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.

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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 commercial point of view, a software package that can cover a diversity of motions is a more economic solution than several specialized packages. The particular argument comes from sports where a general model should cover a diversity of motion tasks imposed to a human athlete or a humanoid.

This work considers a new and generalized approach to the modeling of human and humanoid motion. In principle, modeling may follow an inductive approach or a deductive one. In the inductive approach, one analyzes different real situations like human or humanoid gait and running; playing tennis, soccer, or volleyball; gymnastics (exercises on the floor or by using some gymnastic apparatus); performing trampoline exercise; etc. Each problem needs a different model, appropriate to the situation – it should cover all the relevant effects. Once a number of situations are explored, one may try to make a generalization. However, there is no guarantee that it will be successful. In the deductive approach, one starts with considering a completely general problem. Once the general model is formulated, one may derive different real situations as being special cases. Such approach requires a serious effort to formulate a general model. This chapter is an attempt in this direction; it explains the principles, derives the general methodology and proves the feasibility and applicability on few examples. The initial results in this direction were published by Potkonjak, Vukobratovic, and their associates (Potkonjak & Vukobratovic, 2005; Potkonjak et. al., 2006; Vukobratovic et. al., 2007).

The new approach starts with an articulated system (e.g. a human body, a humanoid, or even an animal) that "flies" without constraints (meaning that it is not connected to the ground or to any object in its environment). We use the term flier. This situation is not uncommon in reality; it is present in running, jumping, trampoline exercise, etc. However, such motions are still less common than those where the system is in contact with the ground or some other supporting *object* in its environment.

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 $\mathbf{q}=[q_1,\cdots,q_n]^T$ (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 θ, ϕ, ψ 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

$$\mathbf{Q} = [\mathbf{X}^T, \mathbf{q}^T]^T = [x, y, z, \theta, \phi, \psi, q_1, \cdots, q_n]^T . \tag{1}$$

We now consider the drives. It is assumed that each joint motion q_j has its own drive – the torque τj. Note that in this analysis there is no drive associated to the basic-body coordinates 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-

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