Chapter 48
Fractional Control of Legged Robots

Manuel F. Silva and J.A. Tenreiro Machado

Abstract Fractional calculus (FC) is being used in several distinct areas of science and engineering, being recognized its ability to yield a superior modelling and control in many dynamical systems. This article illustrates the application of FC in the area of robot control. A Fractional Order PD$^\mu$ controller is proposed for the control of an hexapod robot with 3 dof legs. It is demonstrated the superior performance of the system by using the FC concepts.

48.1 Introduction

Walking machines allow locomotion in terrain inaccessible to other type of vehicles, since they do not need a continuous support surface, but require systems for leg coordination and control [1]. For multi-legged robots, the control at the joint level is usually implemented through a PID scheme with position/velocity feedback. Recently, the application of the theory of FC to robotics revealed promising aspects for future developments [2].

Bearing these ideas in mind, the article presents the application of a FO PD$^\mu$ ($0 < \mu \leq 1$) controller in the control of an hexapod robot with 3 dof legs. Section 2 introduces the hexapod robot kinematic and dynamic models and the adopted controller architecture. Section 3 presents some simulation results showing the superior performance of the system under the action of a fractional-order controller. Finally, Sect. 4 addresses the main conclusions.

M.F. Silva (✉) and J.A.T. Machado
Department of Electrotechnical Engineering, Institute of Engineering of Porto, Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal
e-mail: mss@isep.ipp.pt, jtm@isep.ipp.pt

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48.2 Hexapod Robot Model and Control Architecture

The present study compares the tuning of Fractional Order (FO) algorithms, applied to the joint control of a walking robot with $n = 6$ legs, equally distributed along both sides of the robot body, each with three rotational joints $j = \{1, 2, 3\} \equiv \{\text{hip, knee, ankle}\}$ (Fig. 48.1) [3]. Leg joint $j = 3$ can be either mechanical actuated, or motor actuated. For the mechanical actuated case we suppose that there is a rotational pre-tensioned spring-dashpot system connecting leg links $L_{i2}$ and $L_{i3}$. This mechanical impedance maintains the angle between the two links while imposing a joint torque [3].

Figure 48.1 presents the dynamic model for the hexapod body and the foot-ground interaction. It is considered the existence of robot intra-body compliance because most walking animals have a spine that allows supporting the locomotion with improved stability. The robot body is divided in $n$ identical segments (each with mass $M/bn^{-1}$) and a linear spring-damper system (with parameters defined so that the body behaviour is similar to the one expected to occur on an animal) is adopted to implement the intra-body compliance [3]. The contact of the $i^{th}$ robot feet with the ground is modelled through a non-linear system, being the values for the parameters based on the studies of soil mechanics [4].

The general control architecture of the hexapod robot is presented in Fig. 48.2. We evaluate the effect of different PD$^\mu$ controller implementations for $G_{c_1}(s)$, while $G_{c_2}$ is a P controller. The PD$^\mu$ $0 < \mu_j \leq 1$ ($j = 1, 2, 3$) algorithm is implemented through a discrete-time 4th-order Padé approximation.

The performance analysis is based on the formulation of two indices measuring the mean absolute density of energy per travelled distance ($E_{av}$) and the hip trajectory errors ($\varepsilon_{xy,H}$) during walking [5]. It is analyzed the system performance of the different PD$^\mu$ controller tuning, when adopting a periodic wave gait at a constant forward velocity $V_F$, for two distinct cases: the hip and knee joints are motor actuated while the ankle joint is mechanically (passively) actuated, and the three leg joints are fully motor actuated [3].