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Abstract

Virtual characters playing in a realistic way virtual musical instruments need to interact in real-time with the simulated sounding environment. Dynamic simulation is a promising approach to finely represent and modulate this interaction. Moreover, capturing human motion provides a database covering a large variety of gestures with different levels of expressivity. We propose in this paper a new data-driven hybrid control technique combining Inverse Kinematics (IK) and Inverse Dynamics (ID) controllers, and we define an application for consistently editing the motion to be simulated by virtual characters performing percussion gestures.

Keywords: Physics-based Computer Animation, Hybrid Motion Control

1 Introduction

Playing a musical instrument involves complex human behaviours. While performing, a skilled musician is able to precisely control his motion and to perceive both the reaction of the instrument to his actions and the resulting sound. Transposing these real-world experiences into virtual environments provides the possibility to explore novel solutions for designing virtual characters interacting with virtual musical instruments.

This paper proposes a physics-based framework in which a virtual character dynamically interacts with a physical simulated percussive instrument. It enables the simulation of the subtle physical interactions that occur as the stick makes contact with the drum membrane, while taking into account the characteristics of the preparatory gesture. Our approach combines human motion data and a hybrid control method composed of kinematics and physics-based controllers for generating compelling percussion gestures and producing convincing contact information.

Such physics framework makes possible the real-time manipulation and mapping of gesture features to sound synthesis parameters at the physics level, producing adaptative and realistic virtual percussion performances[1].

2 Related Work

Controlling adaptative and responsive virtual characters has been intensively investigated in computer animation research. Most of the contributions have addressed the control of articulated figures using robotics-inspired ID controllers. This has inspired many works for handling different types of motor tasks such as walking, running (Hodgins et al, 1995), composing these tasks (Faloutsos et al, 2001) and easying the hard process of tuning such controllers (Allen et al, 2007).

[1] More details about sound synthesis schemes as well as our system architecture can be found in (Bouënard et al, 2009).

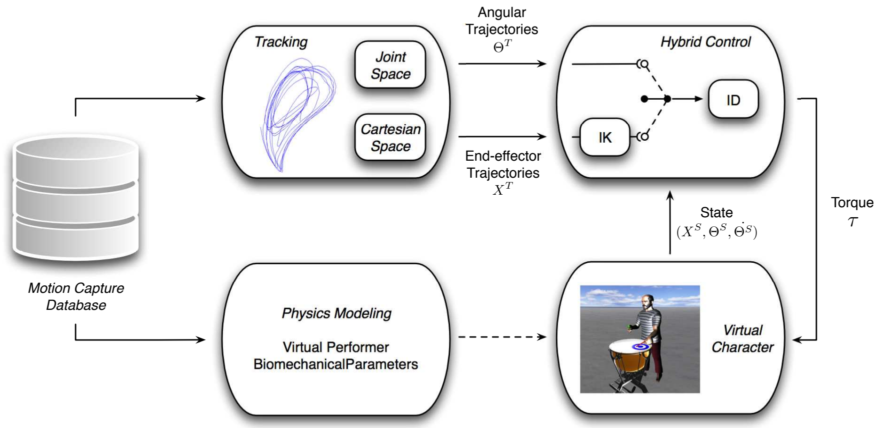

Figure 1: Physics-based motion capture tracking, either in the *Joint Space* from angular trajectories, or in the *Cartesian Space* from end-effector trajectories. The *Hybrid Control* involves the combination of *IK* and *ID* controllers.

More related to our work are hybrid methods, based on the tracking of motion capture data performed by a fully dynamically controlled character. The specificity of our contribution lies in the integration and the collaboration of IK and ID controllers, rather than handling strategies for transtionning between kinematic and dynamic controllers (Shapiro et al, 2003; Zordan et al, 2005). IK has also been used as a pre-process for modifying the original captured motion and simulating it on a different character anthropometry (Zordan and Hodgins, 1999). We rather use IK as a basis of our hybrid control method for specifying the control of a dynamic character from end-effector trajectories. This hybrid collaboration is particularly consistent for the synthesis of percussive gestures, which is not taken into account in previous contributions (Zordan and Hodgins, 1999; Bouënard et al, 2008-a).

3 Data-driven Hybrid Motion Control

A motion capture database contains a set of various percussion performances including different drumstick grips, various beat impact locations and several musical playing variations. We propose two ways for achieving the motion control (Figure 1), either by tracking motion capture data in the Joint space (angular trajectories), or tracking end-effector trajectories in the 3D Cartesian space. Tracking motion capture data in the Joint space requires ID control, whereas tracking in the end-effector (Cartesian) space requires both IK and ID (hybrid) control.

In the latter case, end-effector targets (X^T) in the 3D Cartesian space are extracted from the motion capture database, and used as input for the IK algorithm to compute a kinematic posture Θ^T (vector of joint angular targets). We chose the Damped Least Squares method (Wampler, 1986) driven by equation (1), a robust adaptation of the pseudo-inverse regarding the singularity of the inverse kinematics problem. J_Θ^+ is the pseudo-inverse of the Jacobian and X^S represents the current end-effector position of the system to be controlled. Other IK techniques may be equally used, such as the Jacobian transpose or learning techniques (Gibet and Marteau, 2003).

