

## Dutch Robotics 2011 Adult-Size Team Description

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**Abstract.** This document presents the 2011 edition of the team Dutch Robotics from The Netherlands. Our team gathers three Dutch technical universities, namely Delft University of Technology, Eindhoven University of Technology and University of Twente, and the commercial company Philips. We contribute an adult-size humanoid robot TULip, which is designed based on theory of the limit cycle walking developed in our earlier research. The key of our theory is that stable periodic walking gaits can be achieved even without high-bandwidth robot position control. Our control approach is based on simultaneous position and force control. For accurate force control, we make use of the Series Elastic Actuation. The control software of TULip is based on the Darmstadt's RoboFrame, and it runs on a PC104 computer with Linux Xenomai. The vision system consists of two wide-angle cameras, each interfaced with a dedicated Blackfin processor running vision algorithms, and a wireless networking interface.

### 1 Introduction

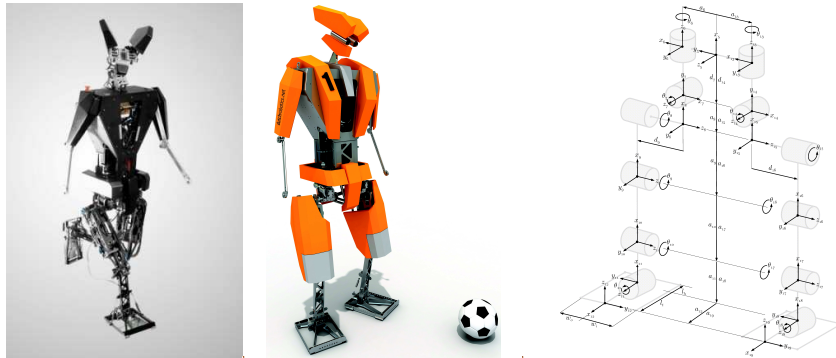
It is well-recognized that the annual RoboCup events promote the implementation of biomechanical analogies in robotics. One should in particular acknowledge importance of these events for development of humanoid robots that, year after year, feature more and more human-like capabilities. Besides human-like appearance and

kinematics, which are the most obvious links between humans and humanoids, these robots progressively acquire capabilities of humans that belong to the domains of cognition, motion control and execution. Especially appealing for implementation in robots is the locomotion ability of humans, having in mind its advantages in terms of versatility and energy-efficiency. Recently, we have demonstrated human-like efficiency in robot walking [1-6], thanks to the development of the theory of “Limit Cycle Walking” [7]. It is our ambition to demonstrate merits of this theory on our humanoid robot TULip at the RoboCup 2011. Besides research on bipedal walking, our RoboCup robot will demonstrate our latest human-like vision technology.

The purpose of this document is to introduce our humanoid robot TULip, which is intended for competitions in the Adult-size Humanoid League in Istanbul, 2011.

## 2 Mechanical Design

TULip is an adult sized (1.30 m, 19kg) 17 degrees of freedom (DOF) autonomous humanoid robot, see Fig. 1. All DOF's are electrically actuated. It is designed to feature a wide range of motions in the lower body joints. The hips each have 3 degrees of freedom which allow for  $90^\circ$  about their x and z axis, and more than  $180^\circ$  around their y axis.



**Fig. 1.** Adult-size humanoid robot TULip: photo, CAD drawing and kinematic configuration in the lower body.

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<sup>1</sup> N.B. We adopt X-Y-Z coordinates that correspond to depth, width and height of the robot, respectively: X is from back to front, Y is from right to left feet, and Z is from toe to head.

## 3 Walking

### 3.1 Limit Cycle Walking

Our research on bipedal locomotion focuses on design and experimental demonstrations of energy-efficient and human-like walking gaits. This research is founded upon the theory of Passive Dynamic Walking [8], which considers passive legged mechanisms capable of walking down a shallow slope without application of actuators or control. Since motions of such mechanisms are naturally stable, no active control is needed. Their energetic cost during walking is less than 0.1 Joules per unit of weight per meter traveled. Passive dynamic walkers are later on enhanced by weak actuators [1,6], leading to prototypes that can walk on level ground with energy consumption of the same range as human walking but ten times more efficient [1] than the Honda Asimo [9]. Asimo and the majority of the actual bipedal robots make use of high-bandwidth position control in all their joints for accurate tracking of the 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 promote idea of trading the position accuracy for power efficiency, by means of force control. To realize such an idea in practice, we do not actuate our robot with standard servo motors, but we 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 through series elastic actuation are the  $R_y$  (pitch rotation) of the knee, ankle and hip as well as the  $R_x$  of the ankle. In addition to allowing accurate force control, the series elastic actuation also increases shock tolerance for the motor gearbox.

