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BunnyBot: Humanoid Platform for Research and Teaching

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Abstract. This paper introduces a cost effective humanoid robot platform with a cluster of 5 ARM processors that allow it to operate autonomously. The robot has an optical foot pressure sensor and grippers all compatible with a Robotis Bioloid. The paper also presents a kinematic model of the robot. Furthermore we describe how the robot uses a complementary filter which combines accelerometers and gyroscope readings to get a stable tilt angle.

Keywords: Inertial Measurement Unit, Complementary Filter, Bipedal Humanoid Robot, FIRA, RoboCup, Motion Control, Bioloid

1 Introduction

In recent years several humanoid platforms have come onto the market aimed at consumers, education and hobbyists [1]. The height of these humanoids is around 0.3m. Some of these platforms have the potential to be extended for research by adding more sensors and computational power. Much of the fundamental work in humanoid robotics can be carried out with these cheap miniature humanoids. This paper will present the development of a miniature humanoid at the University of Plymouth. Firstly an overview of the hardware components is given in Sections 1 and 2. Section 3 introduces the sensors and actuator designs. Section 4 describes the kinematic model of the humanoid. Section 5 concludes with suggestions for future work.

1.1 Purpose

The BunnyBot humanoid platform has been designed with three main purposes in mind: *1. creating an affordable humanoid platform, 2. To advance teaching and* *research at the university and 3. To create a competition platform*. Because of the fairly low cost of the robot (£ 2000 GBP), the university will be able to build enough humanoids for teaching a whole class room. The robot has servos for moving head, eyes and ears. By adding a mouth and eye brows it will be possible to produce facial expressions. The head is in form of a cartoon-like bunny rabbit, hence the name BunnyBot. The idea is to avoid the uncanny valley problem. Cartoon-like features and exaggerated facial features are more likely to be judged friendly [2] and therefore ease human-robot interaction.

The BunnyBot platform has been developed to be compatible with the rules of FIRA HuroCup 2009 [3] (small category < 50cm height) and RoboCup Humanoid League (KidSize <60cm).

1.2 Overview of BunnyBot

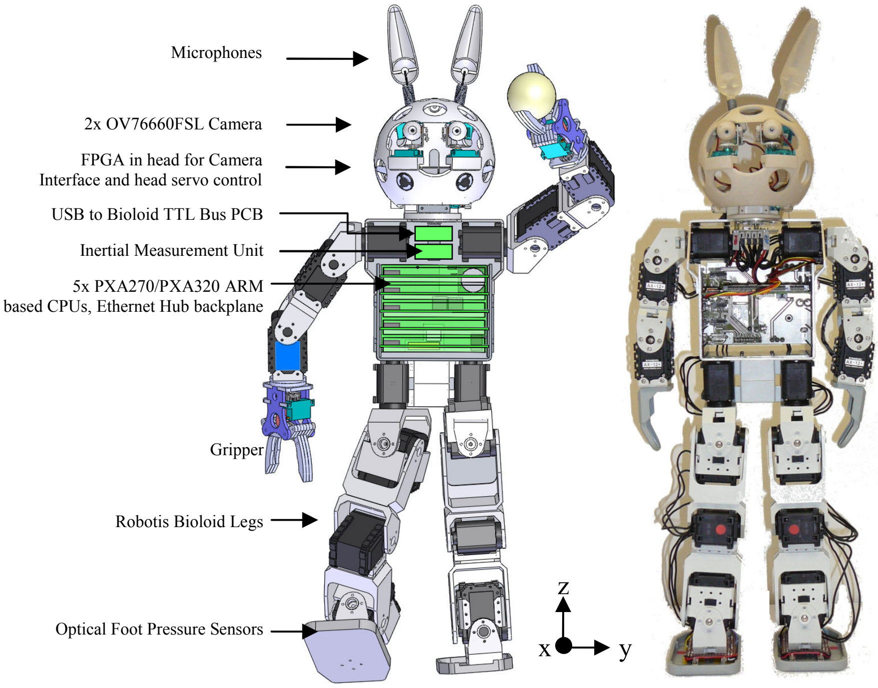

Fig. 1. BunnyBot CAD model left, BunnyBot Photo right. BunnyBot has 8 degrees of movements in the head + optional 4 facial servos (not shown here) and 18 degrees of movement in the body. The batteries can be fitted in front of the hips or in place of the 5th processor board. The total weight of the robot is 2.4 kg.

