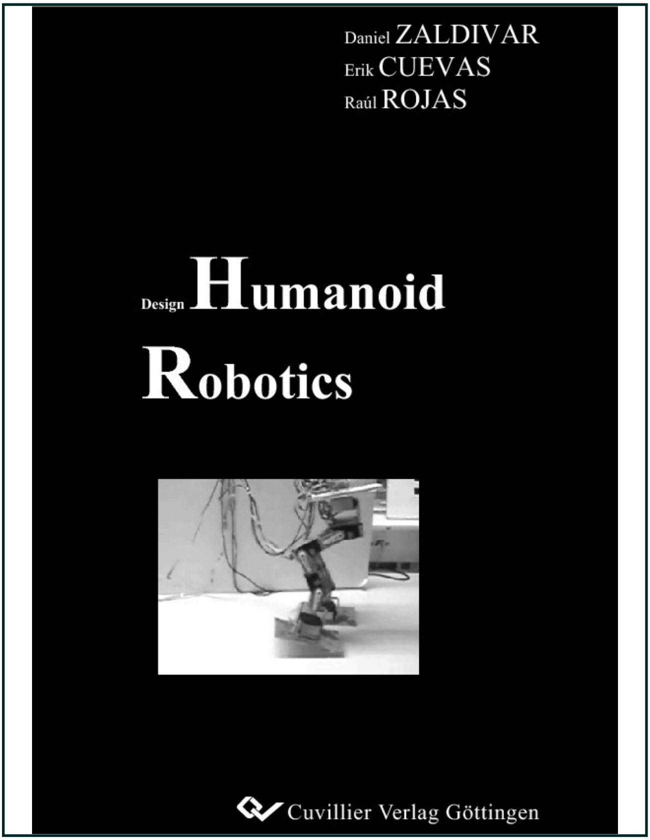
Erik Valdemar Cuevas Jiménez (Autor)
Raúl Rojas (Autor)
Daniel Zaldívar Navarro (Autor)

Design Humanoid Robotics



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Chapter 1

Introduction

1.1 Overview

The goal of this book is bring some experiences on the design process of a low-cost stable biped robot structure to investigate theories of bipedal walking and biped balance control. To achieve the walking and balance some algorithms are proposed. A cubic interpolation algorithm for the walking and a fuzzy PD incremental algorithm based on the ZMP criteria (Zero Moment Point criteria) to control the balance of a biped robot.

An interesting thing on biped robots walking theory is that they can be allowed to walk in almost any type of terrain [1], [2], [3], [4] including those that are impossible for robots with wheels. For this reason, it is promising the use of biped robots in human environments as well as the development of biped robot's control algorithms [4, 5, 6, 7, 8].

In recent years, have been an increasing enthusiasm to study the bipedal walking. In private companies (Sony, Honda, etc.), research institutes and some universities, they have invested huge quantities of human and economic resources to develop sophisticated biped robots prototypes [9, 10, 11]. However, some others researchers have a low-cost biped robot's design philosophy. Such kind of biped robots are similar to his costly counterparts in the sense that they can offer the capacities to study and improve new biped walking algorithms, but they are more affordable. For that reason, the tendency to build low-cost biped robots has been worldwide increased [12, 13]. However, there's a lack of detailed information over the biped robot design process and control. This book intents to share the knowledge and experience acquired during the design process of a low-cost biped robot and the research of its control, to be a possible base for future biped robot designs.

Biped robot design is different from conventional robots since, there are restrictions and differences in the amount, type and size, response time of the actuators, sensors, parts-weight and even configuration, position, and distribution of the biped's robot structure. Thus, a correct robot's hardware design is a previous stage to come closer of a dynamic walk. Lastly, an efficient biped robot balance control and a smooth walking sequence can achieve dynamic walk. Also important are, simulators of the biped robot's cinematic and dynamics to adjust the biped robot's control algorithms.

A biped robot design also require to withstand the rigorous of mechanical stress imposed during experimentation. This book considers some important physical considerations presented at the walking process, that should be know until begin the design and control of a biped robot.

The robot designed in this book has 10 *degree of freedom* (*DOF*) and each joint is driven by a DC servo motor. A modular design was chosen to allow an easy assemble and even a different *DOF* easy-reconfiguration.

