Dutch Robotics 2008 Teen-Size Team Description

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Abstract. This document describes the 2008 TUlip teen-size robot team of the 3TU (Delft University of Technology, Eindhoven University of Technology and University of Twente) and Philips. Our robot design is based on the limit cycle walking robots of the Delft Biorobotics Laboratory. The theory is that a stable, cyclic walking motion can exist without requiring high-bandwidth position control in the joints. Therefore, we have applied Series Elastic Actuation, which provides accurate force control. The control software (using Darmstadt's RoboFrame) runs on a PC104 computer with Linux Xenomai. For the vision, Philips has developed human-like miniature steerable eyes, the stereo output of which will be processed by means of an FPGA for hardware acceleration. Multi-body simulation tools are used for simulation of the low-level behaviour of the robot, i.e. walking motion, standing up, etc.

1 Introduction

RoboCup's main goal is to promote the development of human capabilities in robots. The required capabilities lie both in the cognitive domain as well as in the domain of motion control and execution. One fascinating motion capability of humans is that they can walk in a versatile and yet highly energy-efficient manner. Recently, we have been able to obtain human-like efficiency in robot walking [1-6], thanks to the development of the theory of "Limit Cycle Walking" [7]. Our main goal in participating in RoboCup 2008 is to demonstrate the limit cycle walking motion, and to test its robustness and versatility.

In addition to our walking robot research, our RoboCup robot will demonstrate our latest developments on human-like vision. The eyes, electronics and software were designed to mimic the appearance and functioning of the human vision system.

The goal of this document is to describe the engineering solutions for our RoboCup Teen-size soccer robot which is intended to participate in the competition in Suzhou, July 2008.

2 Mechanical Design

TUlip is a teen sized (1.2m, 15kg) 14 degrees of freedom (DOF) autonomous humanoid robot with 12 electrically actuated joints, see Fig. 1. This, combined with a non-restrictive design, allows for a large range of motion around the lower body joints. The hips each have 3 degrees of freedom which allow for 90º about their x and z axes, with more than 180º around their y axis[1].

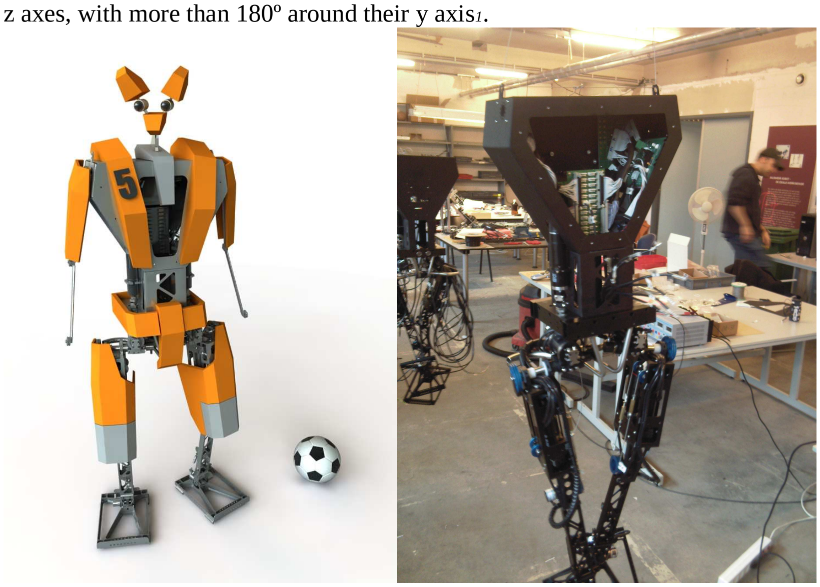

Fig. 1 CAD drawing of TUlip and photograph of TUlip assembly February 2008.

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[1] *N.B.* We took the X-Y-Z coordinate plane to be depth, width and height respectively of the robot, e.g. X is from front to back, Y is from head to 'toe' and Z is 'shoulder to shoulder'.

