the change of positions of opponents or team members can be realized.

Fig. 5. Cooperative team behavior during the 2 on 2 humanoid robot soccer game for 3rd place at RoboCup 2006: Both robots detect the ball, the left robot is closer to the ball, gets the role "striker" and continues to approach the ball while the right robot obtains the role "supporter" and steps back.

A dynamical behavior assignment is implemented on the robots in such a way that several field players can change their player roles between striker and supporter behavior. This change is based on their absolute field position and relative ball pose (cf. Fig. 5). The cooperative behavior of the robots is described in more detail in [8].

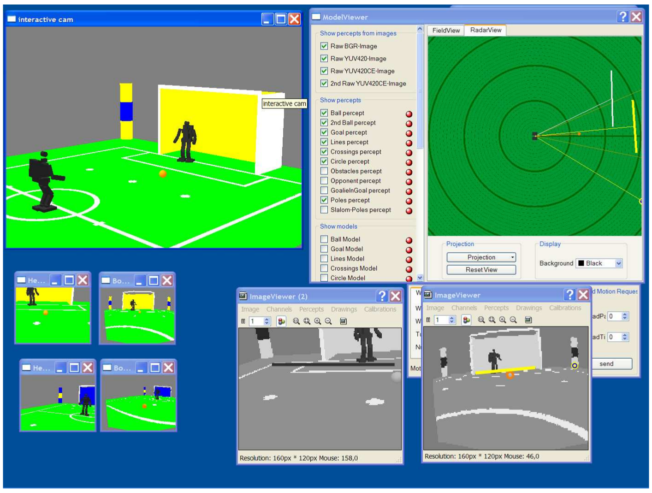

Fig. 6. Left: Simulation of motion and sensing of two humanoid robots, each equipped with an articulated camera in the head and a wide angle camera attached to the chest whose images are displayed below. Right: GUI of control application displaying the striker robot's percepts in robot centric coordinates and within the camera images.

4.4 Simulation

Developing and testing the key modules of autonomous humanoid soccer robots (e.g., for vision, localization, and behavior control) in software-in-the-loop (SIL) experiments, requires real-time simulation of the main motion and sensing properties. These include humanoid robot kinematics and dynamics, the interaction with the environment, and sensor simulation, especially the camera properties. To deal with an increasing number of humanoid robots per team the simulation algorithms must be very efficient. The simulator framework `MuRoSimF` (Multi-Robot-Simulation-Framework) has been developed which allows the flexible and transparent integration of different simulation algorithms with the same robot model. These include several algorithms for simulation of humanoid robot motion kinematics and dynamics (with $O(n)$ runtime complexity), collision handling, and camera simulation including lens distortion. A simulator for teams of humanoid robots based on `MuRoSimF` has been developed [12]. A unique feature of this simulator is the scalability of the level of detail and complexity which can be chosen individually for each simulated robot and tailored to the requirements of a specific SIL test. Currently up to six humanoid robots with 21 degrees of freedom, each equipped with two articulated cameras can be simulated in real-time on a moderate laptop computer.

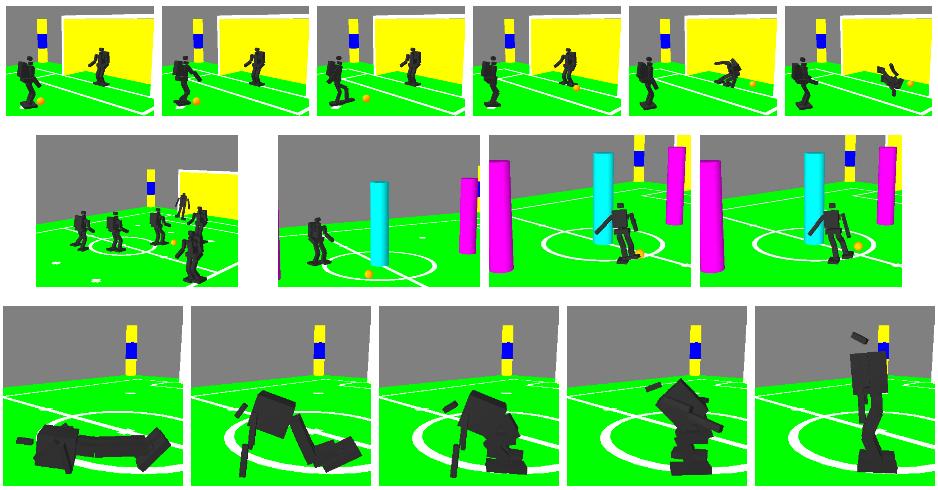

Fig. 7. Real-time SIL simulation for testing various modules for vision, localization and behavior control of humanoid robots. Top: Striker and goalie in penalty kick. Middle left: 3 versus 3 humanoid robot game. Middle right: Slalom challenge. Bottom: Robot standing up, simulated using the simplified dynamics algorithm.

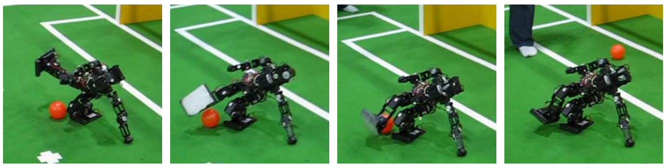

Fig. 8. Bruno is the first humanoid robot being able to perform a backheel kick and scored the first regular goal in this manner during RoboCup 2006.

5 Conclusion

The kidsize humanoid robots of the Darmstadt Dribblers are based on improved hardware and software which has evolved from the versions used by the Darmstadt Dribblers & Hajime joint team in 2006 [1]. Based on the results of RoboCup 2006, we expect the improved striker *Bruno* as well as the goal keeper *Jan* to be highly competitive challengers at RoboCup 2007 although they are using the challenging direct vision and not omnivision for perception.

The team *Darmstadt Dribblers* currently consists of students and researchers of the Technische Universität Darmstadt, namely Armin Berres, Astrid Wolff, Christian Conrad, Dirk Thomas, Dorian Scholz, Josef Baumgartner, Jutta Kiener, Karen Petersen, Marcus Schobbe, Martin Friedmann, Michael Wagner, Nicola Gutberlet, Patrick Stamm, Sasa Vukancic, Sebastian Jakob, Sebastian Petters, Simon Templer, Stefan Buhrmester, Stefan Kohlbrecher, Thomas Hemker, and Oskar von Stryk.

Further information including preprints of publications as well as videos is available online for download from our website `www.dribblers.de`.

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