Adult Sized Humanoid Robot: Archie

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Abstract. This paper describes our first adult sized humanoid robot Archie. This robot has been developed in conjunction with Prof. Kopacek's lab from the Technical University of Vienna. Archie uses brushless motors and harmonic gears with a novel approach to position encoding. Based on our previous experience with small humanoid robots, we developed software to create, store, and play back motions as well as control methods which automatically balance the robot using feedback from an internal measurement unit (IMU). This paper also describes our new inverse kinematics engine and the new parameterized motion controller, the main changes to the Archie in 2011. The paper also introduces Betty, the new upper body and face for Archie.

1 Introduction

Humanoid robots have always inspired the imagination of robotics researchers as well as the general public. Up until 2000, the design and construction of a humanoid robot was very expensive and limited to a few well funded research labs and companies (e.g., Honda Asimov, Fujitsu HOAP). Starting in about 2001 advances in material sciences, motors, batteries, sensors, and the continuing increase in processing power available to embedded systems developers has led to the development of many small humanoid robots, but also allowed the creation of the next generation of humanoid robots that are between 1.3m and 1.8m tall.

The creation of these humanoid robots also coincided with an increased interest in several high profile research oriented international robotics competitions (e.g., RoboCup [2] and FIRA [1]). The researchers chose robotic soccer as a challenge problem for the academic fields of artificial intelligence and robotics.

Robotic soccer requires a large amount of intelligence at various levels of abstraction (e.g., offensive vs defensive strategy, role assignment, path planning, localization, computer vision, motion control). Robotic soccer is a dynamic real-time environment with multiple agents and active opponents that try to prevent the robot from achieving its goal. These competitions allowed researchers to compare their results to others in a real-world environment. It also meant that robustness, flexibility, and adaptability became more important since these robots had to perform for extended periods of time in variable conditions. This is in contrast to researchers that could previously fine tune their system to the specific conditions in their laboratory. The inaugural humanoid robotics competition at RoboCup and at FIRA were held in 2002.

This paper describes ARCHIE, consisting of the legs and torso, and BETTY, consisting of the arms and the face of our humanoid robot. The two projects have different research goals, but are compatible, so that the two parts can be combined to form the complete ARCHIE.

2 Team Members

For the last eight years, the UofM Humanoids team is an important and integral part of our research into artificial intelligence, computer vision and machine learning. Various students and staff have contributed to the 2010 team and a comprehensive list would be too long. The following table lists the core team members of the UofM Adult Humanoids team.

Jacky Baltes	team leader	Peter Kopacek	team leader
Chi Tai Cheng	electronics	Andrew Winton	electronics
Stela Seoh	motion development	M.C. Lau	embedded development

3 Hardware Description

ARCHIE is a 1.4m tall humanoid robot. It has 22 degrees of freedom (DOF). There are seven DOFs for each leg: three DOFs in each hip, one in the knee, and three in the ankle. ARCHIE is one of the few humanoid robots that has activated toes, which allow it to roll over the foot when walking.

ARCHIE uses a novel modular joint design developed by Prof. Kopacek from the TUV. Each of the joints includes a motor, a gear box and one or two encoders. We are using two different types of motors in ARCHIE: DC motors and brush-less motors are the two types.

Each joint uses an independent controller which controls torque, velocity and position using three cascaded PID (proportional, integral, and derivative control) loops. Feedback for each joint is provided by current sensors and a special Hall based sensor. Three current sensors are used for controlling the torque loop. For position feedback we developed a novel approach which is based on Hall effect sensors and is described in the following subsection.

An overview of ARCHIE's control system is shown in Fig. 2.

