RoboCup 2006 Humanoid League: UA Team Description

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Abstract. This paper describes the major design concerns, research approaches and scientific achievements of the UA-Team 1 humanoid robot. The project, started in 2003, has taken up the challenge to build a prototype capable of participating in the RoboCup Humanoid League, being the first time appearance of the team. The main features of the 22 degrees-of-freedom robot include the distributed control architecture, based on a CAN bus, and the modularity at the system level. Although some issues are yet to be addressed, the stage of development is already mature for practical experiments and to obtain the first conclusions on the potential of the proposed solutions.

1 Introduction

The main scope of the project beneath this paper has been the development of a humanoid platform to carry out research on control, navigation and perception, and also to offer opportunities for under and pos-graduate students to apply engineering methods and techniques in such ambitious and overwhelming endeavour. Purchasing a commercial platform carries prohibitive costs and it would reduce the involvement at the lowest levels of machine design, which was posed as a relevant pursuit for the desired engineering approach. The ultimate goal of the project was to build a prototype capable of participating in the ROBOCUP humanoid league where a wide range of technologies need to be integrated and evaluated, giving added value for project-oriented education. Although some issues are yet to be addressed, the stage of development is already mature for practical experiments and to obtain the first conclusions on the potential of the proposed solutions [1],[2],[3].

The paper presents the design concepts and the technological solutions to build the small-size 22 degrees of freedom (DOF) humanoid robot at reduced costs, but still aiming at a fully autonomous platform for research. The most relevant achievements of this implementation include the distributed control architecture, based on a CAN bus, and the modularity at the system's level. On one hand, the key concept for the control architecture is the distributed approach, in which independent and self-contained tasks may allow a standalone operation. This feature allows for localised control capabilities based on feedback control from several sensors, ranging from joint position to force sensors. Moreover, the distributed computational power may allow for the development of sophisticated sensor fusion. On the other hand, a major concern of the project was to provide modularity at the system level. The main advantage is the possibility of reusing specific modules, in terms of both hardware and software, with no major efforts. The demands for limited costs gave rise to the selection of off-the-shelf materials and components.

2 Robot Design

2.1 Mechanical Design

When conceiving a humanoid platform countless decisions have to be made. Specifications must be defined and applied to impose limits both on skills and overall objectives. In what concerns the physical and functional requirements, the initial considerations were largely imposed by the rules of the ROBOCUP, namely, the robot dimensions, the mobility skills, the high level of autonomous operation and the selected tasks (e.g., walk, turn, kick a ball).

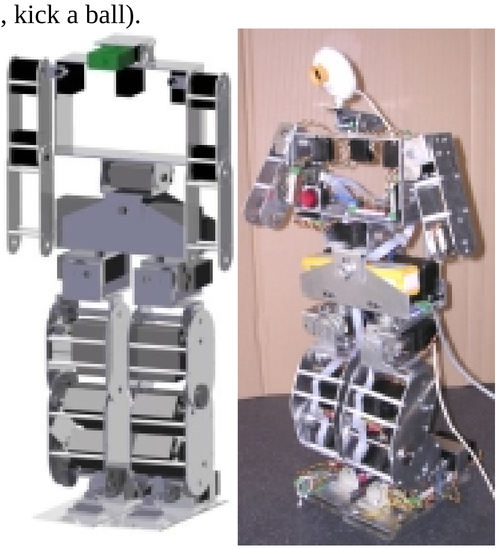

Fig. 1. 3D model of the humanoid robot and current stage of implementation

After the structure height and remainder body proportions, the very first issue has been the number of degrees of freedom. In order to ensure proper and versatile locomotion, the robot is doted with six DOFs per leg, namely one universal joint at the foot, a simple joint on the knee and a spherical joint on the hip. Walking concerns can range from simply ensuring robust equilibrium to static walking up to, hopefully, dynamic walking for energetic efficiency. Connecting the legs to the upper structure of the abdomen was decided to be done with two DOFs mainly aiming at greater flexibility in balance control and account for the perturbations of the centre of mass (CoM). So far, arms have been only partially defined and the head accounts for two DOFs for the vision based perception.