3 Walking

3.1 Limit Cycle Walking

Our walking research focuses on energy-efficient and human-like walking motions. This research is based on earlier research on Passive Dynamic Walking [8], which featured passive legged mechanisms that could walk down a shallow slope with no actuation or control. Their motion was naturally stable without requiring active control. Their energetic cost for walking is less than 0.1 Joules per unit of weight per meter traveled. Adding weak actuation [1,6] to the concept of Passive Dynamic Walking led to prototypes that walked on level ground with similar low energy use, in the same range as human walking but ten times more efficient [1] than the Honda Asimo [9]. Asimo and most other currently existing walking robots use high-bandwidth position control in all of the joints in order to accurately follow pre-defined trajectories. Position control, however, does not fit well with the purpose of walking. It does not matter much what the exact knee angle is, for example, as long as it bends sufficiently during the swing phase. We realized that we can trade position accuracy for efficiency by using force control. As a result, we could not design our robot with standard servo motors, but we had to design our own actuation system.

3.2 Joint Actuation

TUlip uses Series Elastic Actuation [10]; a spring is placed between the load and the motor (i.e., in the steel cable connecting the motor with the joint). The rotational difference between the motor and the joint (measured with two encoders) determines the spring expansion and thus the actuation torque.

The joints actuated trough series elastic actuation are the Ry (rotation about the y axis) of the knee, ankle and hip as well as the Rz of the ankle. All together, the robot uses 10 Maxon type RE30, three of which are located in each hip (Rx, Ry and Rz), one for each ankle and one for each knee and 2 Maxon type RE25 DC motors, for the shoulders, with HEDS encoders to actuate the joints. The Y- rotation of both hips, knees and ankles are series-elastic actuated with springs and Bowden cables.

An additional advantage of series elastic actuation is that it increases shock tolerance for the motor gearbox.

4 Electronics

4.1 Amplifiers and sensors

The MAXON motors are powered by ELMO WHISTLE 5/60 digital servo amplifiers which are PWM controlled by a PC104 stack plus a Mesa 4I65 Anything-I/O PCB running the Mesa Hostmot12 software on its onboard Xilinx Spartan-II 200k gate FPGA.

The hip, knee and ankle of both legs have 8 additional SCANCON encoders, which are connected to a second 4I65 PCB running a modified version of the Hostmot12 software on its FPGA. Each foot has four Tekscan Flexiforce pressure sensors in order to determine the center of pressure. The force sensors are interfaced using custom-designed ARM7 board, which is used to linearize the sensor's signals, and give pressure and position values to the central controller. Furthermore the ARM7 board is equipped with a 3D accelerometer used to determine the precise moment of impact of the foot with the floor or the ball. The foot electronics are interfaced to the main control system using a standard USB interface. These signals will be used for stability control together with an Xsens Mti sensor in the upper body.

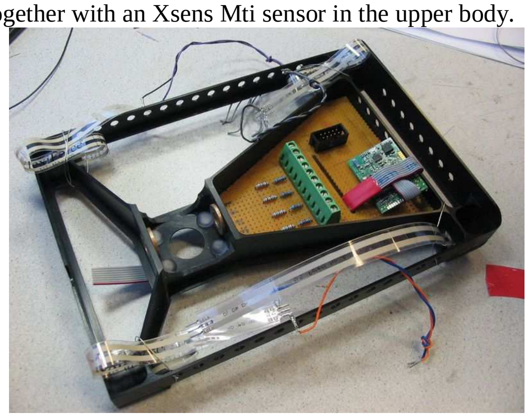

Fig 2. Foot equipped with pressure sensors and accelerometer board

4.3 Control System

Both Mesa 4I65 PCB’s and a 5VDC power supply are mounted on the PC104-Plus stack of an EPIC format sized Diamond Poseidon single board computer with a 1GHz Via Eden CPU. The Poseidon PCB also contains 512MB SDRAM, a 4GB Flashdisk and digital and analog I/O. All encoders are connected to a custom designed Encoder connection PCB, while the 12 Whistle servo amps are mounted on 2 custom designed PCB’s. To monitor the battery status we have a PCB with battery monitor IC’s that automatically switch off the power to prevent excessive discharge of the batteries.

