Construction of a low-cost, general purpose bipedal robot

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Abstract

The construction of a small (0.98 m tall, 7 kg heavy) general-purpose bipedal robot is introduced and described in some detail. The current design comprises 15 degrees of freedom with external power supply and control. The robot is tolerant to shocks due to falling, overload, and joint motion exceeding actuation range.

1 Introduction

In recent years, many bipedal robots have been introduced both in academia [12, 13, 15] and in industry [8, 9, 10, 11]. For a brief review, see e.g. [19]. The robots developed in industry, e.g. Hondas's Asimo robot [8] and Sony's Qrio robot [9] are indeed very impressive. However, the development of these robots been associated with very high costs, far beyond the financial means of most research groups. In academia, it is often necessary to concentrate on low-cost systems, which are likely e.g. to be less shock-tolerant than their commercial counterparts. The aim of the project described in this paper has been to build a low-cost bipedal robot capable of withstanding shocks resulting, for example, from a fall. The robot, shown in Fig. 1, is intended to be used in connection with research related to behavioral organization [18, 2] during locomotion (and other tasks) of behavior-based robots [1]. Clearly, in any robot intended for studies of bipedal walking, the body parts needed for locomotion, i.e. the legs, as well as their actuation and control, are of fundamental importance, and will be the main topic of this report.

1.1 Background

It is predicted that service robots, handling routine duties for people, will be a necessity in the near future, if the economy is to develop as desired [7]. Such duties could, for example, include domestic services, surveillance, and transportation. These service robots *must* be able to work in environments designed for people. i.e. essentially all constructed environments, such as offices, factories, and homes. For this reason, it has been suggested [14, 15] that such robots should be humanoids, i.e. robots having a human-like shape.

In addition, it appears that humanoid robots will be easier to accept socially[1] than non-humanoid robots [6], since, for example, communication with such robots can be based partly on body language.

General acceptance of robots in society is essential, if they are to have the large positive impact on world economy, as is intended and hoped for.

2 Construction details

Developing a humanoid is a grand challenge. Several design issues must be solved, many of which are interconnected. Developing such a robot directly, in one step, is difficult. Thus, a bottom-up approach, in which subsystems are first developed and then assembled to form the complete robot, is more feasible.

In the following section, the construction of the robot is described in some detail, starting with a description of the mechanics. Next, the actuators, sensors, and power systems are described, and the section is concluded with a brief description of the low-level digital control of the

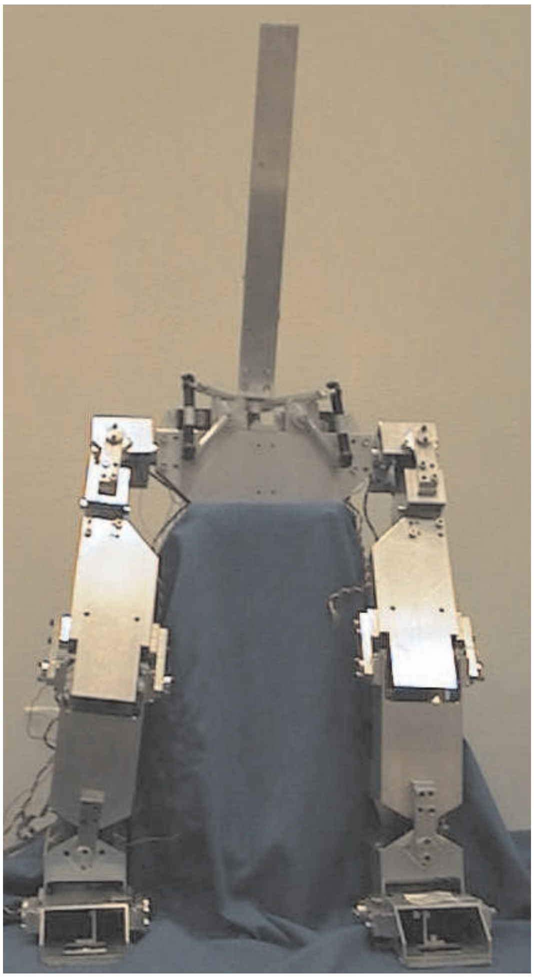

Figure 1: The mechanically assembled bipedal robot, measuring 0.98 m and 7 kg in length and weight, respectively.

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[1] The matter of social acceptance has been a key issue in the development of Honda's humanoid ASIMO [6].

robot.

