NimbRo 2004 Team Description

Sven Behnke, Norbert Mayer, Jürgen Müller, and Michael Schreiber

Albert-Ludwigs-University of Freiburg, Computer Science Institute
Georges-Koehler-Allee 52, 79110 Freiburg, Germany
{ behnke | nmayer | jmuller | schreibe } @ informatik.uni-freiburg.de
http://www.NimbRo.net

Abstract. This document describes the RoboCup Humanoid League team NimbRo of University of Freiburg.
It details the mechanical and electrical design of a humanoid robot, as well as robot simulation, perception, and behavior control.

1 Introduction

The project NimbRo - Learning Humanoid Robots - has been established at the Computer Science Institute of the University of Freiburg in January 2004. Its goal is to build humanoid robots, one robot each year for the next five years, in order to investigate various machine learning techniques in this challenging domain. The robots are supposed to demonstrate their performance in test beds such as the RoboCup soccer play and the work as a museum guide.

While for the museum guide the intuitive multimodal communication with visitors is most important, the RoboCup test bed focuses on robust and efficient bipedal locomotion and ball manipulation.

This document describes the current state of the project as well as the intended development for the 2004 RoboCup competition.

2 Mechanical Design

The 2004 NimbRo soccer team consists of a single robot only. It is designed for competition in the H120 size class of the Humanoid League. Its total height will be about 150cm.

The robot's skeleton is constructed from carbon composite materials to achieve a low weight of about 38kg. The hard skeleton is covered by soft materials to protect the robot in the case of falling.

The robot is designed to have a total of 22 degrees of freedom (DOF): 6 in each leg, 3 in each arm, and 4 in the trunk. It is planned to add more DOFs after RoboCup 2004 for the arms, hands, and the head to allow for multimodal communication.

The joints of the robot are driven by Faulhaber DC-motors of different sizes. They have integrated motion encoders and planetary 66:1 reduction gears. This reduction ratio should allow for a maximum step frequency of about 5Hz.

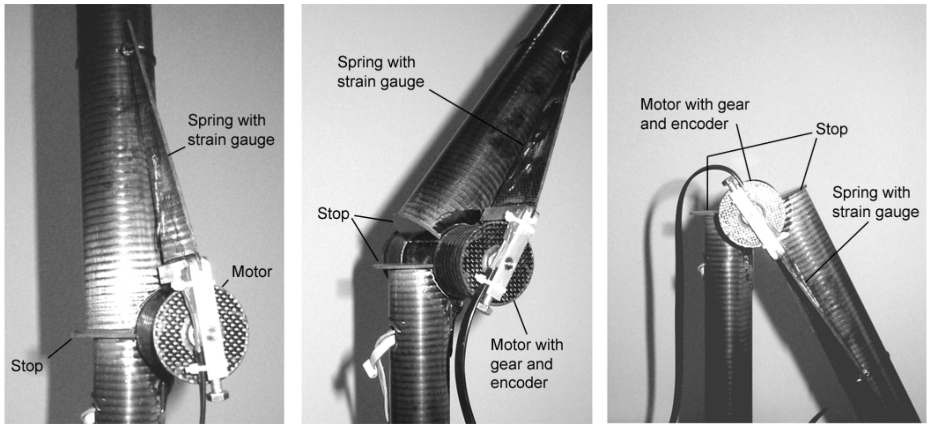


Fig. 1. Knee joint, constructed from carbon composite tubes and sheets. The DC-motor and the flat spring form a series elastic actuator [6]. The strain gauge measures the bending of the spring, which is proportional to the actuator torque.

The gear axis is not directly connected to the skeleton, but coupled by a spring, as shown in Fig. 1 for the knee joint. The spring works similar to a tendon between a muscle and a bone. Such a series elastic actuator arrangement [6] protects the gear from shock loads. It simplifies torque control and also allows for storing energy between gait phases. On the other hand, stiffness and bandwidth are compromised. These effects must be considered when designing motion control algorithms.