A complete humanoid model and a view of the current stage of implementation are illustrated in Fig. 1. This is a small-size robot with 22 DOF's, about 64 cm height and 6 kg weight. The system was designed to be self-contained, low-priced, modular and expansible.

2.2 Servomotors and Their Control

For the dimensions involved, off-the-shelf technologies of actuation do not offer significant alternatives other than small servomotors, such as those from FUTABA, HITEC and similar. Static simulations made with the developed 3D model showed that some joints would require torques as large as 2.6 Nm in a typical simple gait. Common commercially available motors pointed to the HITEC servo-devices, but their highest torque is smaller than 2.3 Nm, which is the case of the HS805BB model.

To account for lower mechanical efficiency and larger safety coefficients, transmission gear ratios had to be inserted. This requirement complicates the mechanical design and, at the end, toothed transmission belts were used imposing gear ratios of about 1:2.5. Fig. 2 shows one of such transmission systems used on the humanoid foot.

A second problem concerning the servomotors is that they do not offer directly velocity control. Instead of changing the motor internals, as some other authors do, it was decided to implement velocity control by software. That is achieved by a variable PWM (pulse width modulation) throughout the full excursion of a joint. In other words, the software tracks motor position with time and adjusts the PWM in order to accelerate or pause motor motion. Further developments will possibly require better performance, for instance, by replacing the electronics control unit of the motor package (we plan to move in that direction in the mid-term).

Concerning power, there are no clear official indications of the power of the servomotors, which is an important issue for velocity/torque performance. Experimental results point to an overall electric power maximum consumption of circa 12 W, which, of course, translates in less than that for usable mechanical power due to electrical and friction losses.

Fig. 2. Transmission belt with an adjustable tensile roller

2.3 Batteries

Power to drive the motors is a central issue since servos require a high current, namely at start-up and when producing motion in some configurations. Two ion-lithium batteries were installed and the system counts with a 7.2 V/9600 mAh pack, with maximal sustained current specified by the vendor at more than 19A. Each one of the two batteries weights circa 176 g and confines to a box of 37x37x65 mm^3. Proper fusing, polarity protection and charge monitoring were also implemented. Later on, polarity protection was removed since the power diode used dropped voltage by more than 1 V, affecting some parts of the circuits ahead when batteries discharged for a while. Fig. 3 shows the selected batteries and their location on the robot.

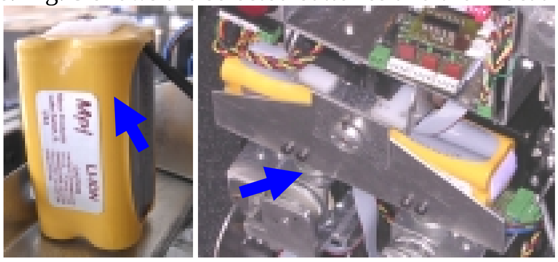

Fig. 3. Batteries and their location on the robot

3 The Distributed Architecture Approach

From the very beginning of the project, one major concern has been the development of a flexible control system based on a distributed architecture approach. The system joints have been grouped by vicinity criteria and are controlled locally by a dedicated board inserted in the CAN bus using a slave configuration. A master unit relays all slave units by dispatching medium and high level orders and by collecting sensorial data to be eventually processed on a central unit, which interfaces the master controller by a serial RS232 link. The central unit is currently an off-board computer but will be migrated to a local controller based on a PC104+ board with image processing capability. Fig. 4 shows a generic diagram of controlling units.

