Animating Brachiation

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Abstract

This paper presents a physically-based animation system for generating realistic motion of primate brachiation. One of the main aims of this system is to facilitate the process of generating brachiation sequences with appropriate automaticity and also provide the animator with adequate controllability. A hybrid system based on an integration of three control modules of different levels. The low-level control module, namely forward dynamics interactive module can be employed to rapidly manipulate the torque values at specific joints of a simplied primate figure. Both the mid-level and high-level control modules are designated to automate the process of generating the basic global brachiation movements of the primate figure. The performance of the system is evaluated by measuring the animation results qualitatively and quantitatively. Experimental results have demonstrated the effectiveness and robustness of the paradigm by generating animated sequences of realistic brachiating motion.

1. Introduction

An effective animation system should comprise of two essential features, namely, controllability and automaticity. Generally, controllability is defined as the capability of an animation system to aid an animator in realising his/her required aesthetic motion of a character. Whereas, automaticity is referred to the capacity of an animation system to generate appropriate motion of characters without human intervention. In the last decade, many physically-based animation system were developed for generating realistic gaits of various creatures. In particular, animation frameworks based on the application of physically-based controllers have demonstrated promising results for simulating the dynamics movements of creatures [9, 5, 13, 6].

In this paper, a hybrid system comprising of three levels of control, namely, low-level interactive control, mid-level tailored control and high-level control are appropriately integrated for generating realistic brachiating movements of a simplified primate model. The main feature distinguishing our approach from prior works is the proposed animation model for the generation of brachiating motion of a simplified three link tree structure figure is considered. In this brachiating locomotion model, the knowledge of brachiating primate [8], acquired from the literature of biology and biomechanics has been appropriately incorporated into the animation system.

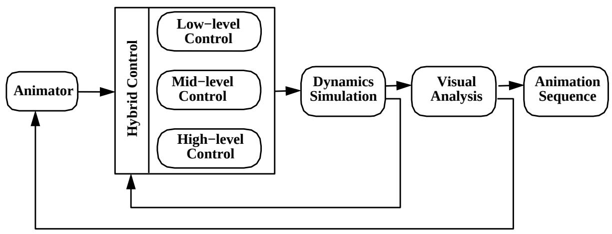

Figure 1: *Overview of Brachiation Animation System*

2. Related Work

Brachiation of a primate is generally referred to a primate suspending and swinging with arms shifting from one holder to another. A video sequence illustrating brachiating motion of Siamang can be found in the web site [7]. The representation of articulated primates for synthesizing brachiating movements is categorized as an underactuated system in which the number of actuators is less than the degrees of freedom (DOF).

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Brachiation is an active-constrained motion since a primate model can actively act with at least one arm held (hence the constraint) with the palm grasping a holder. This is distinguished from full active motion where the posture can be completely controlled (e.g. humanoid torso dancing[6]), and from fully free body motion (e.g. human diving[14]). To the best of our knowledge, the generation of brachiation motion in the domain of computer animation has not been considered. Although, there are several researchers implemented brachiating robots [11, 12, 3, 2, 1], their models were mainly considering the efficiency and stability of swing-up motion based on a simple chain structure model. In this aspect, the realism and naturalness of brachiation is not an essential requirement of a brachiating robot. On the contrary, this is a crucial component of a plausible model for generating animated sequences of brachiation.

3. Simplified Primate Brachiating Model

In our system, a primate is represented using a simplified primate model consisting of three rigid links connected by two rotary joints with one degree of freedom each (see Fig. 2). The configuration of these links representing the trunk, holding and grasping arms is shown in Fig. 2. Each of the two rotary joints consists of an angular actuator to apply the internal torque to the joint. In this case, no torque is applied at the joint between a holder and the palm of the grasping hand. Having defined the model structure, SD/FAST[10]is employed to generate the equations of motion for the dynamics simulation of brachiating movements.

4. Control Modules

4.1. Low-level Interactive Control

To increase the controllability of the system, an interactive dynamics simulation module is employed to modify the subtleties of the brachiation movement of the simplified primate figure. An animator is able to modify the subtle movements by adjusting the torque applying to the joints. This can be achieved by manipulating the control points of a B-spline curve approximating the trajectories of the joint torques. It is anticipated the joint torque values can be iteratively tuned by studying the visual results generated from the state outputs (i.e. angle, velocity and acceleration) of the dynamics simulation.

4.2. Mid-level Tailored Control

By studying the biomechanics literature [8] and observing the video clip of brachiation motion of a primate[7], two desired requirements are required, namely the pump energy of the dynamics motion for enabling a proper swing-up and the grasping of targeted holder when the swing reaches a certain height. A tailored controller is developed to accomplish these requirements and the details are explained in the following subsections.

