Chapter 4.7
Dynamics and Simulation of General Human and Humanoid Motion in Sports

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ABSTRACT
This chapter relates biomechanics to robotics. The mathematical models are derived to cover the kinematics and dynamics of virtually any motion of a human or a humanoid robot. Benefits for humanoid robots are seen in fully dynamic control and a general simulator for the purpose of system designing and motion planning. Biomechanics in sports and medicine can use these as a tool for mathematical analysis of motion and disorders. Better results in sports and improved diagnostics are foreseen. This work is a step towards the biologically-inspired robot control needed for a diversity of tasks expected in humanoids, and robotic assistive devices helping people to overcome disabilities or augment their physical potentials. This text deals mainly with examples coming from sports in order to justify this aspect of research.

INTRODUCTION
Currently, researchers in biomechanics and robotics are investigating many different problems in motion of humans and humanoid robots. Generalization is still missing. This general approach would be useful for several reasons. From a purely academic point of view, general methods are always seen as a final target. From a com-
A contact can be rigid or soft. With a rigid contact, one LINK (or more of them) is geometrically constrained in its motion. For instance, in the single-support phase of a bipedal gait, the foot (being a link of the system) is fixed to the support and does not move (or it moves in accordance with the motion of the support). With a soft contact, there is no geometric constraint imposed on the system motion, but the strong elastic forces between the contacted link and some external object make the link motion close to the object. Two examples of such contact are walking on a support covered with elastic layer, and a racket hitting a ball in tennis.

**MATHEMATICS**

**Free-Flier Motion**

We consider a flier as an articulated system consisting of the **basic body** (the torso) and several **branches** (head, arms and legs), as shown in Figure 1. Let there be \( n \) independent joint motions described by joint-angles vector \( \mathbf{q}=[q_1, \ldots, q_n]^T \) (the terms joint coordinates or internal coordinates are often used). The basic body needs six coordinates to describe its spatial position: \( \mathbf{X}=[x, y, z, \theta, \phi, \psi]^T \), where \( x, y, z \) defines the position of the mass center and \( \theta, \phi, \psi \) are orientation angles (roll, pitch, and yaw). Now, the overall number of degrees of freedom (DOF) for the system is \( N=6+n \), and the system position is defined by

\[
\mathbf{Q} = [\mathbf{X}^T, \mathbf{q}^T]^T = [x, y, z, \theta, \phi, \psi, q_1, \ldots, q_n]^T.
\]

(1)

We now consider the drives. It is assumed that each joint motion \( q_j \) has its own drive—the torque \( \tau_j \). Note that in this analysis there is no drive associated to the basic-body coordinates \( \mathbf{X} \) (this is a real situation with humans and humanoids in “normal” activities, however, in space activities—actions like repairing a space station, etc. — reac-