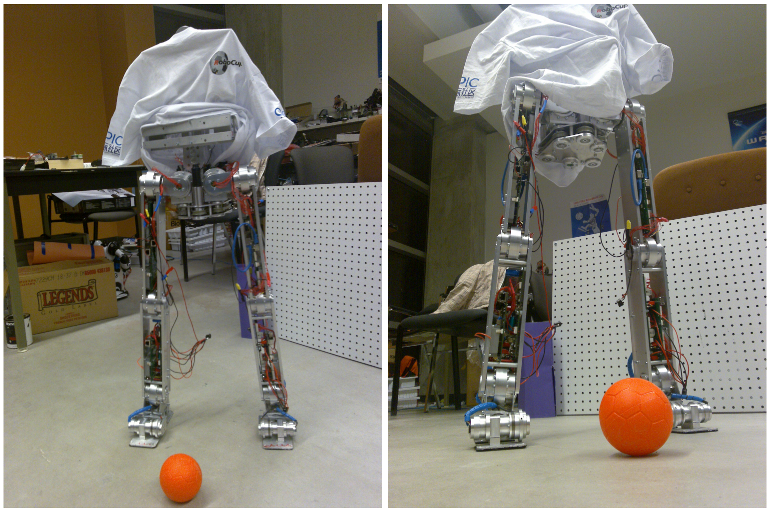

Fig. 1. ARCHIE adult sized robot

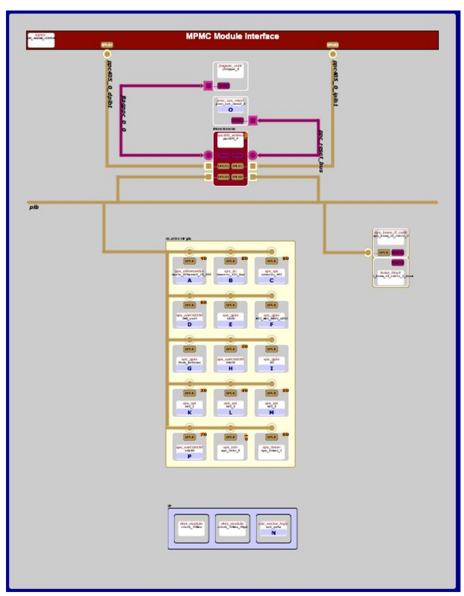

Fig. 2. ARCHIE: Block Diagram of ARCHIE's control system

3.1 Modular Joint Design

As shown in Fig. 3 for the harmonic gearbox we have two colored arrows. The red arrow represents the input and the black one shows the output of the harmonic gearbox.

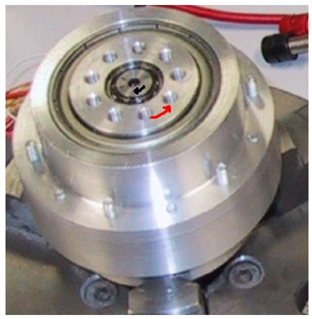

Fig. 3. ARCHIE: Modular Joint Design combining a brushless motor and a harmonic gearbox

The magnitude of these two arrows is related via the gearbox ratio. For our current model this ratio is 1:160. For a 360 degree revolution on the black arrow we require 160 revolutions of the red arrow, and trade off speed for torque.

In ARCHIE we are using three types of motors: brush-less motors, DC motors and RC motors. Some of the key benefit of using a brush-less motor in ARCHIE are increased efficiency and less noise of the motor. However, control of a brush-less motor requires more complex control logic, but allows for finer control. Given those advantages it would have been sensible to use only brush-less motors for ARCHIE, but to save cost, the joints that do not need to generate very high torque were implemented via DC motors.

3.2 Brush-less Motor Controller

We use a three phase brush-less motor power stage to control the brush-less motors. The power stage is connected to a CAN5 bus with a CANopen software layer. In this power stage we have a particular DSP that controls the PID loop to controlling torque, velocity and position in the Joint.

3.3 DC Motor Controller

This controller is based on a DSP processor that controls the torque, velocity and the position of the joint by driving an H-Bridge connected to the DC motor. Furthermore, a Hall based current sensor is used to measure the energy that is going to the motor to determine the torque. The output of this sensor is an analog signal, that is measured by a 10-bit ADC after an RC filter.

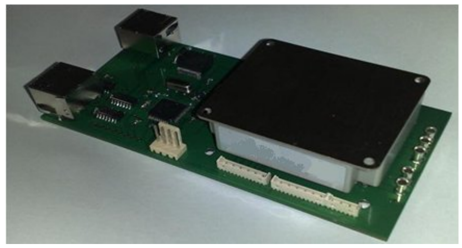

Fig. 4. ARCHIE: Brushless Notor Driver

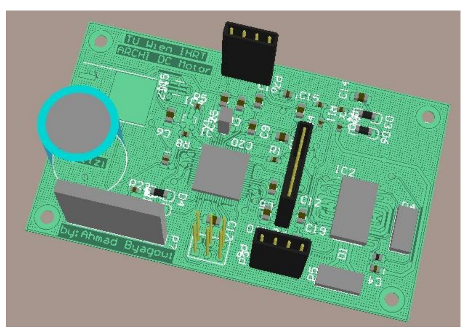

Fig. 5. ARCHIE: DC Notor Driver

3.4 Position Encoders On Start Up

Determining the absolute position is necessary for all motors that are used in ARCHIE except the RC motors. In the toe joint we have an incremental positioning system that is based on a zero point and requires that the motor is moved to a fixed position at start up.

Thereafter. the position will be determined using incremental encoders that are mounted on the motor. For the heel joint we use a permanent magnet and a Hall sensor based absolute encoder that gives us always the correct position of the joint. This design only needs to be calibrated once during construction.

3.5 Contact-free Position Encoders for Brushless Motors

The most common approach to determining the absolute position of the motor is to use end-switches. However, this approach requires the robot to move into possibly unstable positions at initialization, which is unsuitable for large and expensive adult sized humanoid robots.

