Real time comunications in a small biped robot YABIRO.

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Abstract

In this paper we present real time architecture for embedded control systems to be used into a biped robot called YABIRO[1]. YABIRO is an anthropomorphic small biped robot with a total of 14 DoF (Degrees of Freedom). Its mechanical structure gives us enough mobility, enabling us to produce many different gait configurations, being also suitable to test and validate the proposed real time control architecture, based in the TTCAN protocol, which has been adapted to YABIRO control structure. Together a real time protocol a new embedded intelligent motor controller driver (IMCD) has been also designed and implemented into each joint node of the distributed architecture, to work inside the real time network. YABIRO includes a multi-tasking real time control platform, based on a Transmeta Crusoe processor board, where RTLinux 3.0 real time kernel is running.

1. INTRODUCTION

In recent years walking robots have become more common. On TV we can see entertainment robots playing with children – such as the Aibo dog by Sony. These robots feature complex system control with vision and voice recognition. This level of complexity was unthinkable when in 1973 Kato developed WABOT – the first biped robot. Since then, the number of research groups addressing the problem of bipedal walking has increased every year.

The many current research groups have developed several different control architectures and mechanical designs. Groups studying bipedal walking locomotion can be classified into two groups. The first group uses the dynamic parameters of a robot to prepare walking patterns: e.g. mass, location of centre of mass, and inertia. The knowledge of dynamic parameters can be more or less precise. One of these cases is the simulation and control design schemes based on an inverted pendulum model. This approach represents a simplified model of robot dynamics. Many engineers use this control technique in their robot control strategy, as discussed in [1] and [2]. Similarly, there are other researchers that base their biped control systems on a precise model of the robot. These models include the WABIAN-RII and Honda robot series and mainly rely on the accuracy of the model data.

Fig.1 YABIRO

[1] YABIRO stands for Yet Another BIped RObot, and is currently being developed with funds from the projects DPI 2002-04434-C04-03 from Spanish FEDER-CICYT, and the GV04B-392.

[2] This work has been developed inside of CTIDIA 2002/21 project

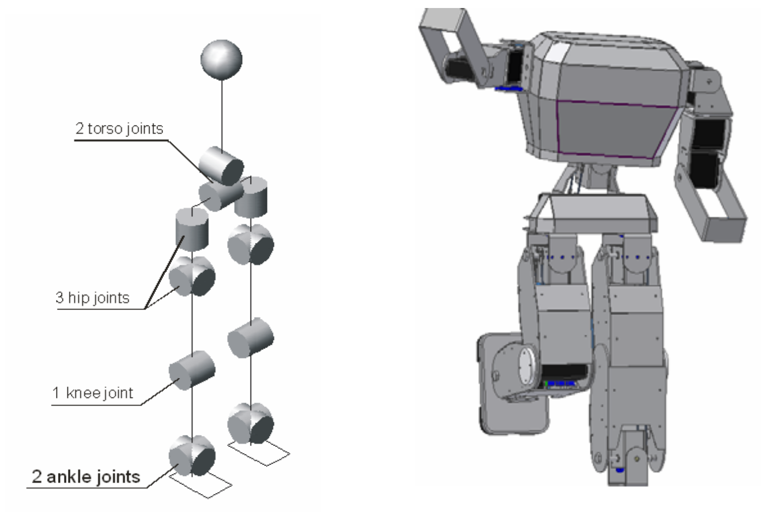
A second group of researchers focus their investigations on applied learning and intelligent control systems based on a biological computation. Several teams around the world have studied the use of neural networks for learning in different problems of bipedal locomotion. [3] implement a CMAC NN for adaptive control, others apply fuzzy control architectures, and many others combine these techniques [4].

All of the control architectures mentioned above, need a reliable communication structure which all the different systems can send and receive information without time delays. Our research has been focused on the design of a small and low cost platform, which could be used to study a complex control system and create an accessible platform for students, with a real time network. For these reasons the design of the anthropomorphic robot YABIRO has a total of 14 DOF, which is a large number of joints for a robot that is only 31 cm tall and weighs just 2 kg. Its very smallness makes it easy to use and transport. The final goal of this design is to produce a robotic platform that can be used to design new control architectures, vision systems, humanoid behaviour, etc. Therefore, to test all these final goals and create a simplified robot model based on inverted pendulum model control (IPMC) we implemented easy and intuitive system control architecture with a real time network communications, based in TTCAN protocol.

This paper is organized as follows. An outline of the mechanical design of YABIRO is given in Section 2. The real time distribute architecture is described in Section 3. In Section 4 the SW layer distribution is showed, we explain the control system of the biped robot. Finally in Section 5 we discuss about the final experimental results.