This robot is based on a commercial Robotis Bioloid robot. The torso of the Bioloid has been completely replaced; grippers and foot pressure sensors have been added.

2 Distributed Processing

Other teams such as Humanoid Team Humboldt [4], NimBro [5] and UofM Humanoids [6] have also used Bioloid Robots combined with handheld computers. A previous version of our teams FIRA competition robot also had a handheld computer [7]. We are going a step further and integrating 5 handheld-type CPUs onto one robot. These 5 CPUs are from the Marvell XScale family (former Intel) based on a ARMv5TE core. The XScale family has no floating point instructions. The XScale PXA270 with 520MHz and PXA320 with 806MHz. Each processor has 64MB RAM and 32MB Flash (PXA270 – 500MHz) or 128MB RAM and 64MB flash (PXA320 – 806MHz) and draws 350mw of power. The XScale processors are on a SO-DIMM type connector and can be purchased from Toradex (www.toradex.com). These SO-DIMM modules plug into a motherboard for breakout connectors. For future work we are developing a motherboard with an OMAP3530 (600MHz) which will be used for SLAM processing in Linux.

2.1 Mainboard Cluster

Five miniature processor PCBs and one FPGA provide the hardware and software support for the robot. They are mounted as motherboards with 91mm width and can then be inserted into a small card-cage in the body of the robot. All five processors communicate via Ethernet on the Backplane. The backplane also contains a USB hub for host (PC) communication.

The processors provide the following services:

1) Moton Control and host communications [PXA270]
   a) Direct control of servos
   b) WiFi link (IEEE802.11b) Spectec SDW-823 SD Card
2) Central Planning and Action control [PXA270]
   a) Planning, memory and sense of time
   b) TCP client to other processors
3) Vision – face recognition [PXA320]
   a) Runs Viola and Jones object recognition [8] with the first 3 filters in the FPGA (planned)
4) Vision – stereo and SLAM processing [PXA320]
   a) Mono camera SLAM [9] partly with PFGA based feature detection (planned)
5) Audition – sound output and stereo input from ears [PXA270]
   a) Stereo hearing processed and sent to host PC via WiFi (processor 1) for speech recognition processing

An Altera Cyclone III (EP3c25F256C8N) FPGA chip was placed into the head of the robot in order to offer local pre-processing of the video streams coming from the cameras, such as colour blob tracking. The FPGA chip generates PWM signals for the analogue head servos. The head has SuperTec TITCH-44 servos, since they are the smallest servos (4.5g) for a competitive price. Furthermore a 2-axis gyro is also processed by the FPGA to allow eye gaze stabilisation.

An XScale processor features a USB-host. A FTDI USB-to-Serial chip was used for communication with the Robotis AX-12 servos.

3 Sensors and Actuators

3.1 Novel Foot Pressure Sensor

A foot pressure sensor was developed to explore balance control. The sensor measures the pressure in four points (figure 2) providing information on the total force vertical applied onto one foot (F_z) and the moments in the forward-backward direction (M_x) and in the left-right direction (M_y). This allows determining the projection of the centre of mass of the robot onto a plane normal to the gravity vector.

The pressure is measured by suspending the BunnyBot foot on leaf springs modeled as cantilever beams. The deflection of the springs causes a displacement which is measured using reflective IR light sensors (Honeywell HOA1397-002). When the robots leans forward, the leaf springs are loaded more in front and the two front sensors have a smaller distance to the foot sole. The sensors have the characteristics that for distances to a reflective surface of less than 1.2 mm, the signal increases quasi-linearly with the distance. The potential on the phototransistor varies between 0.4V and 4.8V, given a power supply of 5V. This is a large variation that can easily be read with standard analogue inputs of microcontrollers.

The springs are two strips of stainless steel (1.6mm x 5.5mm x 90 mm) attached to the sole of the BunnyBot with 4mm spacers.

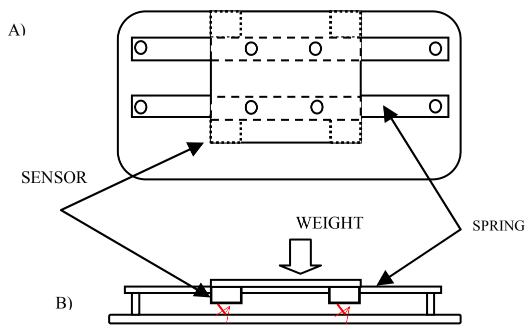

Fig. 2. A) Top view of the sensor arrangement on a Bioloid/BunnyBot foot-plate. B) Side view.

