Darmstadt Dribblers

Team Description for Humanoid KidSize League of RoboCup 2008

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Abstract. This paper describes the hardware and software design of the kidsize humanoid robot systems of the Darmstadt Dribblers in 2008. 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. In 2007 the Darmstadt Dribblers made it to the quarterfinals of the 2-2 games, where they were defeated by the later world champion in a very tight match which ended 6:8 (5:5, 6:6) after overtime. The technical challenge were completed with the fourth place (just 0.2 points after third place).

In RoboCup 2008 the Darmstadt Dribblers participate in the Humanoid KidSize League with further enhanced hardware and software based on the achievements of previous years. The robots are equipped with onboard vision, perception

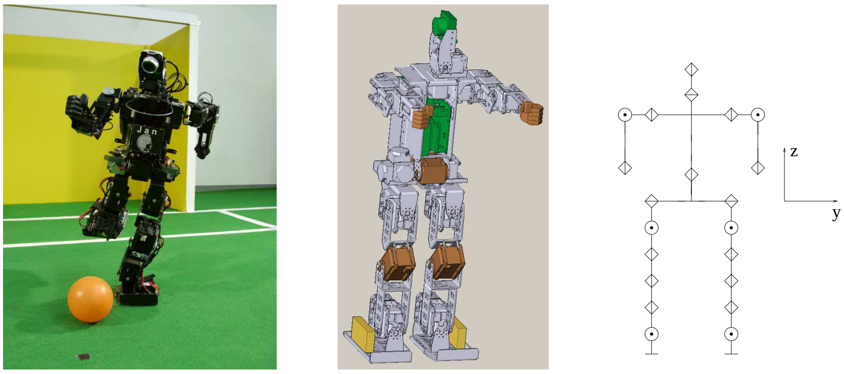

Fig. 1. Autonomous humanoid robot *Jan* (model 1) kicking a ball (left), CAD-drawing of new robot (model 2) (middle) and kinematical structure of both robots (right).

and planning capabilities implemented on an embedded PC104 board as main onboard computer and an articulated and (as in the years before) directed camera. 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.

2 Research Overview

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],
- 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 [11, 12],
- humanoid perception using an articulated, directed camera: The robots are equipped with a camera which is mounted on a pan-tilt-joint. To stabilize the camera's viewing direction during motion of the robot, additional gyroscopes are used.

3 Hardware

In 2008 two different robot designs will be used by the Darmstadt Dribblers. Both designs share the same kinematic structure with 21 DOF (Fig. 1). A similar feature is the distributed computing hardware consisting of a controller-board for motion-generation and stability control and an embedded PC board for all other functions. The technical data of both models are listed in the appendix.

Model 1 is a further improved version of the robot already used in 2006 in 2007. However, instead of using two directed cameras, one fixed in the chest and one articulated in thead, now only one camera is being used in the head but with a higher resolution and a wider aperture angle. Two additional gyroscopes were added to the robot's head to enable research in inertial stabilization of the robot's view.

Model 2 is based on a re-design of the mechanical motion system jointly developed with Hajime Research Ltd. where new motors have been used. Also the controller board is replaced by a stronger version to allow a higher communication rate with servos and main PC.

4 Software

The robots' control software consists of two parts. Hard real-time tasks like motion generation and stability control are executed on a microcontroller board. High level control like vision, world modeling, behavior control and team coordination is executed on a standard embedded PC board. Both parts of the control software communicate by a serial connection.

The development process for the software is supported by several tools including a graphical user interface (GUI) and a real-time simulation of the robots which can be used to transparently replace a real robot for software-in-the-loop (SIL) tests of the software.

4.1 Low-Level Control Software (Reflex Layer)

The main task of the low-level control software is the generation of stable walking motions in real-time. To ensure real-time performance it is executed on a microcontroller board allowing a 10 ms control-cycle. Motion generation is based on a inverse kinematics model of the 6 DoF robot's legs. For each time-step the pose of the robot's feet and hip is calculated and respective angles for the leg joints are calculated. The basic trajectories of hip and feet are based on ZMP-theory and can be parametrized and altered at runtime [1]. Stability control is based on the robot's gyroscopes. Readings of the gyros are used to generate balancing motions with the robot's arms and to calculate offset angles for the leg joints.