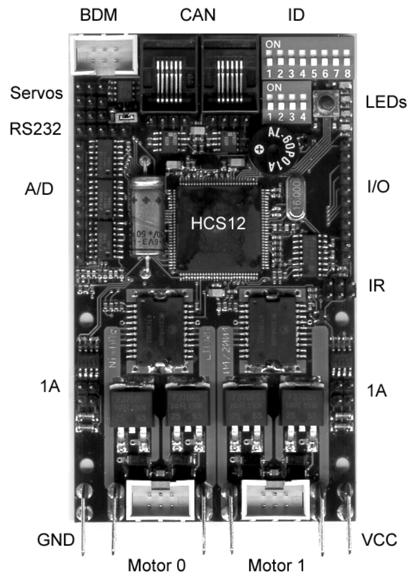
3 Electrical Design

The robot is powered by Ni-MH rechargeable batteries, located in the trunk. No chord to an external power supply is needed.

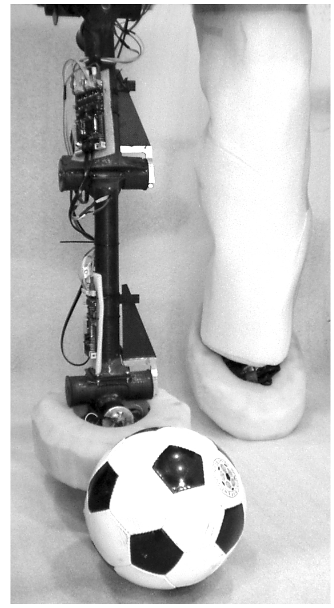
A subnotebook, also located in the trunk, will provide computational power. It will be connected via a wireless LAN to external PCs, via a Firewire interface to two Apple iSight cameras, located in the head, and via a CAN-bus to multiple microcontroller boards.

The microcontroller boards, shown in Fig. 2(a), are designed to control two DC-motors each. They are located throughout the body, close to the motors they control. Each board contains a Motorola HCS12 microcontroller, two high-current H-bridge motor drivers, and a CAN interface. The HCS12 has pulse width modulation (PWM) modules that are used to gradually drive the DC-motors. These modules can also be used to provide the target position for servos.

The motor position is measured by decoding the quadrature signals, generated by the motor encoder, to directional pulses, which are in turn counted by hardware pulse accumulators of the HCS12. In addition, a photo interrupter will provide an absolute position reference for initialization of the pulse integration.



(a)



(b)

Fig. 2. (a) HCS12 electronics board; (b) two legs (one exposed, one coverd with soft material) consisting of a 3DOF arm and a 2DOF foot each, attached to the lower part of the trunk.

The motor current is mirrored by the motor-driver ICs, converted to a voltage, and captured by the A/D-converter of the HCS12.

The torque of the joint actuator causes the spring to bend. This bending is measured by a strain gauge, attached to the spring, which is interfaced via an instrumental amplifier chip to the A/D-converter of the microcontroller.

One of the microcontrollers, located in the trunk, is connected to a two-axis accelerometer and two single-axis gyroscopes. The measured accelerations and rotational velocities are transmitted to the PC.

The two microcontrollers located in the feet measure the force between the ground and the foot using four force sensitive resistors (FSR) each and transmit these measurements to the PC.

4 Simulation

In parallel to the development of the physical robot a simulator for it is under construction. This simulator will be used for designing behaviors without having access to the physical robot.

After evaluating the tools Open Dynamics Engine (ODE) [8] and OpenHRP [4], we decided to use the NovodeX Physics SDK [5] for this purpose. This engine is intended to support the development of computer games in virtual 3D environments. Similar to ODE, it is capable of simulating rigid bodies, springs, and motors. In addition, it is able to compute collisions between large meshes.

5 Perception

The task of the perception module is limited to proprioception and balance support. The perception module is supposed to provide the state of the individual DOFs as well as the orientation of the robot relative to the ground as a basis for behavior control.

The state of the individual joints, consisting of position, velocity, motor current, and torque, is measured and aggregated by the microcontrollers. They transmit it to the PC at a rate of 30Hz. The PC combines the local measurements to a global state.