3.2 Inertial Measurement Unit with Complementary Filter

The BunnyBot has a 6-axis IMU (inertial measurement unit) that consists of a 3-axis gyroscope and a 3-axis accelerometer. Data from this type of sensors is noisy and has drift. The usual solution to unite two noisy sensor readings into one low-noise signal is the Kalman Filter [10], which uses variable reliability on each sensor according to the user's input. The complementary filter is a simpler approach to sensory fusion [11]. The complementary filter works without a user input, all it needs is the noisy data from both sensors and a cut-off frequency set at the beginning of the operation.

The main advantage of the complementary filter is that it is much easier to code than the Kalman filter and uses a lot less processing power. The solution is to combine both sensors by applying a low pass filter (LPF) on the gravity vector angle, thus removing the noisy jerk response, and a high pass filter (HPF) on the gyroscope, thus removing the drift. A special case of the complementary filter has been implemented by following the method that was briefly described in Kumagai and Ochiai [12]. The initial equation is given by:

$$LPF[\theta_a(s)] + HPF[\theta_g(s)] = 1 \quad (1)$$

This means that the amplitude of the signal θ is split into two components coming from accelerometer and gyro. The frequency spectrum of the two filters always adds up to a gain of 1. In the time domain, the output is the amplitude of θ is

$$LPF[\theta_a(t)] + HPF[\theta_g(t)] = \theta_y(t) \quad (2)$$

However, a further implementation was derived for this filter in order to reduce the number of multiplications during the processing time. A high pass filter can be written as:

$$HPF[\theta_g(t)] =1- LPF[\theta_a(t)] \quad (\mathbf{3})$$

Therefore by changing eq. [3] into eq. [2]:

$$LPF[\theta_a(t)] -LPF[\theta_g(t)] +\theta_g(t)=1 \quad (4)$$

The 'Gyro' component of eq. [4] is the Gyro input without filtering. Eq. [4] can be further simplified into:

$$LPF[\theta_a(t)-\theta_g(t)] +\theta_g(t)=1 \quad (5)$$

This reduces the number of multiplications necessary.

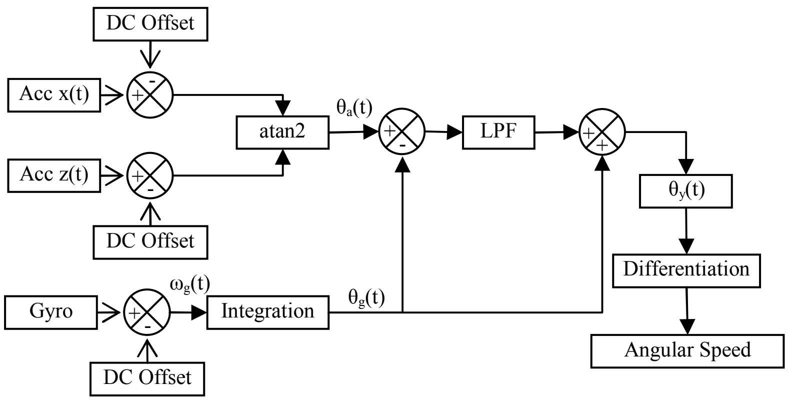

Fig. 3. Complementary filter to determine the robots attitude $\theta_y(t)$.

3.3 Robust Gripper Design

The gripper was designed to fulfil two purposes; to be able to pick up randomly folded cloth for a research project [13], as well as being able to hold a 40mm diameter ball for the FIRA HuroCup. For the first purpose a rotating wrist axis was included, so that the gripper could be lined up square to a cloth fold. In order that the fingers were less likely to interfere with the cloth during the action of gripping, the fingers were made pointed.

The gripper was rapid prototyped using 3mm acrylic sheet, cut by a CNC laser cutter. Consequently, for the second purpose, a composite of three layers was made for the fingers with the middle layer being smaller than the outer two such that the surface of the ball made contact with the outer fingers. This made it less likely that the ball would slip sideways out of the gripper.

Aesthetic considerations dictated that the overall size of the mechanism should be in proportion to the rest of the BunnyBot. This meant that the servos needed to be arranged in a manner that minimised wasted space. A design criterion connected to a potential use of the BunnyBot in competition was that parts should be easily changeable, such as a different finger design for better ball handling. This, in conjunction with the difficulty of assembling the small size required, meant that a square dovetail method was used to connect the top and bottom to the sides. Weight was also reduced by adding holes to the larger flat surfaces.