2.1 Mechanics

The proportions of the lower body of the robot are similar to those of a child[2] measuring 1.05 m. The length of principal body parts developed thus far are given in Table 1.

Body part	**Length [m]**
Ankle height	0.085
Lower leg	0.165
Upper leg	0.250
Pelvis width	0.230

Table 1: Dimensions of the bipedal robot. Measures are taken from ground to joint, or joint to joint.

Each leg is controlled using 6 **degrees-of-freedom** (DOFs), two in the ankle, one in the knee, and three in the hip. The joint between the spine and pelvis is controlled using 3 DOFs. A blueprint of the completely assembled bipedal robot is shown in Fig. 2. In addition to the parts shown in the figure, a simple rod has been connected to the spine joint of the robot, making the total height equal to 0.98 m.

The metal skeletal parts were manufactured from rectangular aluminum profiles measuring 40×80×2.5 mm. Using such a profile gives high strength, low weight, and protective housing for the installed servo motors. Each part was milled according to its specific function as given by the blueprint.

There are two types of joints on the robot. The first, a two-sided hinge joint, called type I, is used in all but two cases in a leg. The second joint type, called type II, based on an axial and radial bearing supported shaft, is found in the sagittal and transversal actuators in the hip. Both joint types are shown in Fig. 3.

All joints are equipped with Teflon® slide bearings from Nomo Kullager AB [3]. The use of such bearings reduces the weight and cost significantly, compared to roller bearings, while maintaining robustness to wear and shock. In addition, the use of a slide bearing gives low static friction.

The width of the robot was primarily determined by the size of the actuators, as shown in Figs. 2 and 3(b). A narrower hip would require a different type of actuator or a different design altogether.

2.2 Actuators

All DOFs are actuated using standard HS-805BB+ RC-servo motors [5]. The maximum speed and torque obtained from this servo are approximately 120^o/s and 2.4 Nm at 6V operation, respectively. However, the standard HS-805BB+ servo motor does not provide a reading of the actuator position. Thus, the servos were modified in order to make it possible to extract such readings. This issue is discussed further in Subsect. 2.3.1 below.

The position of the servo motor wheel is set using a **pulse-width modulated** [16] (PWM) signal, shown in Fig. 5(a) and controlled internally using an analog proportional controller (P-controller). The P-controller is an **on-off controller** (i.e. giving either full current or no current) where the duration of the applied power is proportional to the er-

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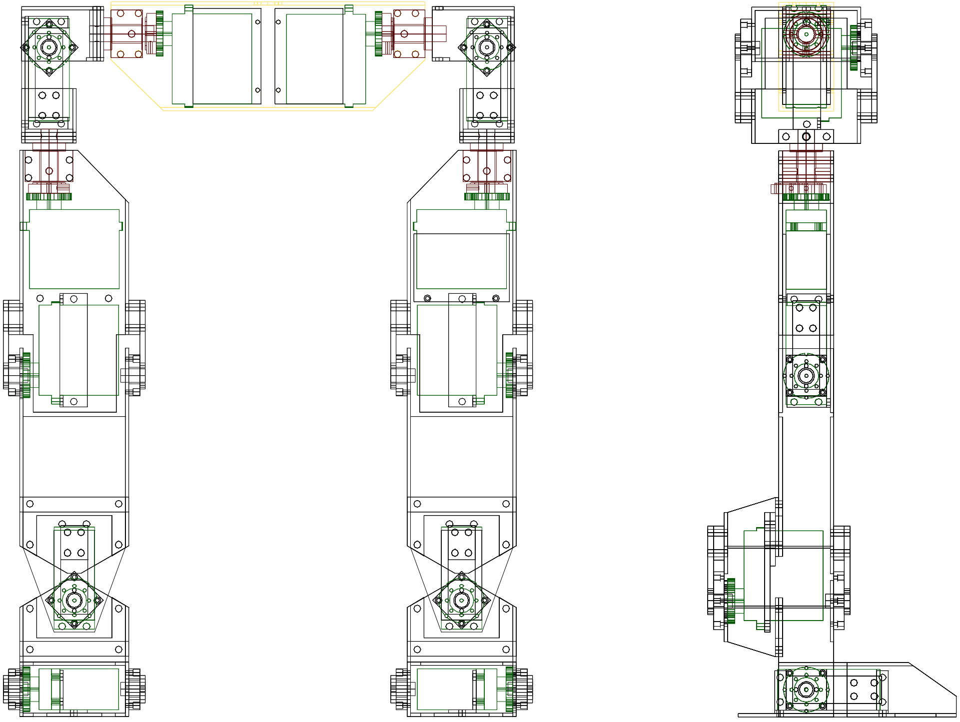
[2] The proportions are essentially the same as Leonardo Da Vinci (1453-1519) derived in studies of the human body.