The walking engine's parameters (e.g. different length and time variations during one stride) are well suited for optimization. By applying black-box optimization a maximum walking speed of 40 cm/s in permanent operation was achieved [3]. 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. The low-level control software also includes several hardware related drivers and a main control function which is executed at the robot's control rate. For software-in-the-loop testing the control function can be re-compiled to a DLL which can be executed within the Darmstadt Dribblers' multi-robot simulator [11].

4.2 High-level Control Software (Cognitive Layer)

RoboFrame. 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 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]

Current modules. At the moment mainly four interacting modules developed with the framework described above are used: image procession, world modeling, behavior decision and motion control.

Image processing. 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 center circle, the ball, goals, poles and obstacles.

World modeling. The world model consists of a set of models which are updated by different modellings using the detected percepts from the vision module. One part of the world model is a self localization, which is accomplished by Markov localization with particle filtering [13]. Additional for nearly every percepted object a modeling exists, for example the ball and the obstacles. A selected subset of informations from the models is exchanged between all robots in the scenario via wireless LAN using an UDP broadcast. These informations are integrated into the various models, for example if no ball is seen by a robot, it uses the ball position communicated by its team players to start its own ball search. Additionally these informations are used in a role model to dynamically selected the different player roles of the field players.

Behavior decision. The data provided by the world model 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]. The basic motion actions are transferred to and interpreted by the motion module, other basic actions are processed in further modules.

Motion control. The current motion module is mainly used to calculate walking trajectories (see Sect. 4.1) and to control the neck joints with two DOF depending on the robot type. The control of the other joints in the arms is mainly for balancing aspects during walking or kicking.

4.3 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 efficient 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 [11, 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 ten humanoid robots with 21 degrees of freedom, each equipped with an articulated camera can be simulated in real-time on a moderate laptop computer.

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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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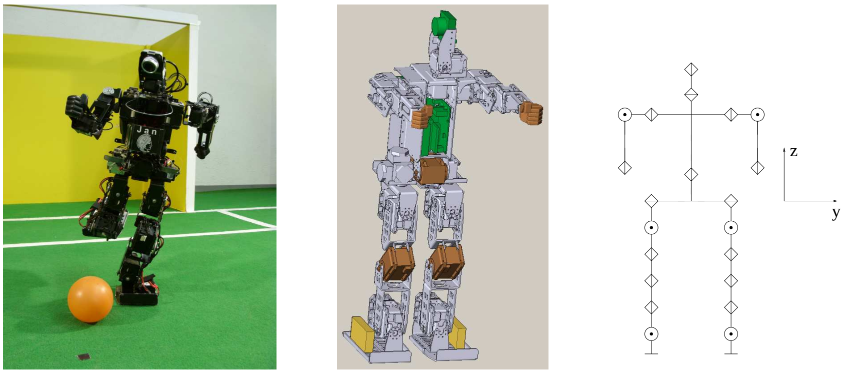

Autonomous humanoid robots *Bruno* and *Jan* kicking a ball (model 1, left), CAD-drawing of new robot (model 2, middle) and kinematical structure of both robots (right).

	Model 1	Model 2
Height [cm]:	55	57.5
Weight [kg]:	3.3	tbd
Walking Speed [m/s] :	0.4 (max.)	tbd
Degrees of Freedom:	21 in total with 6 in each leg, 3 in each arm, 1 in the waist, 2 in the neck	
Servo Motors:	18 DX-117 3 RX-64 (all from Robotis)	18 RX-28 3 RX-64
Sensors:		
Camera	Philips SPC 1300 NC	
Resolution	up to 1.3 MP	
Color space	YUV	
Frame rate [fps]	up to 90	
Angle [°]	80	
Joint Angle Encoder	21 (integrated in servos)	21 (integrated in servos)
Gyroscope (body)	Silicon-Sensing CRS03-04, 3 axes	Silicon-Sensing CRS03-04, 3 axes
Accelerometer	Crossbow, CXL04LP3, 3 axes	Analog Devices ADXL330, 3 axes
Control frequency [Hz]	100	100
Microcontroller Board:		
Manufacturer	Hajime Research Institute Ltd.	Hajime Research Institute Ltd.
Processor	32bit μC SH2/7145	32bit μC SH2/7211
Speed	50 MHz	160 MHz
Onboard PC:		
Manufacturer	DigitalLogic PC/104	
Processor	AMD Geode LX800	
Speed	500 MHz	
Operating system:	Windows CE 5.0, Linux	
Network:	Wireless LAN, LAN	
Batteries:	Li-Po 14.8 V, 1300 mAh	

Technical data of the two humanoid kid size robot models used by the Darmstadt Dribblers in 2008.