In traditional legged robots, stability is maintained by having at least three contact points with the ground surface at all time. With biped machines, only two points are in contact with the ground surface, for that reason algorithms to achieve balance most be implemented.

There are some techniques to implement a balance control for a biped robot, many of them are implemented using classic control techniques, but some others are implemented using soft computing or artificial intelligent techniques. In this book an incremental fuzzy PD controller to achieve balance in a biped robot is proposed.

In order to implement the balance control in this book, a feedback-force system at each foot was implemented to obtain the ZMP and feed it in to the incremental fuzzy PD controller to calculate the ZMP error. Then the controller adjust the lateral robot's positions (balance) to maintain always the ZMP point inside of the support region [14].

To control the biped robot's walking sequence a dynamic walking algorithm was implemented. The algorithm is based on cubic polynomial interpolation of the initial conditions for the robot's position, velocity and acceleration. This guarantee a constant velocity at each robot's link an a smooth transition in the control of the walk trajectories and shows to be helpful to decrease the instability produced by violent transitions between the different walk phases [15]. Both algorithms (the fuzzy PD incremental algorithm for the biped robot's balance control and the cubic polynomial interpolation algorithm for the robot's walking sequence control) were programed using a C++ compiler running on two

PIC16F873 microcontrollers and successfully tested on the bipedal robot "Danny walker" designed at the Freie Universität Berlin.

1.2 Contribution of this book

In this book a biped robot structure is build to test walking and balance control algorithms. This book makes several contributions which are described in the following sections:

1. A biped robot structure based on modules is designed. The proposed modular design by its mechanical characteristics allows a quick and stable biped's robot configuration. It is designed following a low-cost philosophy. This philosophy, become such biped robot structures more affordable to a wide number of researchers. Likewise, this book describes the experiences gained during the construction of two previous biped robots structures.

2. A real-time biped walking based on a cubic polynomial interpolation algorithm is implemented. Real-time robust biped walking on the designed biped robot structure was achieve. The experimental results are presented in section 6.3.

3. A real-time biped balance control based on a fuzzy PD incremental algorithm is proposed. This algorithm, is based on the ZMP as a balance control criteria. The fuzzy PD incremental algorithm is quite compact. It allows a best computational efficiency than an adaptive control algorithm. The experimental results of the algorithm presented in section 6.2 demonstrated a smooth balance control response and a correct interaction between the robot's walking sequence algorithm.

4. A hybrid approach dynamic biped robot model is proposed. It combine the inverted pendulum model approach to model the biped's walking and a back-propagation neural network system identification approach to model the biped's balance. The neural network, predicts the behavior of the ZMP during walking. Its behavior is reported in section 4.3.2.2.

1.3 Book Organization

This book is organized as follow:

Chapter 1 briefly describe the biped robot research reported on this book. Introducing the biped robot problems, as well establishes the goals and, comments over the methods used on this book to resolve them.

Chapter 2 Pretend to classify the previous and related works on research labs and universities and some commercial companies a round the wold.

Chapter 3 describes the biped robot's design considerations that must be take in order to implemented a low cost biped robot hardware. The hardware design is presented, by the mechanical structure design and the electronic design. In this chapter, the modular-flexible design for an easy links robot's configuration is also presented.

Chapter 4 explains the robot's mathematical model. In this chapter, the deduction of the kinematics and the dynamic model for a 10 DOF biped robot are exposed. The mathematical robot's kinematic model is obtained to implement the simulation of the biped's robot kinematic. The kinematics is obtained by the handle of homogeneous transformation matrix applying the Denavit Hartenverg method. The robot's dynamic is obtained by the use of the inverted pendulum approach, to model the sagittal plane (walking sequence), and an artificial neural network used as a system identification to model the ZMP robot's dynamic (balance).

Chapter 5 explains the biped's robot walking theory. The ZMP concept as a balance control criteria is described. In this chapter, the walking problem is divided on two themes: the *balance control* and the *walking sequence control.* A fuzzy PD Incremental algorithm is proposed as a robot's balance controller, and *cubic polynomials algorithms* are presented to control the *walking sequence control*.

Chapter 6 proposes some simple tests in order to measure the robots performance. These test where implemented during the balance control and the walking sequence control for a 10 DOF low cost biped robot. This chapter also proposes, how some off-line adjustments (means a Matlab program) for the robot's walking sequence parameters can help to achieve stable walking trajectories.