4.2.1. Swing-up Control

The main idea of swing-up control is to extend the body so as to pull down the centre of mass of the body and to contract the body so as to pull up the centre of mass of the body according to different swinging states[8]. In our work, a complete cycle of swing motion consists of four states, namely, Swing Forward-Down (SFD), Swing Forward-Up (SFU), Swing Backward-Down (SBD), and Swing Backward-Up (SBU). The details of the configuration of each of these states are shown in Fig. 2. In the state of SFD, it is further subdivided into two sub-states, namely, SFD-U and SFD-L which are referred when the trunk of a primate is above and below the extending line of the holding arm, respectively (see Swing Forward Down State in Fig. 2). To achieve a swing motion, a joint-space PD control method is employed to compute the appropriate torque values for the rotary joints of a primate at different states for accomplishing the targeted postures.

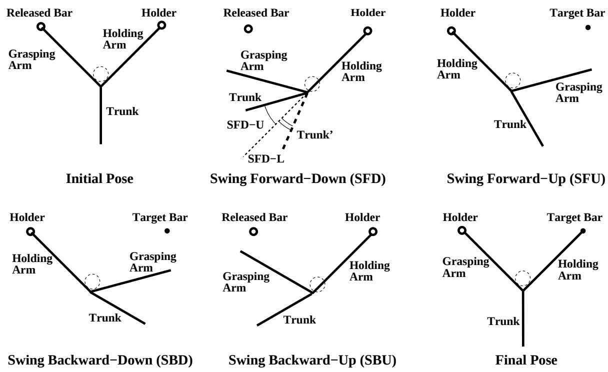


Figure 2: *Swing States*

4.2.2. Grasping Control

Two alarm attributes are designated to trigger the execution of grasping control (GRP). One of the alarms is the distance, D_{gt}, between the palm of a grasping hand and a targeted holder. The other alarm is the holding arm angle, θ_h, measured between the holding arm and the vertical axis. The meaning of these two alarm attributes can also be referred to Fig. 3. Once the values of these two alarms reach certain prespecified threshold values, the tailored controller will execute the grasping control module attempting to reduce the angles, α and γ by using PD control approach to move the primate model, where α denotes the angle, $\angle GST$ and γ denotes the angle measured from the trunk to the vertical axis (see Fig. 3).

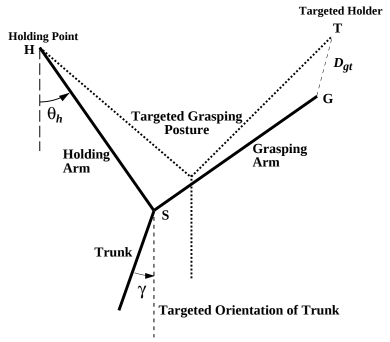


Figure 3: *Grasping Control*

4.3. High-level Control

The automatic adjustment of the position of the control points of the curves representing the rotary torque values is accomplished by dynamically observing the outcome of the performance metric computed using the current torque curve. The performance metrics employed in the high-level control at different states are shown in Table 1. For example, in the case of SFD state, the objectives of the performance metric are designated to maximise the kinetic energy E_K of the primate body to achieve the desired posture, namely the trunk in parallel with the holding arm of the primate.

State	Energy	Targeted Posture
SFD	Maximise E_K	Trunk $\parallel$ Holding Arm
SFU	Maximise E_P	Trunk $\perp$ Ground
SBD	Maximise E_K	Trunk $\parallel$ Holding Arm
SBU	Maximise E_P	Trunk $\perp$ Ground
GRP	Minimise D_{gt}	Trunk $\perp$ Ground

Table 1: *Objectives of Performance Metrics at Different States*

5. Integration of Control Modules

The above mentioned three levels of control modules can be applied to different intervals of a brachiating animation sequence either as an individual module or a combination of them. To apply in a combinational manner, we generally combine the low-level with the mid-level control modules or the low-level with the high-level control modules for maintaining the balance between controllability and automaticity. To combine the low-level and mid-level control modules, the mid-level tailored controller is first applied for generating a reference brachiating motion for an interval. Next, an animator can then employ the low-level interactive control module for accomplishing the subtle motion of the final motion sequence by manipulating the control points of the signal curve representing the torques of the rotary joints. Similary, the combination of low-level and high-level control modules is first executed by the high-level controller for generating a reference animation sequence before embarking on the low-level module. In this case, the animator can easily obtain a reference sequence without having to specify the details of the performance metrics which is certainly a non-trivial task.