2. MECHANICAL DESCRIPTION

In this mechanical robot design, we have analyzed human walking movement and behaviour in different states such as walking, climbing stairs, seating, etc. Through these studies of walking motion, we have obtained initial valuable specifications which helped us chose the initial mechanical design. In this way, we estimated the location of every joint in the robot. The multi-link model shown in Figure 2 is the result.



a) Location joints b) CAD Model

Fig. 2: Robot model.

The number of joints has been reduced when compared with a human, but this mechanical structure gives us a successful mobility. Because we adopted the joint structure in the robot design, it has a total of 14 DOF. The joints are distributed as follows, two in the ankle, one in the knee, three in the hip and two in the torso. Many biped robot designs have been implemented with a similar structure because it provides a very good mobility.

Table 1: YABIRO specifications.

Dimensions(mm)	Hip-trunk		55
	Upper leg		115
	Lower leg		100
	Ankle-sole		40
Mobility(deg)	Ankle	Sagital plane:	± 75º
		Lateral plane:	± 55º
	Knee		110º
	Hip	Sagital plane:	-50º to 90º
		Lateral plane:	± 55º
		Rotational plane	± 90º

Mechanically, we have designed a robot platform that can be assembled and disassembled easily, as most of the parts are aluminium sheets that only have to be screwed together. The result is a low maintenance platform.

3. ACTUATORS DISTRIBUTED ARCHITECTURE

The system implemented into the biped robot is embedded and distributed. The configuration of the architecture is easily adaptable and parametrical to the current and future requirements of the biped robot. The robot has been built using different electronic boards, each one implementing different tasks.

3.1 Bus control board

Together with the main embedded Trasmeta control board, a new intelligent PC104-CAN controller board has been designed and included into the main node. This additional board has been designed to manage a real time CAN protocol without intervention of the main control board. This board has two main tasks, first is to adapt all the input messages from the embedded-PC to a TDMA-CAN bus. This means that the CAN controller board uses a previously programmed messages time table to send all the CAN messages in their correct time window.

The second task of this CAN board is to guarantee and control the timing correctness for all the time slots on the bus. For this task all the nodes must be previously loaded with an updated time table. Since the bus starts in time-triggered mode the bus control board manages all the starting procedures in each node.

The CAN board is based on the PIC18F458 microcontroller, with 1Kbyte DPRAM for message data storage and communication with the embedded-PC, and a CPLD to adapt the PC memory map to the CAN board memory map.

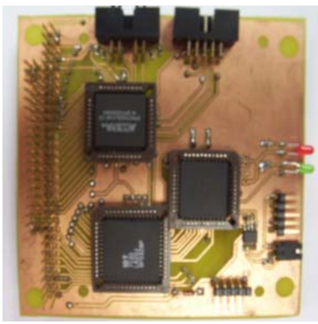


Fig.3 Bus control board

3.2 The Intelligent Motor Control Driver (IMCD)

Also, one of the most important improvements that YABIRO achieves in comparison with other similar robot platforms is the use of an intelligent motor control driver board inside of each servomotor box.

This IMCD board try to solve one of the main problems in low cost biped robots. YABIRO uses powerful model making commercial servos for one main reason: the motor and all the gearbox pieces are included in a small and robust package at a reasonable price.

Despite their advantages, the use of commercial servo motors presents an important problem: the lack of feedback signals. A position feedback cannot be obtained in a conventional servomotor. This signal is very important if the robotic platform wants to achieve an accurate position control in each joint.

Fig. 4 IMCD photo.

For this reason a small embedded board has been developed to control the motor position and the node communications. Its design is based on the PIC18F248 microcontroller with capacity to communicate the motor node via CAN bus, and can also control the motor using a power full-bridge with optocouplers in their digital lines. Inside of the IMCD board, two main tasks have been programmed: a real time CAN bus protocol, and a PD controller which guarantees an accurate position control. The final aspect of the enhanced servo can be appreciated in Fig. 4.

3.3 RT communication protocol.

The YABIRO communication bus is based on the CAN field bus network. This is one of the most used field buses in embedded control systems, as in robotics, automotive, automatic industrial controllers, etc. The non-destructive access to the CAN bus is based on fixed priorities attached to each message. This scheme neither guarantees the minimum jitter, nor the precise transmission timing of messages due the high variability of response times in CAN [5] [6] [7].

Aiming to overcome this problem, some new hybrid real-time communication protocols have been developed to be used in combination with distributed control schemes. The emergences of new hybrid protocols are focused to a time triggered schema, contrary to event triggered used in normal CAN communications. Thus, the YABIRO communication bus protocol is based on Time Triggered CAN (TTCAN) protocol, witch is another extension of CAN, based on static schedule TDMA. TTCAN uses a reference message to indicate the beginning of each basic cycle. A basic cycle is constituted with three different types of windows: *private* windows, used to transmit a specific message only, *arbitrary* windows, where the nodes compete by the access to the bus as in a conventional communication of CAN, and *free* windows, used for future extensions.