Our robot TUlip is actuated with Maxon DC motors, three of which are located in each hip ( $R_x$ ,  $R_y$ ,  $R_z$ ), two in each ankle, one in each knee, and one in each shoulder. All the motors have optical encoders. Transfer of torque in the drive trains is done via planetary gearboxes.

## **4 Electronics**

### **4.1 Amplifiers and sensors**

The MAXON motors are powered by ELMO WHISTLE 5/60 and 20/100 digital servo amplifiers that are PWM controlled by a PC104 stack. In addition, there is 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 eight additional SCANCON encoders that 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 to determine position of the center of pressure. The force sensors are interfaced using a custom-designed ARM7 board, which linearizes the sensor signals and gives the pressure values to the central controller. Furthermore, the ARM7 board is equipped with a STMicroelectronics 3D accelerometer, which is used to precisely detect moments of impacts of the foot with the floor or with the ball. The feet electronics are interfaced to the main control system using a standard USB interface. Their signals are used as feedback information for walking stability control, together with readings from an Xsens Mti sensor in the upper body.

### **4.2 Control System**

Both Mesa 4I65 PCB's and a 5VDC power supply are mounted on a PC104-Plus stack of an EPIC format sized Diamond Poseidon single board computer with a 1GHz Via Eden CPU. The Poseidon PCB contains 512MB SDRAM, a 4GB Flashdisk, digital and analog I/O's. All encoders are connected to a custom designed connection PCB, while 12 Whistle servo amps are mounted on 2 custom designed PCB's.

The computer is powered by a Kokam 3-cell 6 Ah LiPo battery, the motors by a separate 8 cell 3.3V Ah LiPo battery. Uptime with this setup is about 30 minutes. A PCB with battery monitor IC's automatically switches off the power to prevent excessive discharge of the batteries.

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 University of Twente.

## **5 Software**

### **5.1 Overview**

The software control system of TULip is based on the concept of independent modules, each performing a specific own task. The corresponding software architecture is based upon the RoboFrame framework developed by the German RoboCup team of Darmstadt Technical University [11]. This C++ based framework 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 TULip robot is partly developed based on principles of the biped Flame, designed at the University of Delft, their software designs are similar. Flame uses a motion control based on hierarchical state machines. The state machines aid efficient concurrent design and implementation of the various behaviors for robot control.

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 supplied by the RoboFrame. An example of the interface is the set of commands the motion module accepts from the rest of the system; each message indicates a particular type of motion and, optionally, a list of parameters.

The main modules 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 reliability, the motion control is implemented as a separate real-time process interfacing with an adapter module which runs inside the RoboFrame application. This RoboFrame module accepts commands from other modules (strategy) and relays these 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**

### **6.1 Head**

The stereo vision system on the head is the Surveyor SVS, and it consists of two wide-angle camera modules, each equipped with a dedicated on-board Blackfin processor. LAN communication connects both cameras to the Poseidon computer. The processors run a firmware for detection of objects by color and extraction of 3D coordinates of these objects.

The head is connected to the body by three Dynamixel RX-28 motors giving three DOF's in the neck. The head-neck combination is about 15cm of height. Ranges of motion are 180° for panning, 100° for tilting and a forward-backward stroke of about 4cm.

### **6.2 Control**

The stabilization algorithm uses orientation and acceleration data from the Xsens to counteract head rotations and displacements. The saccade algorithm points the camera 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.

### **6.3 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 as follows:

- apply lens distortion correction and epipolar alignment to the images,
- segment by color,
- detect features in segmented image,
- perform sparse stereo-vision on color-segmented features,
- combine many different hints gathered from the images to determine position in the world.

In addition, there is a possibility of dense stereo-vision. This allows, for instance, detection of the ground plane. This ground plan can be used to provide on-line color calibration information for adaptation to varying light conditions.

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