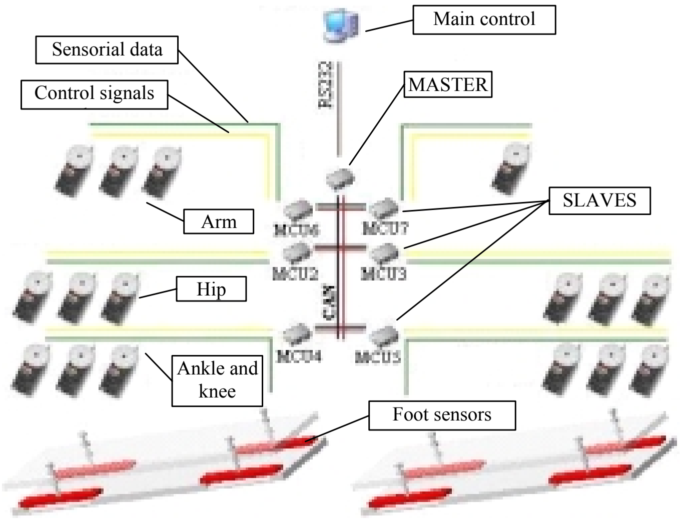

Fig. 4. General architecture layout

Although RS232 may seem slow, the relevant fact is that it will not be used to close the low-level control loops of the robot. Only motion directives and some sensor status are to be exchanged. Even in an unlikely worst-case scenario requiring continuous information for all motors and gathering information from all sensors, circa 20 full cycles per second would be possible at 38400 baud.

3.1 Hardware for the Units in the Architecture

Master and slave units are based on a PIC microcontroller. Slaves are all alike and can be distinguished by a configurable address. Slaves can drive up to 3 servomotors, and can monitor their angular positions and electrical current consumption. Concerning additional sensors, each slave unit has the possibility of accepting a piggy-back board where additional circuit can lay to interface to other sensors. Some examples of the developed piggy-back boards include force-sensors, accelerometers and gyroscope.

Fig. 5 shows a generic diagram of a slave unit. There, the main internal blocks can be seen, such as power supply regulation, CAN interface, the PIC controller, the multiplexer for sensor interfacing, PWM lines, CAN address switches and also lines prepared for RS232 communication. This kind of layout allows high versatility both on hardware and software approaches.

Being all similar, the construction of the boards is easier, along with software development (the same base code for all units). The master unit is different since it is not expected to drive motors neither to acquire many sensorial data. Furthermore, it communicates both by CAN and serial RS232 to the upstream controller. Hence, its piggy-back module was used to interface electrically the RS232 communications by installing a MAX232 circuit instead of sensor acquisition.

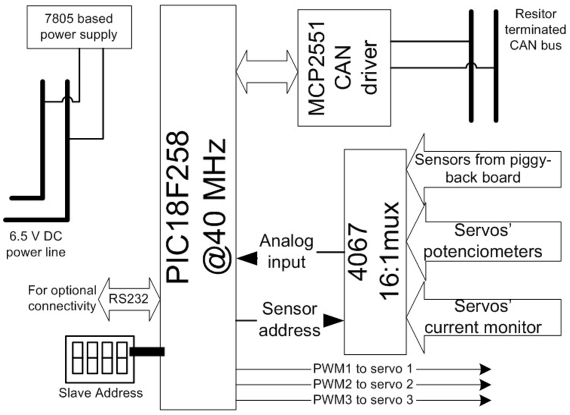

Fig. 5. Block diagram of generic slave unit

Slaves will be able to perform local control when adequate algorithms will be developed. In the slave units, three PWMs are generated for the three servomotors with resolutions of about 1 µs according to directives received from the CAN bus, but in the future local algorithms may decide better how to control the motors instead of relying on central control. Still at the slaves, the sensorial data is currently acquired with 8 bits, but 10 bits are possible in case it becomes necessary and adequate signal filtering and conditioning is provided. Fig. 6 shows a slave unit PCB with the main components and also includes a piggy-back board for signal electric conditioning. Currently, only the master uses the RS232 plug to communicate with the main control unit; slaves do not use it for now but it is there for future developments or debug.