4. SW DESCRIPTION

Frequently, the main control of a distributed system resides into a single node. This node works in higher control layers than other nodes in the control system, (as our IMCD nodes). This is especially frequent in robotic applications. Thus, several distributed control architectures with these characteristics have been described in the bibliography [8] [9]. Normally the main control node runs different tasks such as deliberative system control, sensor fusion, human interface, robot system supervision, etc.

To carry out some of these tasks, YABIRO includes a multi-tasking real time control platform, based on a Transmeta Crusoe processor board, where RTLinux 3.0 real time kernel is running. The use of this kernel together with a Linux 2.4.18 kernel, makes possible the division between critical tasks and other tasks into the same control system.

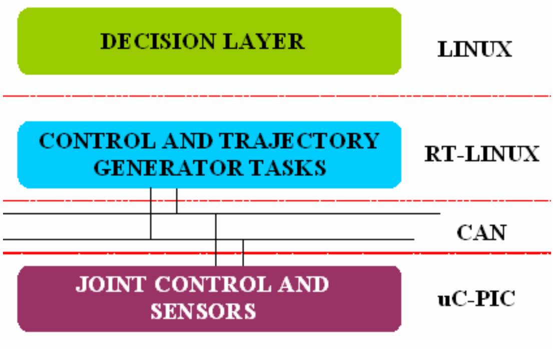


Fig. 5 Control layer distribution.

A schema with this layer distribution is shown in Fig. 5, where the three main layers of YABIRO can be observed. The top layer is the decision layer, where non real time tasks, like path planning, behavior, and human interaction tasks can be executed. The decision layer is implemented into the Linux kernel. The middle layer or RT layer has been implemented in RTLinux. In this layer, real time tasks, such as control task, robot path generation, sensor data fusion, etc., can be executed. Finally the lower layer, named local layer, is made up for all the distributed nodes in the robot.

4.1 Gait generation.

One of the most important research points in bipedal locomotion is obtaining the correct pattern gait in real time. These researches have focused on the ability to walk with stability in various environments, such as rough terrain, up and down slopes and stairs. To do this, it is necessary for the robot to adapt to the ground conditions.

Biped walking is a periodic phenomenon. A complete walking cycle is composed of two phases:

- Double support phase: during the double support phase both legs are in contact with the ground. We can suppose that this phase is the most stable but many studies have assumed that the double support phase is instantaneous. We assume that it represents 20% of the total walking interval as a correct value for the basis for our calculation.

- Only one support phase: during this phase the robot moves forward one leg, while the other leg is in contact with the ground.

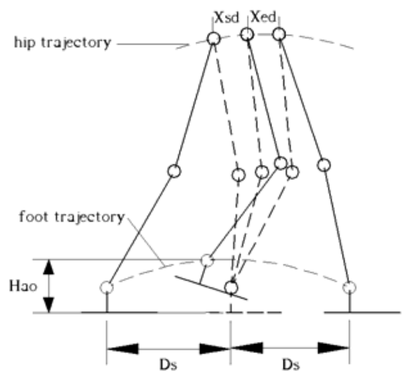


Figure 6: walking parameters.

In this way we have implemented a walking pattern that enables YABIRO to walk and is based on known points of the foot and hip trajectories. The walking parameters define the behaviour of the walking robot, and these parameters can be changed online. This implementation is only for the sagital plane.

The YABIRO walking pattern generator has been divided into two online pattern point generators, one for feet and another for the hip trajectory as shown in Figure 6. The foot trajectory generator is based on a point series where both feet have to pass through. These points are calculated online because this depends on run time walking parameters such as a step length (2 Ds) and step height (Hao). With these points we obtain a foot trajectory using a cubic spline interpolation [10].

In the same way, we apply the second pattern generator for the hip motion. The hip movements are critical for the robot stability, and for this reason we have calculated a series of hip points that perform ZMP robot stability in static positions. The cubic spline function is also used in a hip trajectory.

5. CONCLUSIONS

To conclude and validate this new distributed control architecture for a small bipedal platform, some experiments have been designed and carried out. These tests are based on smooth terrain walking using different step. These tests are based on an offline ZMP calculation robot trajectory [15], and they are focused to prove the communications protocol and its real time stability.

In the walking experiments the bus has been stressed with irrelevant information messages together with control messages to check the correct bus behavior and its jitter in the control and sensor data messages. The total number of messages send by basic cycle was 120, the maximum determined by the protocol. With this message load in the network the jitter obtained is always delimited and deterministic, defined by the control time table response, to 10 µsec maximum.

Finally in some tests YABIRO can walk without stability problems with a walking velocity that has been increased to 5cm/sec (1 step/sec).

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