It is planned to combine three information sources in order to estimate the robot's attitude: force sensors on the feet that measure the load distribution, accelerometers and gyros in the head, and two cameras in the head which point forward. Two of these information sources are already in place.

The measurements of the accelerometers and gyros are fused to an attitude estimate by automatically calibrating the zero-motion bias of the gyros. The gyro bias is estimated by assuming that in the long run the accelerometers measure gravity. The same assumption is used to initialize the integration of rotational velocities to an attitude estimate.

The measurements of the FSR sensors in the feet are aggregated by computing the center of pressure within the foot area and the maximum over the sensor readings.

The two cameras provide streams of uncompressed 320×240 images in YUV-color space at a rate of 30fps. Algorithms are under development to extract optical flow, providing attitude changes, and to track the horizon (or horizon-like edges between the floor and a wall), providing an absolute attitude reference.

6 Behavior Control

It is planned to control the behavior of the robot in a semi-autonomous way. While low-level behaviors, such as balance and the maintenance of posture will be controlled autonomously, a remote control module will provide an interface for a human operator to guide the robot motion.

The implementation of the autonomous parts of the behavior control is currently done using a framework developed at FU Berlin that supports a hierarchy of reactive behaviors [1]. In this framework, simple behaviors are arranged in layers that work on different time scales.

The fastest time scale has been implemented on the microcontrollers at a rate of about 60Hz. The microcontrollers control the rotation speed of individual joints. All other layers are executed by the onboard PC. On the fastest PC layer, running at 30Hz, some test behaviors have been implemented, e.g. to balance the lower foot or to control the foot position using a joystick. These behaviors output target speeds for the individual DOFs that are transmitted via the CAN-bus to the microcontrollers that drive them.

Besides the time hierarchy, additional structure in the behavior control mirrors the structure of the robot's body parts. In this way, for instance, the 6 DOFs of each leg form a module, allowing for intensive communication within the leg and mediating communication to other body-parts.

Two major tasks of the behavior control system are the maintenance of balance and robot posture, and the generation of different dynamic gaits.

We plan to use reflex-like postural reactions [7] to prevent the robot from falling. Such reactions might be, for example, the making of a step to change the area of support when the robot appears to leave the current area of support or the unloading of a foot when it appears that the foot is not properly supported by the ground.

One important goal of the motion control is to utilize the dynamics of the system, e.g. to achieve dynamic walking. Similar to the passive dynamic approach to bipedal walking [3, 2], the NimbRo robot will have an oscillatory walking pattern which is inherent in its mechanical construction. If this pattern can be recognized and supported trough actuation, fast, elegant, and efficient walking should be possible.

7 Conclusion

At the time of writing, May 10, 2004, the construction of the robot has been started, but has not been completed. Individual body parts, such as two 2DOF feet, two 3DOF arms, and the lower part of the trunk are working and have been combined to two legs, shown in Fig. 2(b). The legs can be moved in a coordinated way using the behavior framework that also logs all relevant variables, such as motor positions and speeds. Some balance experiments have been carried out with a foot and a lower leg, combined with the accelerometers and gyros.

Other body parts, such as the 4DOF legs and the 4DOF trunk are still under construction. Much work remains to be done to have a walking humanoid robot for RoboCup 2004. While this implies a tight schedule, it might not be impossible. A revised team description paper will be provided after the competition.

Acknowledgements

Funding for the project is provided by Deutsche Forschungsgemeinschaft (German Research Foundation, DFG) under grant BE 2556/2-1 and Albert-Ludwigs-Universität Freiburg. Dr. Fritz Faulhaber GmbH & Co KG and Motorola Halbleiter GmbH provided additional support. The RoboCup team FU-Fighters provided the sources of a framework for implementing a hierarchy of reactive behaviors.

Team Members

Currently, the team has the following members:

- Team leader: Dr. Sven Behnke
- Staff: Dr. Norbert Mayer and Jürgen Müller
- Students: Thorsten Kramer, Tobias Langner, Holger Neub, Michael Schreiber, Sven Seuken, Jörg Stückler, Andreas Werber, and Rui Zhou
- Other contributors: Alexander Kleiner and Dr. Achim Liers

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