# Teen Sized Humanoid Robot: Archie

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**Abstract.** This paper describes our first teen 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).

## 1 Introduction

This paper describes our new 1.2m tall humanoid robot ARCHIE, a collaboration between the labs of Prof. Kopacek from the TU Vienna and Prof. Jacky Baltes from the University of Manitoba.

## 2 Team Members

For the last six 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 2009 team and a comprehensive list would be too long. The following table lists the core team members of the UofM Teen Humanoids team.

| | | | |
|---|---|---|---|
| Jacky Baltes | team leader | Peter Kopacek | team leader |
| Ahmad Byagowi | electronics | Jonathan Bagot | active balancing |
| Shunjie Liu | motion development | David Schwimmer | path planning |
| Nicole Storen | motion control | Yunhsiang Sun | embedded development |
| Michael De Denus | coordination | Jeff Allen | path planning |

# 3 Hardware Description

Archie is a 1.2m 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.

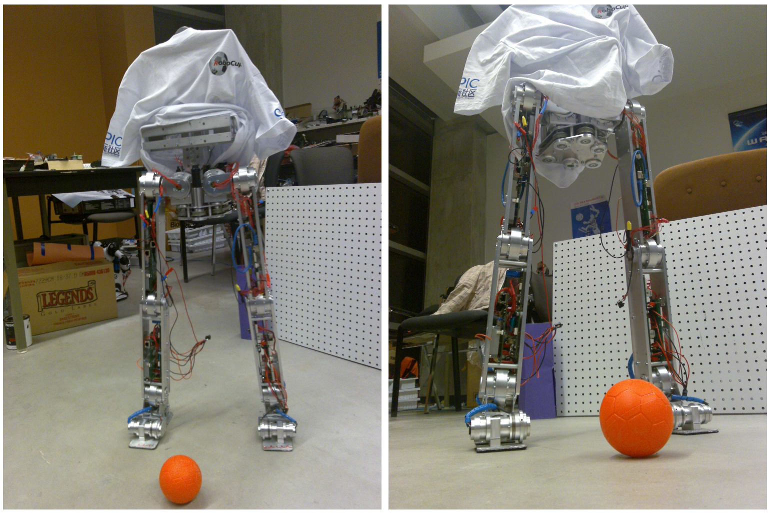


**Fig. 1.** ARCHIEteen sized robot

## 3.1 Modular Joint Design

As shown in Fig. 2 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.

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.

**Fig. 2.** ARCHIE: Modular Joint Design combining a brushless motor and a harmonic gearbox

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.

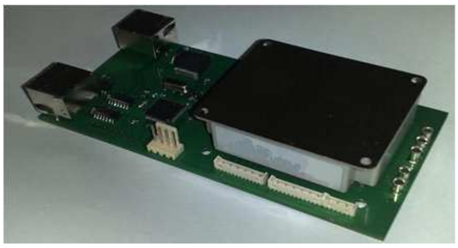

**Fig. 3.** Archie: Brushless Notor Driver

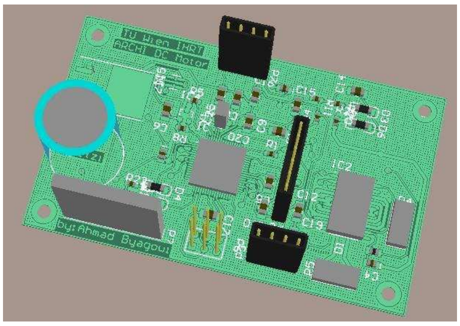


**Fig. 4.** Archie: DC Notor Driver

### 3.4 Spinal Processing Unit (SPU)

The SPU is responsible for motion control and balancing of the robot. We use a Virtex-4 family FPGA from Xilinx, which contains a hardcore PowerPC 405 processor.

The FPGA also contains custom hardware to control the inertia measurement unit, which provides us with angular velocity and linear acceleration for 3 axis each. The robot uses an inverted pendulum model and ZMP control to balance the robot.

Moreover the SPU includes three Master SPI units implemented in hardware FPGA that are connected to the RS422 physical layer. These three communication buses control the left leg, right leg, and torso respectively. each of these buses has a maximum of 7 clients. This limitation comes from the communication protocol that is used for data exchanging between the motor controller and the SPU.

The SPU also provides internal diagnostics and fail-safe tests to make sure that he robot's operation is safe.

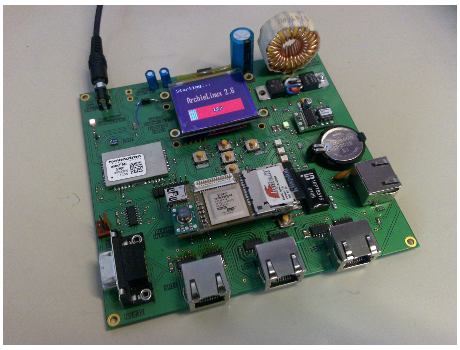

**Fig. 5.** ARCHIE: Spinal Processing Unit

### 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 teen 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.

## 4 Conclusion

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