Appendix A present the robot's spatial localization. This appendix describes mathematical tools that allows the space localization of its points. In this section the rotation matrix concept is introduced, also the homogeneous transformation matrix and its composition, explained by some examples.

Appendix B presents the recursive identification of parameters, which can be used to estimate a robot´s model on line (at the same time as the input-output data are received). Inquire possible time variation in the system's (or signal's) properties during the collection of data.

Appendix C As an extension of the sensory capabilities of a biped robot, a tool to implement artificial vision is presented. This is the MatLAB toolbox of *image processing.* A advantage of the used of this tool is with it, the time of implementation becomes the minimum with the trust of using algorithms scientifically proved and robust.

The toolbox of *image processing* implements a group of well-known algorithms to work with binary images, geometric transformation, morphology and color manipulation that together with the functions already integrated with MatLAB allows to carry out analysis and transformations of images in the domain of the frequency (Fourier and Wavelets transform).

This appendix is divided in 3 parts, the first one treats the basic concepts of the images how they are represented in MatLAB as well as an introduction to the basic operations of handling of files. The second part, covers the common and representative image processing functions in the area of computer vision; explaining the use of these functions through examples. Finally the third part explains the use of the tool vfm used to capture images of devices installed in the computer such as video cards and USB Webcams.

Appendix D As a option to implement the balance for a biped robot. An introduction to control systems theory by classical methods is presented. In this appendix, first the elements of a control system are presented, then some mathematical representations for a physical system are explained, finally the implementation of the controller is presented.

Chapter 2

Related work

Next, a description of some previous and contemporary related work research is presented. Pointing out the contributions and their limitations. The biped robot related work exposed, was principally done on universities and labs on the hole word. Also, some relevant commercial biped robot projects are presented. Is hard to establishes a classification, but attending to the available resources some of the research can be classify as a low-cost biped robot approach. Such kind of biped robots are similar to his costly counterparts in the sense that they can offer the capacities to study and improve new biped walking algorithms, but they are more affordable.

2.1 Biped robot research on universities and institutes

Next, a recapitulate of some research work achieve by some universities and research on institutes around the world. A lot of improvements on the biped robot technology have been achieve by them, but unfortunately, most of them do not publish their project details, the same case for the cost of their projects. They use sophisticate components, like sensors and actuators, but fairly of that, a important quantity of researchers on their research groups.

2.1.1 Early researchers

Shuuji Kajita [8] at National Institute of Advanced Industrial Science and Technology (AIST) designed and developed an almost ideal 2-D model of a biped robot. Kajita supposed for simplicity that the robot's COG (Center of gravity) moves horizontally and he developed a control law for initiation, continuation

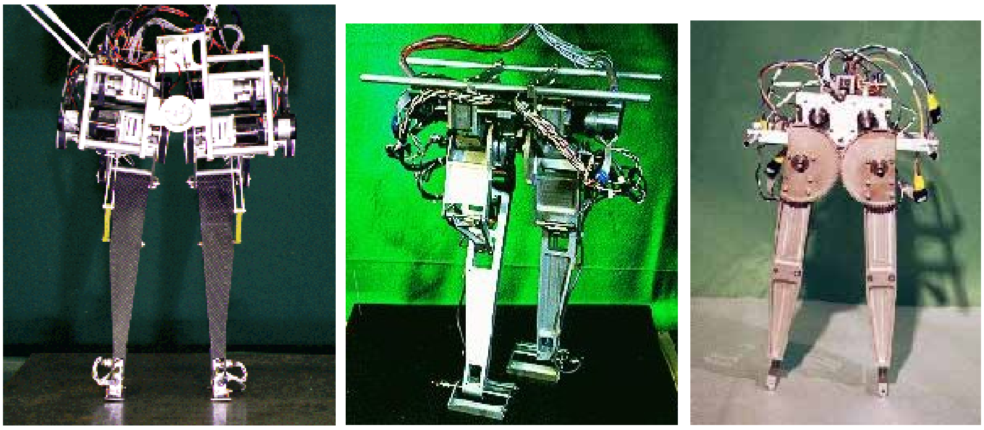

Figure 2.1: Biped robots used in earliest Kajita's experiments.

and termination of the walking process. Figure 2.1 shows some kajita's earliest biped robots.