Angular targets Θ^T and current states (Θ^S, $\dot{\Theta^S}$) are then used as inputs of the ID algorithm, as expressed in equation (2), for computing the torque (τ) to be exerted on the articulated rigid bodies of the dynamical virtual character. This one is composed of rigid bodies articulated by springs parameterized by damping and stiffness coefficients (k_d, k_s).

$$\Delta\Theta^T = -\lambda.J_\Theta^+.(X^S - X^T), \;\; \Theta^T = \Theta^S + \Delta\Theta^T \tag{1}$$

$$\tau = k_s.(\Theta^S - \Theta^T) - k_d.\dot{\Theta^S} \tag{2}$$

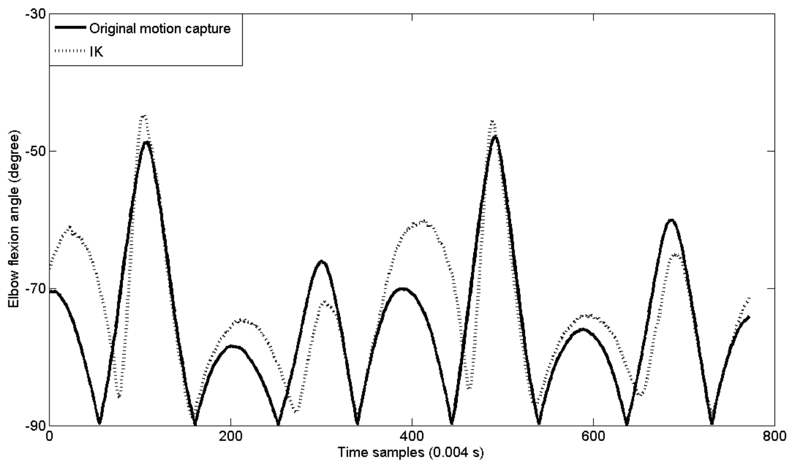

Figure 2: Comparison of elbow flexion angle trajectories: original motion capture data vs. data generated by the IK algorithm.

This hybrid approach enables the manipulation of physically simulated motion capture data in the 3D Cartesian space (X^T) instead of the traditional angular space (Θ^T), which is more consistent and intuitive for controlling percussion gestures by using end-effector trajectories, for instance drumsticks extremities obtained from the motion capture database.

4 Results

The results obtained by the two tracking modes are compared, keeping the same parameterization of the damped springs composing the virtual character. We ran the simulation on a set of percussion gestures (French grip, legato) recorded at a sample rate of 250 Hz for capturing the whole body of the performer as well as the drumsticks. The hybrid control scheme tracks one percussion gesture for synthesizing whole arm movements solely from the specification of drumstick tip trajectories.

Figure 2 presents the comparison between raw motion capture data and data generated by the IK process. It shows that data generated by the IK formulation are consistent with real ones, especially for the elbow flexion angle that is one of the most significant degree of freedom of the arm in percussion gestures, especially during preparatory phases (Bouënard et al, 2008-b).

We finally present the comparison of the two control modes (ID control only and hybrid control) in Figure 3. One interesting issue is the accuracy of the hybrid control mode compared to the simple ID control. This observation lies in the fact that the convergence of motion capture tracking is processed in the Joint space in the case of ID control, adding and amplifying multiple errors on the different joints and leading to a greater error than processing the convergence in the Cartesian space for the hybrid control. The main drawback of this improvement is however the additional computationnal cost of the IK algorithm which is processed at every simulation step. It provides nevertheless a more consistent and flexible motion edition technique for controlling a fully physics-based virtual character.

5 Conclusion

We proposed in this paper a physically-enabled environment in which a virtual character can be physically controlled and interact with the environment, in order to generate virtual percussion performances. More specifically, the presented hybrid control mode combining IK and ID controllers leads to a more intuitive yet effective way of editing the motion to be simulated only from drumstick extremity trajectories. Future work includes the extension and improvement of our hybrid control technique for editing and simulating percussion motion in the 3D Cartesian space.

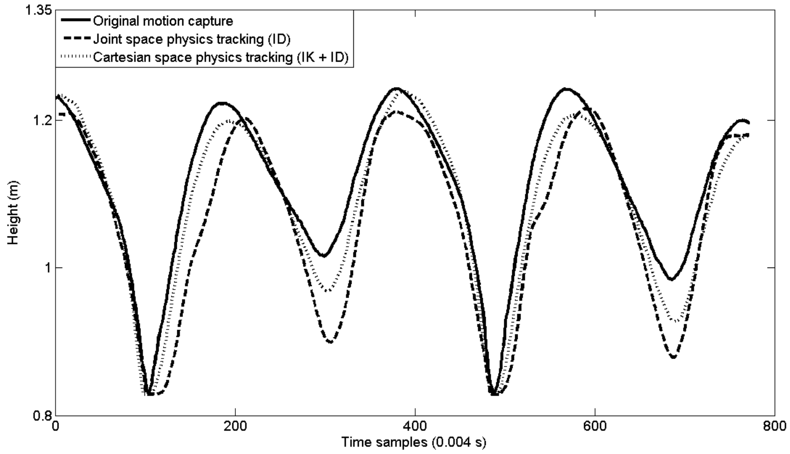

Figure 3: Comparison of drumstick trajectories: original motion capture data vs. Joint space (ID) physics tracking vs. Cartesian space (IK + ID) physics tracking.

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