(a) Front view of drawing of the bipedal robot.

(b) Side view of drawing of the bipedal robot.

Figure 2: Blueprint of the assembled body parts of the bipedal robot, measuring 524 mm in height (excluding the rod representing the spine, which is not shown in the figure) and 361 mm in width. The robot has 12 degrees-of-freedom (DOF) in this configuration. An additional three DOFs, not shown, have been added to the joint between the spine and pelvis, in order to move the upper body.

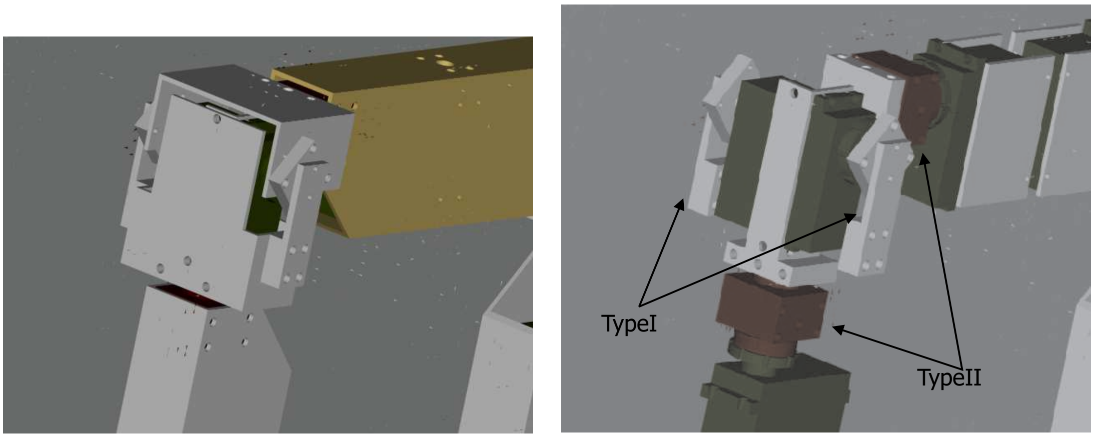
ror between the set value and the actual value, shown in Fig. 6.

2.3 Sensors

Two kinds of readings are currently extracted for controlling the bipedal robot, namely the position of, and the current to, each actuator.

2.3.1 Position measurement

The printed circuit board (PCB), shown in Fig. 4 has been fitted with a wire for direct sampling of the position signal, which is read from a potentiometer attached to the PCB. However, the signal is subjected to two sources of noise, random noise and controller induced noise. The latter type, shown in Fig. 5(b), severely disturbs the position reading. However, this kind of noise is predictable and therefore manageable if signal sampling occurs *before* the noise is added. It is essential to sample before the addition of the noise since the length of the noise signal depends on the position error of



(a) View with all parts present.

(b) View with all housings removed, showing type I and II joints.

Figure 3: Detailed view of the right hip. Observe the compact assembly in the pelvis, showing that, with this actuator configuration, the width of the robot is stipulated by the size of the servos.

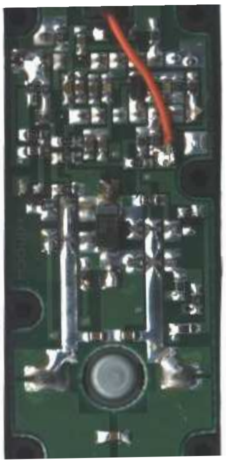


Figure 4: Wire soldered to the servo PCB for sampling of the position signal.

the servo. The sampled signal ranges between 0.46 and 2.0 V and is amplified to 0 to 5 V.