Zhen [1] proposed a scheme to enable the robot climb inclined surfaces. By force sensors placed in the robot's feet, the transition of the type terrain can be detected and then to compensate the inclination, the appropriately motors movements can be generated. Using other approach, Zhen, uses the inclination of the mechanical structure, as indirect measure of the COG to control the gait walking.

Cubic interpolation is used for many researchers as a biped robot's gait generation. Shih [18] and Huang [19] have used cubic polynomials to generate the hip and foot trajectory to walk on uneven terrains. The work of Shih discusses only the static walking, while the work of Huang proposes a method for dynamic walking.

Kajita and Tani [17] used the inverted pendulum model to accomplish the walking in rugged terrain. They conducted 2 experiments: the single leg support phase and the change of support leg and they found that to achieve a smooth exchange of support leg is necessary to maintain a vertical speed as well to maintain for some instants the double support phase. Figure 2.2 shows more biped robots used in the Kajita's experiments.

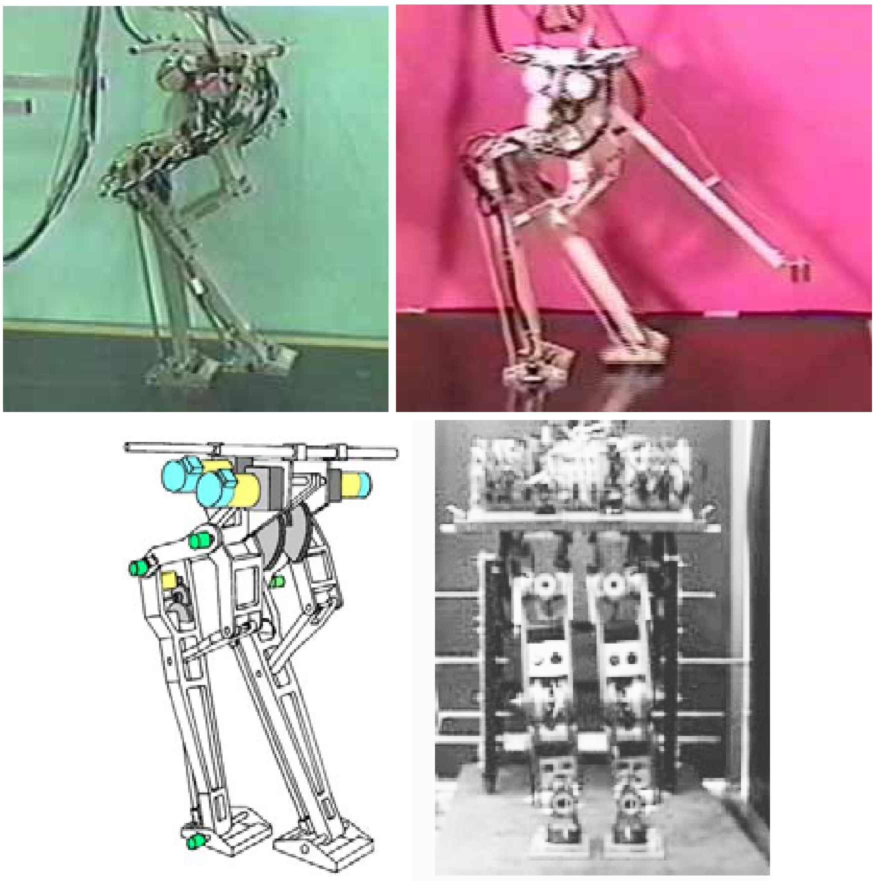

Figure 2.2: Biped robots used in Kajita's experiments.

2.1.2 Flamingo robot at Massachusetts Institute of Technology (MIT)

Pratt [16] proposed the control of a seven link planar bipedal robot by natural dynamics. This is an algorithm based on human gait: the swing leg can swing freely once started; a kneecap can be used to prevent the leg from inverting; and a compliant ankle can be used to naturally transfer the center of pressure along the foot and help in toe. Each of these mechanisms helps make control easier to achieve and results in motion that is smooth and natural looking. The advantage of this algorithm is that don't require many sensors to allow the robot to walk and using natural mechanisms the robot requires very little computation. The necessary sensing consists of joint angles and velocities, body pitch and angular velocity, and ground reaction forces. Figure 2.3 shows the spring flamingo robot developed at MIT by Pratt. However, on the information is not clear if the balance problem was resolved on this planar biped robot.