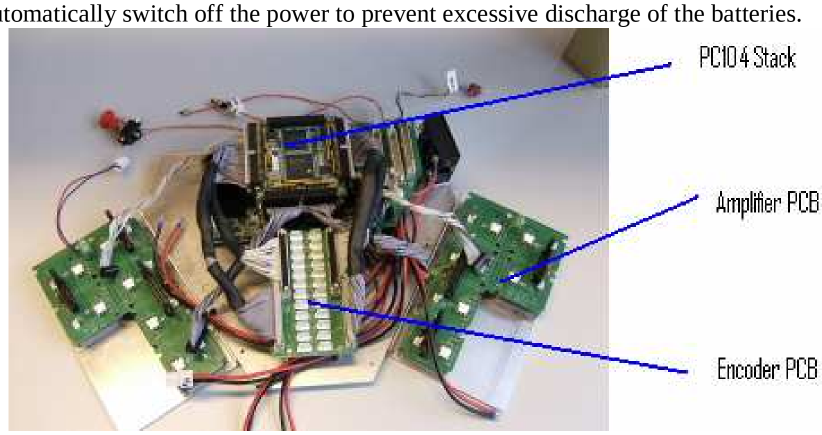

Fig 3. TUlip test setup with the CPU stack, encoder panel and servo

The computer is powered by a Kokam 3-cell 6 Ah LiPo battery, the motors by a separate 8 cell 26.4 Ah LiPo battery. Uptime with this setup should be about 30 minutes.

On the head we implemented a stereo vision system using special vision accelerating hardware from the Quantitative Imaging group of the TUD. On the Poseidon we run an Xenomai Linux build on Debian as RTOS platform. Linux drivers for the Mesa4I65 Anything-IO boards have been developed by the Embedded Systems group of the UT.

5 Software

5.1 Overview

The software system controlling TUlip is based on the concept of independent modules each performing their own specific task. The software architecture is based on the RoboFrame framework developed by the German Robocup team of Darmstadt Technical University [11]. This is a C++ based framework that provides a number of services to robot control applications such as module management, timers, intra and inter-process communication, a GUI template, and wireless UDP communication using 802.11g hardware.

As the current TUlip robots are partly based on principles learned from the TU Delft Flame biped some of the software design is similar. Flame uses a motion control based on hierarchical state machines. The state machines aid efficient concurrent design and implementation of the various behaviors used to control the robot.

To offer a particular service to the rest of the application a module needs to publish a well defined interface consisting of messages that can be transmitted using the communication facilities the RoboFrame supplies. An example of such an interface is the set of commands the motion module accepts from the rest of the system; each message indicates a particular type of motion with optionally a list of parameters.

The main modules present in the Dutch Robotics robots are Motion, Vision, Communications, World Model and Strategy. All these modules run on the Poseidon SBC.

5.2 Motion

The RoboFrame has no native software support for real-time platforms required for motion control. Therefore, this part of the system is implemented outside of the RoboFrame application, but still on the Poseidon SBC. There are no dedicated hardware control systems. For operational realibility, the motion control is implemented as a separate real-time process interfacing with an adapter module that is running inside the RoboFrame application. This RoboFrame module accepts commands from other modules (strategy) and relays those to the real-time process running the actual motion control. Sensor data from the motion controller is sent back through the adapter for use by the rest of the modules. This prevents disastrous motor behavior when a non real-time application (vision, and behavior modules) crashes.

5.3 World Model

The world model is responsible for maintaining information about the state of the external world. It receives sensor data from both the motion and vision modules, as well as information through the communications module. All other modules that need information on the robot state (attitude, position, viewing direction) depend on the world model. Strategy relies on the world model for performing autonomous control of the robots actions in the soccer field.

6 Vision

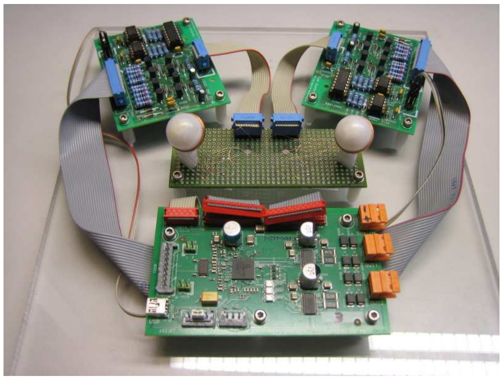

Fig. 4 Experimental setup of the eyes and the driving electronics

6.1 Eyes

Figure 3 shows an experimental setup of the eyes and the driving electronics. At the time of writing, we intend to use this setup in our TUlip robot. The head and neck as used on the robot are currently under construction. For a sense of scale: eye-to-eye distance is approximately 8 cm. The hardware in the picture was developed by Philips.