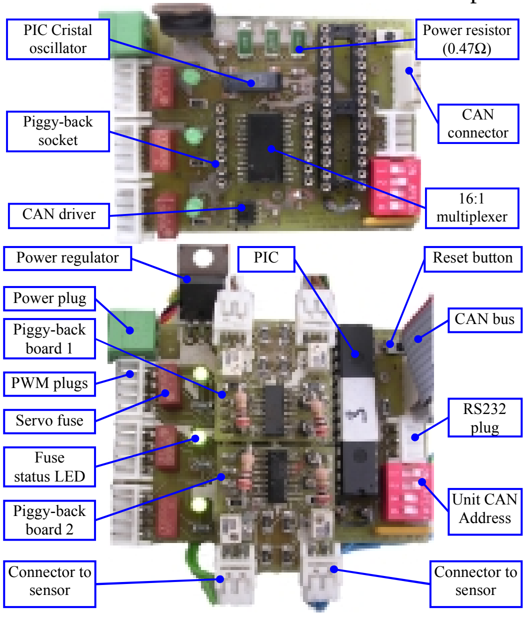

Fig. 6. The basic slave processing board (up) and with two piggy-back boards (down)

3.2 Communications: CAN and RS232 messages

In the current stage of development, on power-up or reset, each slave checks its address and starts monitoring the CAN bus. While no messages arrive, the slave unit will drive its joints to a home position at a reduced speed and starts monitoring local sensors at a given rate (pre-programmed). When messages from the CAN bus arrive, the slave unit will process them; messages are of two kinds: imposing new desired position and speeds to each of the three motors, or query for sensorial data. These requests come from the master only and at a rate imposed at 10 kHz. Currently the system has 8 slave units; assuming one message for each slave and 2 messages back for the master from each slave, this results in a more than 400 Hz [10000/(3×8)] full cycle at the architecture intermediate level; actuators are controlled locally with much finer resolution. The CAN bus is driven at 1 Mbit/s.

CAN messages contain a data field with 8 bytes, enough to exchange (in one message only) orders for three servos (3 positions and 3 speeds). On the other hand, to gather data from the slaves, more than one message may be necessary. Indeed from 3 motors 6 variables are required (3 positions and 3 current levels), and additional sensor values (such as force or inertial) must go on other messages.

The master keeps a current status of the full system and delivers that data to the main control unit when requested by the RS232 link. Currently, this protocol defines a 3-byte message to master and a 6-byte message from master to control unit.

4 Sensors and Perception

Perception assumes a major role in an autonomous robot and, therefore, it must be reliable and abundant. For this platform the following perception was planned:

- Joint position (reading servo own potentiometer)
- Joint motor current (related to torque)
- Force sensors on the feet (ground reaction forces)
- Inclination of some links (using accelerometers)
- Angular velocity of some links (using a gyro)
- Vision unit (located on top)

Up to now, only vision has not yet been implemented on the system. The remainder sensors were addressed with different levels of accuracy, but all potentially usable with current hardware. Now follow details on foot force sensors, inertial sensors and vision system.

4.1 Foot force sensors

The foot sensors are intended to measure the force distribution on each foot to further assist during locomotion or simply keeping upright. Moreover, it is expected to use that information for future local control, and some work is already on the road [1].

Four sensors on each foot will allow balance evaluation both on static and dynamic motion. Commercial force sensors are expensive, so it was decided to develop a system based on strain gauges and to amplify the deformation of some stiff material. The result is a kind of foot, whose details can be viewed in Fig. 7, based on 4 acrylic beams located on the four corners of each foot that deform according to the robot posture. A simple Wheatstone bridge and an instrumentation amplifier complete the measuring setup (Fig. 8). The electronics hardware lays on a piggy-back board mounted on the slave unit, as can be seen in the lower part of Fig. 6.