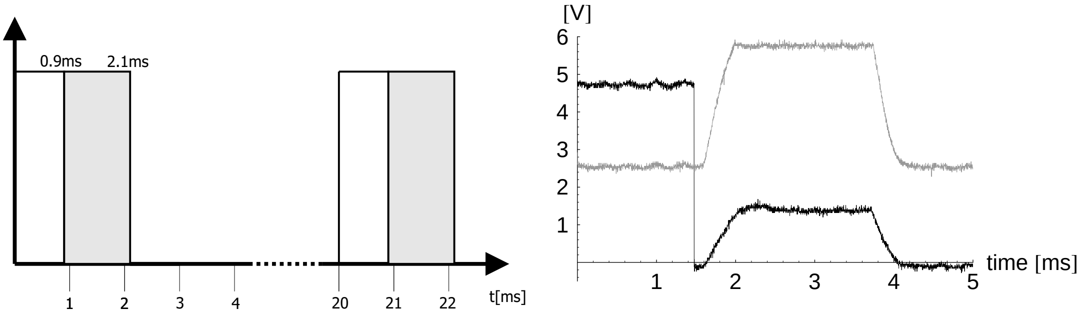
2.3.2 Measure servo load

The current to the servo is measured over a $0.05\,\Omega$ shunt resistor and is then amplified. Since the controller is an on-off controller, the current is integrated using an operational amplifier based integrator. Sampling the state of the integrator gives the load on the servo. The PWM and current related to two different load cases are shown in Fig. 6. In the case where the error is zero, i.e. the set position is the same as the read position, no disturbance originating from the controller is found.

2.4 Power

Each servo requires, at the most, 3.5A at 6.4V resulting in a peak current of the bipedal robot of $15 \times 3.5 = 52.5$ A. Since the servos are running at 6.4 V and the electronics at 5 V, two separate power supplies are needed. The current needed for the electronics is less than 100 mA.

For autonomous operation the robot must, of course, be equipped with an onboard power supply such as e.g. batteries or fuel cells. However, in the present



(a) The period time of the servo controlling PWM signal is 20 ms. The duty time of the PWM signal is between 0.9 and 2.1 ms, representing minimum and maximum position, respectively.

(b) Measured servo PWM signal (black line) and sampled position signal (gray line). The first 1.45 ms of the black line is the generated PWM signal while the curve-forms (both black and gray) between 1.6 and 4.0 ms are cross-talk originating from the internal analog controller in the servo.

Figure 5: PWM and position signal for the servo motors.

design, external power supplies are used.

2.5 Low-level control

The robot is equipped with a low-level controller, capable of handling 32 channels of software controlled PWMs for the servos, and sampling 128 AD-channels, 8 bits each, at a rate of 50 Hz.

Communication between the low-level controller and PC is currently implemented using an RS232[3] serial line at 115 kbaud. The data rates needed are 20 kbaud downstream, i.e. from the PC to the robot, and 80 kbaud upstream.

The controller is implemented on a PIC16F874A microcontroller from Microchip [4], operating at 20 MHz. Generating 32 channels with PWM signals simultaneously is not possible using the PIC16F874A processor. Instead a time-sharing system is implemented where groups of eight PWM channels and 32 AD channels are administrated simultaneously, together with the related RS232 communication. A time-sharing and sequence diagram is found in Fig. 7. Each group contains eight PWM channels and four sub-groups with eight AD channels each, and is executed for 5 ms. The AD-channels related to the servo group are sampled in advance, thus avoiding noise originating from the servo motor controller. While generating the PWM signals, the CPU is fully occupied, and therefore no AD sampling or communication can be handled. After the PWM signal generation, auxiliary channels are sampled. The sampling frequency of the auxiliary AD channels is limited by the RS232 communication speed. Sampling eight 8-bit AD-channels takes 0.16 ms, while communicating the result takes

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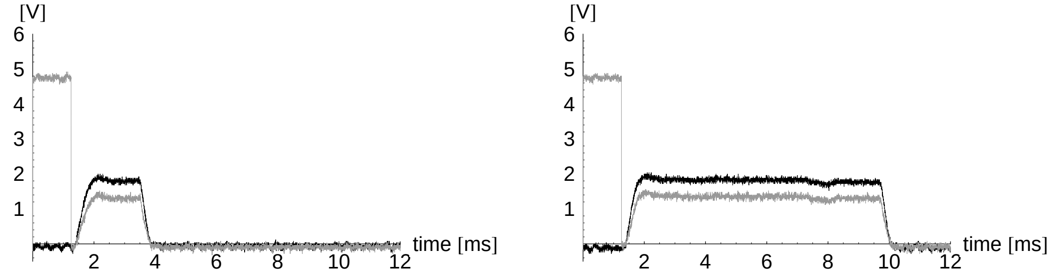
[3] RS232 defines the electrical interface and data coding in the serial communication line and was defined by the Electronic Industries Alliance (EIA) in the 1960s. RS means *Recommended standard* and 232 is a serial number for this recommended standard.



(a) Low load on servo.

(b) High load on servo.