An important aspect of human eyes is their ability to move. It serves several purposes, including:

- stabilization to prevent motion blur
- increasing the effective resolution of the eye by pointing at and
- tracking interesting features
- communication with other humans

Stabilization is directly applicable to a walking robot. So is searching out and tracking interesting and relevant features in a large search space. The third reason, communication, is a rapidly developing robotics research field in itself. These reasons motivate us to develop a human-like vision solution with two actuated eyes.

The range of motion for the eye is approx 30 degrees from neutral in all directions, 60 degrees total. Speeds and accelerations match those of the human eye (roughly 100 deg/s and 10,000 deg/s2).

6.2 Head-Neck Assembly

The main function of the head is to support the two eyes. In addition it has been designed to look friendly and non-threatening. The design matches that of the robot exterior. In order to see its feet or objects to its sides the neck provides pan and tilt ability. An additional degree of freedom in the neck provides the ability to move the head forwards and backwards in a gesture indicating interest or fright.

The head is about 15 cm in height with a 5 cm neck. Ranges of motion are 120 degrees for pan, 100 degrees for tilt and a forward-backward stroke of about 3 cm.

Positioning is accurate to about 1 degree and speeds are such that the range of motion can be covered within one second.

6.3 Control

The stabilization algorithm takes orientation and acceleration data from the Xsens and counteracts head rotations and displacements. The saccade algorithm points the eye at salient features in the environment. The most challenging part here is the detection, selection and tracking in time of these features. The pursuit algorithm, finally, smoothly tracks a selected salient feature if it is moving. Again, the most challenging task here is visual.

6.4 Image Processing

The task of image processing is to determine the location of features in the world from the images produced by the cameras. Interesting features in a Robocup game are ball, goal, opponents, field markers and such. The vision software proceeds basically as follows:

- Apply lens distortion correction and epipolar alignment to the images
- Segment by color
- Detect features in segmented image
- Perform sparse stereovision on color-segmented features
- Combine many different hints gathered from the images to determine position in the world

In addition, there is the possibility of dense stereovision. This is computationally more expensive, but allows for instance the detection of the ground plane. This ground plane, with a known color, can then be used to provide on-line color calibration information for adapting to varying light conditions.

7 Simulation

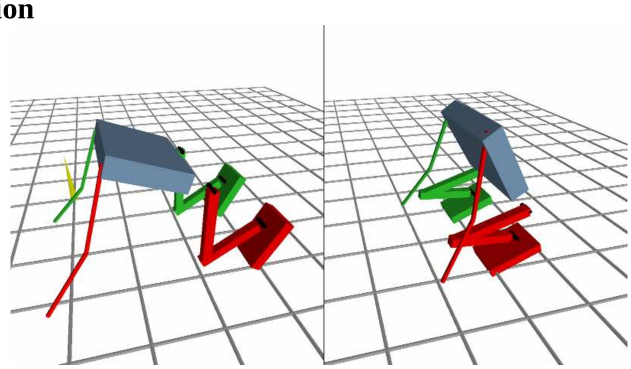

Fig. 5 Animation of the Tulip robot standing up in simulation

7.1 Introduction

In order to get up to speed with the proposed motion control of the TUlip robot, a dynamic simulation model has been made for testing algorithms and controllers for various robot tasks. Currently, simulations are available of basic movements such as standing up [5].

7.2 The Simulation Package

The simulation consist of a multi-body dynamics model of the robots mechanical structure, combined with detailed models of the used actuators (Maxon RE30 series), models of the used ELMO amplifiers, modeled discrete PID controllers and a separate DLL containing the setpoint generation. Eventually it will be possible to use the source-code of the DLL directly within the robot's control software. This enables several parties to write their controllers and testing them using simulation, before uploading them to the robot's control framework and doing the 'real world' testing.

The multibody-model is made in the 3D-mechanics toolbox of 20sim. This model uses screw-theory [12] and port-based modeling techniques, focusing on energy flow within the system.

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