One further consideration was that the servos, being the most expensive parts, needed protection from sudden loading, such as might come from the BunnyBot falling over. For this reason the gripper was held shut with a spring and the fingers moved apart with a cam and follower mechanism.

4 Kinematic Model

A forward kinematic model gives the robot the ability to calculate the position of its limbs in relationship to the torso, given the current joint angles. This can be useful for motion planning, determining its current centre of mass and deriving the inverse kinematics. The kinematic model given in the tables below is only slightly different from the original Robotis Bioloid, which makes this model interesting to a wider audience. The hip servos 7 and 8 have been mounted the other way round (see figure 1) and the distance between the arms and the legs may be different. The following model follows the Denavit-Hartenberg parameters and the frame assignment conventions as laid out by Craig [14]. The order of multiplication to go from one joint to the next joint is:

1. Rotate around the x-axis of the reference frame with angle α
2. Move along x-axis of the reference frame a distance ℓ
3. Rotate around the new frame's z-axis with angle θ
4. Move along the z-axis with distance d

This gives a homogeneous transformation matrix given in formulae 3.

$$A_{\mathrm{New}}^{\mathrm{Ref}} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 & \ell \\ \sin(\theta)\cos(\alpha) & \cos(\theta)\cos(\alpha) & -\sin(\alpha) & -\sin(\alpha)*d \\ \sin(\theta)\sin(\alpha) & \cos(\theta)\sin(\alpha) & \cos(\alpha) & \cos(\alpha)*d \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (6)$$

For instance, to calculate the position RHND(x,y,z,α,β,γ) of the right hand of the bunny robot with respect to the centre C(x,y,z,α,β,γ) we first need to multiply all transformations from the tables given in the Appendix.

$$A^{C}_{RHND} = A^{C}_{1} \quad A^{1}_{3} \quad A^{3}_{5} \quad A^{5}_{\mathrm{RHND}} \tag{7}$$

The origin of the coordinate system C(x,y,z) where the forward transformation starts from, is placed on the intersection between the sagittal plane and coronal plane at the height of the arm servo axis (Servo 1 and Servo 2). When all servos are at 0 degrees (home position) the robot is standing straight and its arms are normal to the sagittal plane.

5 Conclusion

This paper introduced an affordable humanoid platform that will be used to advance teaching and research at the university and to create a competition platform for HuroSot and RoboCup. A detailed kinematic model was introduced that can be implemented into Bioloid-related platforms. Future work will include human-robot interaction experiments and work on gait and balancing.

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Appendix

Table A1. Denavit-Hartenberg Parameters for Left Leg and Right Leg

Matrix	α	l	d	θ	Servo
A_{CH}^{C}	π	20	166	-π/2	-
A_{8}^{CH}	0	33.5	0	0	8
A_{10}^{8}	π/2	0	0	π/2	10
A_{12}^{10}	-π/2	0	0	0	12
A_{14}^{12}	0	75	0	0	14
A_{16}^{14}	0	75	0	0	16
A_{18}^{16}	π/2	0	0	0	18
A_{AKL}^{18}	0	0	0	π/2	-
A_{FL}^{AKL}	-π/2	0	-32	π/2	-

Matrix	α	l	d	θ	Servo
A_{CH}^{C}	π	20	166	-π/2	-
A_{7}^{CH}	0	-33.5	0	0	7
A_{9}^{7}	π/2	0	0	π/2	9
A_{11}^{9}	π/2	0	0	0	11
A_{13}^{11}	0	75	0	0	13
A_{15}^{13}	0	75	0	0	15
A_{17}^{15}	-π/2	0	0	0	17
A_{AKL}^{17}	0	0	0	π/2	-
A_{FL}^{AKL}	-π/2	0	-32	π/2	-

Table A2. Denavit-Hartenberg Parameters for Left Arm and Right Arm

Matrix	α	l	d	θ	Servo
A_{2}^{C}	-π/2	0	83.25	0	2
A_{4}^{2}	π/2	15	0	π/2	4
A_{6}^{4}	0	68	0	0	6
A_{LHND}^{6}	0	100.5	0	0	-

Matrix	α	l	d	θ	Servo
A_{1}^{C}	-π/2	0	-83.25	0	1
A_{3}^{1}	π/2	15	0	-π/2	3
A_{5}^{3}	0	68	0	0	5
A_{RHND}^{5}	0	100.5	0	0	-