Figure 6: Measured current to servo. The gray line shows the PWM signal, including the cross-talk, while the black line shows the measured and amplified potential over the shunt resistor. Integration of the potential over time gives a correct measurement of the load.

0.87 ms.

3 Cost-related issues

An important constraint on the development of the bipedal robot introduced here, was the limited budget In order to minimize costs, standard components were selected, implying that some modifications had to be made, as described e.g. in Subsect. 2.3.1 above. A list of component costs, measured in EUR, is shown in Table 2.

Note that the table only lists the cost of the components, and thus neglects the cost of development and assembly, which far exceeded the component cost. However, given the finished blueprint, additional copies of the robot can be assembled quite rapidly.

4 Discussion

In this paper, the main steps of the construction of a low-cost bipedal robot have been described. The parts of the robot needed for the purpose of research on balancing and walking (i.e. the legs) have been completed, with a total component cost of less than 1,000 EUR.

Care has been taken to make the robot as shock-tolerant as possible, by placing sensitive parts in shielded locations in the metal skeleton, and by using slide bearings.

In its current state, the robot allows manual setting of the actuator positions. In addition, it is possible to read the position and load of each actuator. The presented bipedal robot is at present time still under development and full controllability has yet to be implemented.

The next step will be to install pressure sensors under the feet and develop a closed-loop control for setting and keeping postures. At a later phase, accelerometers and gyros will be introduced, and the weight of the robot will be reduced through removal of excessive material in the skeletal parts. It is also the intention to construct an actuated upper body for the robot, to replace the simple rod currently used.

Once completed, the robot will be used

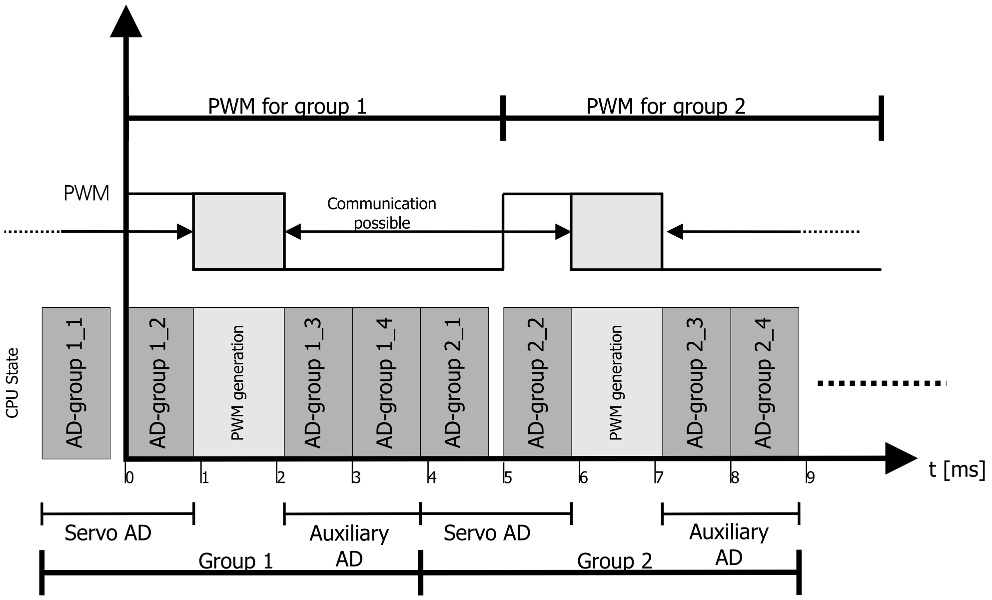


Figure 7: Timing and sequence diagram for two groups of software generated PWM signals and sampling of AD-channels.

Component	**Amount**	**Unit cost [Euro]**	**Subtotal cost [Euro]**
HS-805BB+	15	55	825
Aluminum	1	30	30
Fastening devices	1	10	10
Electronics	1	50	50
Total cost			**915**

Table 2: An overview of component costs for the robot.

in research on behavioral organization, i.e. the selection of appropriate behaviors in different situations. For example, a bipedal robot must not only be able walk along a path. It must also be able to avoid collisions with suddenly appearing obstacles, and must also be able to find and use a charging station at regular intervals.

In addition to the development of the bipedal robot, a specialized simulator for multi-body systems has been developed [17], and is currently being used in connection with evolutionary algorithms for developing balancing, gaits, and behavioral organizers for various behaviors that are to be implemented in the robot.

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