Our method uses a special chip (AS 5134) that contains four Hall sensors, a flash analog to digital converter (ADC), an embedded micro-controller and a permanent magnet. The permanent magnet is mounted on the input of the gearbox. Each of the four Hall sensors has a different angle to the permanent magnet. We can thus measure the absolute angle between the chip and the permanent magnet. This implements a contact-free absolute encoder that provides pulses like an incremental encoder as well as an absolute position of the permanent magnet. The Hall chip is mounted on the output of the harmonic gear box and the permanent magnet is connected to the input of the gear box that is coupled to the rotor of the brush-less motor.

This system using four Hall sensors and a permanent magnet is able to determine the absolute angle of the output of the gearbox. However, the accuracy of this method alone is not sufficient to control the position with the required accuracy. The harmonic gearbox has a ratio of 160:1.

To improve the accuracy we extend our design by reusing the permanent magnet on the rotor of the brush-less motor to trigger a Hall switch mounted on the chassis of the brush-less motor. Therefore, the absolute position measured by the four Hall sensors can be improved by comparing it to the absolute position of the rotor.

One difficulty is that the absolute position when the Hall sensor is triggered moves because of the rotation of the motor. However, this rotation is determined by the gear ratio of the brush less motor.

The following formula shows allows us to determine the rotation measured by the Hall sensor given a complete revolution of the rotor:

$$\text{Sensor Angle} = 360^o + \frac{360^o}{r}, \text{ where } r \text{ is the gear ratio}$$

The sensed angle is the sum of two terms: the first term corresponds to one full revolution of the rotor and the second term corresponds to the movement of the output of the gearbox.

In our case, a gear ratio of 1:160 results in an additional term of 2.25^o.

Because of the rotation of the crossing point which is detected by the Hall switch, we can compensate for different values in the absolute sensor. These values are constant, and allow us to calculate the absolute position of the joint. On the other hand, we have a high resolution for the incremental encoder that is used to control the excitation of the brush-less motor.

3.6 Inverse Kinematics Engine and Parameterized Motion Controller

In 2011, we added a new flexible inverse kinematics (IK) engine. In our IK engine, the humanoid robot is modelled as a rigid body system with four independent chains that are anchored on the centre of the torso. The four chains are right hand, left hand, right toe, and left toe respectively.

Using the parameterized motion controller (see Fig. 6), the user can specify parameterized motions for each end of a kinematic chain. For example, the movement of a swing leg can be represented as an ellipsoid with parameters for the leg height and stride length.

Certain constraints can be implemented on joints (i.e., the fact that the annkle angle should be thus that the robot's foot is parallel to the ground.

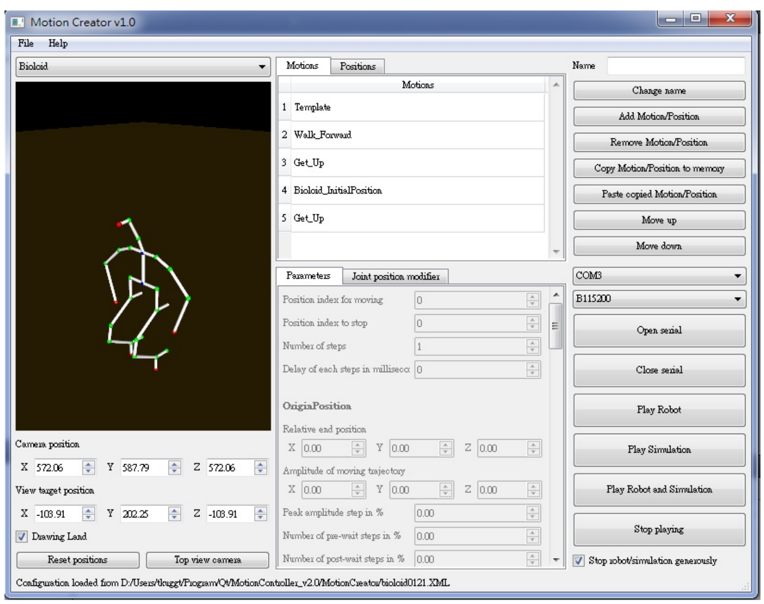

Fig. 6. ARCHIE: Parameterized Motion Editor

3.7 Upper Body: Betty

In 2011, we also completed the design of Betty, the upper body for Archie. Betty consists of two arms with 3 DOFs each, a head with three DOFs (e.g., pan, tilt, and sway), and a face with 5 DOFs (e.g., pan and tilt in each eye and the mouth).

Betty uses Robotis Dynamixel RX-64 servos for the arms and Robotis AX12+ servos for the head. The head contains a stereo vision system consisting of two Logitec Orbit Sphere webcams, which have built in pan and tilt.

Betty is used for research in human robot interaction. At the moment, we implemented drumming and portrait drawing as sample applications as shown in Fig. 7.

Fig. 7. Betty: Upper body and face robot acting as portrait artist and drummer

4 Conclusion

This paper describes the hardware and control electronic of Archie, a adult sized humanoid robot. Archie uses brush-less motors and novel methods to implement absolute position encoders.

References

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