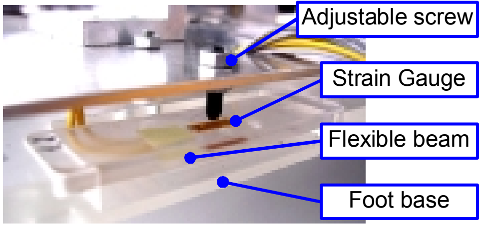

Fig. 7. Foot sensor details

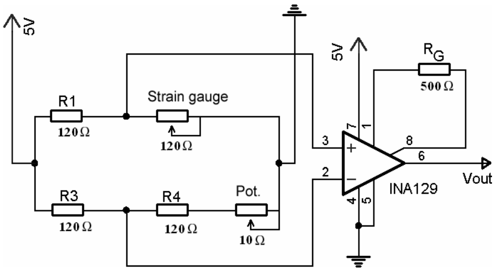

Fig. 8. Circuit to measure force on the feet

4.2 Inertial devices

Inertial perception is also a relevant source of information for dynamic and also static locomotion and balancing. Accelerometers and gyroscopes furnish information on acceleration and angular velocity.

Concerning accelerometers, they can be used to measure the acceleration of gravity, or better said, its component aligned with some axis. In other words, they can be used to measure inclination; however, this is only true in static positions or for very slowly accelerated motions. Nonetheless, the inertial information provided by accelerometers can be exploited in the future with software yet to develop. The accelerometer chosen was ADXL202E from Analog Devices and was interfaced with a circuit similar to one suggested by the vendor datasheet. This very small MEMS device has two accelerometers in orthogonal axis that can be used to monitor tilt and roll angles of the platform. The system was mounted on a small PCB as shown in Fig. 9. The sensor provides information both in analogue and digital form, which is also an advantage to exploit in other developments.

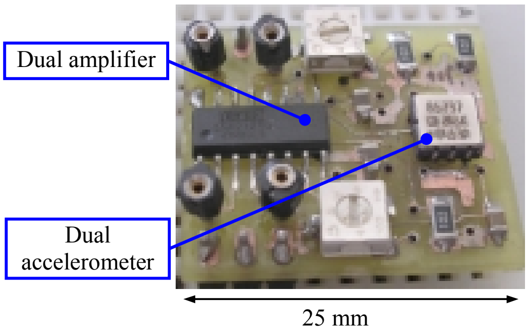

Fig. 9. Piggy-back board with two accelerometers

Finally, in what concerns sensors, a gyroscope unit has also been developed. The GYROSTAR ENC-03JA from MURATA has been selected for several reasons: ease of interfacing; high angular velocities (±300º/s), relatively high response (50 Hz), low cost and commercial availability. Up to now, the unit has not yet been used in practical control of the developed platform. Its circuit is simply adapted from the vendor datasheet and using a INA129 amplifier.

4.3 Vision System

Ongoing developments cover the inclusion of vision and its processing capabilities. A partial implementation of this approach was already evaluated in other research activities. The approach includes two main components: (*i*) one compact FireWire camera; and (*ii*) the open source operating system Embedded Linux with a system based on a PC104+ board. The OpenCV library is used for object identification, segmentation and recognition (e.g., color and shape recognition).

5 Conclusions and Perspectives

This paper described the technological and engineering solutions to build the UA-Team 1 humanoid robot. The principal features of the 22-DOF system include a distributed control architecture with local control possibility, based on a CAN bus. At the same time, the system is prepared to use many types of sensors, from joint position monitoring to force sensors on the feet.

Most of the final platform hardware has been built and results are promising since the system now is able to stand, lean on the sides and forward-backward. One of the current endeavors is to be able to achieve primitive locomotion steps, such as walking and penalty kick. Recent work has concentrated on the improvement of motor control (position, velocity and torque), namely providing a novel approach currently used to estimate the joint motor current. On-going developments cover also the integration of vision and processing capabilities in the system.

References

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