Whole body motion planning

Elements for intelligent systems designs

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Humanoid robots become increasingly sophisticated, both in terms of their movement as well as their sensorial capabilities. This allows to target for more complicated problems, eventually leading to robotic systems that can perform useful tasks in every days environment. In this paper, we will give an overview on some elements we consider to be important for a movement control and planning architecture. We will first explain the whole body control concept which is the underlying basis for the subsequent elements. We then present a prediction and action selection scheme that evaluates a set of behavioral instances within a parallel prediction architecture. This architecture allows the robot to quickly react to changing environments. We then review a more global movement planning approach which casts the overall robot movement into an integral optimization problem, and leads to smooth and collision-free movements within interaction time.

1 Introduction

While in its beginning, humanoid robotics research focused on individual aspects like walking, current systems become increasingly sophisticated. Many humanoid robots are already equipped with full body control concepts and advanced sensorial capabilities like stereo vision, auditory and tactile sensor systems. This is the prerequisite to tackle complex problems, such as walking and grasping in dynamically changing environments. Motion planning seems to be the most promising way to deal with this class of problems. State of the art planning methods allow to flexibly account for different criteria to be satisfied. Further, many computationally efficient methods have been proposed, so that fast planning and replanning can be achieved in real-world, real-time problems. Many results in the field of planning reaching and manipulation employ sampling-based methods like randomized road maps [1] or rapidly exploring random trees [2]. Model-based approaches are presented for optimal gaits [3] and for full body movements [4]. In general, two problem fields in humanoid robot motion planning have emerged. One recent research focus is centered to solve the foot step planning problem in dynamic environments [5, 6]. This is complemented by efforts to plan collision free arm movements for reaching and grasping [7, 8], and to incorporate the dynamics of the objects to be manipulated [9].

However, there seems to be no approach to address all problem domains within a consistent architecture. In this article, we will present some steps into this direction. We start out with the whole body control concept applied to our humanoid robot *Asimo* in Section 2. Based on this, we add reactive prediction and action selection with an architecture described in Section 3. It compares a set of different behavior alternatives and selects the most suitable one according to their prediction result. However, this scheme only has a limited time horizon. To generate movements that satisfies criteria throughout the whole trajectory, we present a controller-based optimization scheme in Section 4 in which we determine the attractor points describing the trajectory. The elements share a common basis, the whole body control concept.

The work presented here is part of the efforts towards researching intelligent systems at the Honda Research Institute. For instance the comprehensive systems presented in [10, 11] are based on the motion generation described in this contribution.

2 Whole body control system

In this section we briefly review the chosen redundant control concept: the general definition of task spaces, inverse kinematics and attractor dynamics to generate whole body motion for high-dimensional humanoid robots. Findings from the field of biology impressively reveal how efficiently movement is represented in living beings. Besides the well-known principle of movement primitives, it is widely recognized that movement is represented in various frames of reference, such as in eye centered, reach and grasp centered or object centered ones [12].

We borrow this principle and represent robot motion in a suitable task representation. For this, the robot control model is described in the form of a tree structure. The individual links are connected by degrees of freedom (joints) or fixed transformations. Further, the tree may also comprise objects from the environment. This allows to derive the inverse kinematics equations not only with respect to a heel or world reference frame, but also to formulate task descriptors accounting for robot-object relations. We define a task as the relative movement of two tree nodes[1] and such can compute the task velocity as $\dot{x}_{task} = \dot{x}_{ef} - \dot{x}_{base}$. Indices *ef* and *base* denote the effector body and its reference, respectively.

The choice of effector and reference yields some interesting aspects. This is illustrated in Figure 1 for a simple planar example. Representing the movement of the hand with respect to the cylinder results in the left part of Figure 1. A coordinated hand-object movement has to consider three

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[1] There are other special cases for tasks, for instance the overall linear and angular momentum, etc.

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