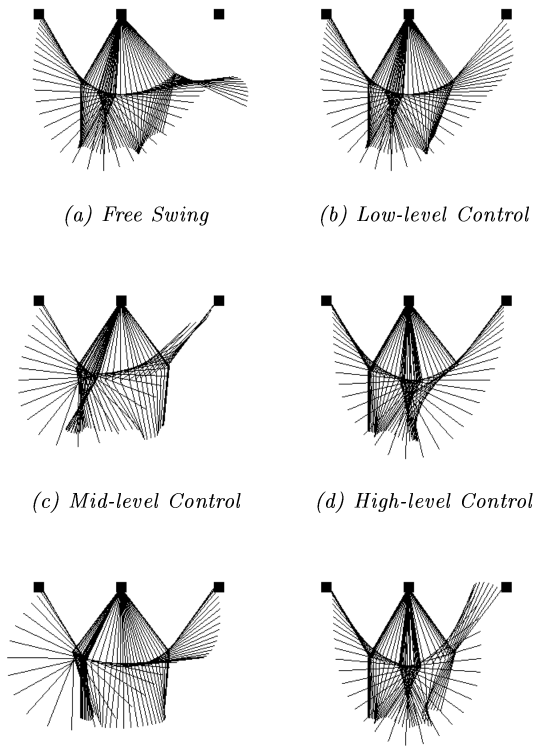
6. Experimental Results

In this section, a representative experiment is employed to exemplify the effectiveness, robustness and problems of the proposed brachiation animation system. In this experiment, we will summarize the analysis of the kinetic energy (E_k), potential energy (E_p), distance between the palm of a grasping hand and a target (D_{gt}) and the realism of an animated sequence. The first three metrics, E_k, E_p and D_{gt} are employed to quantitatively measure the performance of the controllers for swing down, swing up and grasping, respectively. In the case of the measure of the realism of brachiating motion, this can only be pursued qualitatively.

The quantitative and qualitative evaluation of the results of controlling a swing forward motion (i.e. in this case swing up motion) and a grasping motion are reported. In this example, a free swing (FS) and five different setups of control modules, namely low-level (L), mid-level (M), high-level (H), a combination of mid- and low-levels (M-L) and a combination of high- and low-levels (H-L) are employed. The quantitative and qualitative measures of the results are tabulated in Table 2. In the case of free swing (FS), the primate figure was not able to grasp the targeted holder (e.g. smallest value of D_{gt} is 0.8) due to the lack of strength being applied to the rotary joints. For the rest of the cases, the primate figure was able to grasp the targeted holder successfully. The animation sequences of the experimental results can be referred to http://www.cgit.ntu.edu.sg/~zzheng/Research/index.html.

Control	E_k	E_p	Qualitative Evaluation
FS	24.7	-0.894	Lack of strength, grasping unsuccessful
L	28.1	-0.894	Uniform motion, lack of momentum
M	32.6	-0.768	Strong momentum, excessive power
H	27.9	-0.707	Grasping posture unnatural
H-L	25.8	-0.736	Grasping posture more natural
M-L	51.2	-0.779	Realistic motion achieved

Table 2: *Quantitative and Qualitative Evaluation*



(a) Free Swing *(b) Low-level Control*

(c) Mid-level Control *(d) High-level Control*

(e) M-L Control *(f) H-L Control*

Figure 4: *Samples of Brachiating Sequences Generated With (a) Free Swing, (b) Low-level Control, (c) Mid-level Control, (d) High-level Control, (e) A Combination of Mid-level and Low-level Controls and (f) A Combination of High-level and Low-level Controls.*

7. Conclusion

A physically-based animation system for generating brachiating motion of primates has been presented. A hybrid system comprising of low-level, mid-level and high-level control modules has been developed to maintain the balance between controllability and automaticity of the system. The relevant knowledge of the biomechanics of primates has been incorporated into the design of the mid-level and high-level controllers. Experimental results have been reported to demonstrate the effectiveness and robustness of the proposed animation paradigm for producing realistic brachiating movements.

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References

1. G. N. Boone, Minimum-time control of the Acrobot, *IEEE International Conference on Robotics and Automation*, pp. 3281–3287, 1997.
2. G. DeJong and M. W. Spong, Swing Up the Acrobot: An Example of Intelligent Control, *Proceedings of the American Control Conference*, pp. 2158–2162, 1994.
3. T. Fukuda and F. Saito, Motion Control of a Brachiation Robot, *Robotics and Autonomous System*, 18, pp. 83–93, 1996.
4. R. Grzeszczuk, D. Terzopoulos and G. Hinton, NeuroAnimator: Fast Neural Network Emulation and Control of Physical-Based Models, *Proceedings of SIGGRAPH'98*, pp. 9–20, 1998.
5. J. K. Hodgins, W. L. Wooten, D. C. Brogan, and J. F. O'Brien, Animating Human Athletics, *Proceedings of SIGGRAPH'95*, pp. 71–78, 1995.
6. M. J. Mataric, V. B. Zordan, and M. M. Williamson, Making Complex Articulated Agents Dance: An Analysis of Control Methods Drawn from Robotics, Animation, and Biology, *Autonomous Agents and Multi-Agent Systems*, 2(1), July 1999.
7. The Oakland Zoo, "Brachiation of Siamang", http://www.oaklandzoo.org/atoz/siamang.html.
8. H. Preuschoft, and B. Demes, Biomechanics of Brachiation, In *The Lesser Apes*, Preuschoft H., Chievers D. J., Brockelman W. Y. and Creel N. (eds.) Edinburgh University Press, 1984.
9. M. H. Raibert, and J. K. Hodgins, Animating of Dynamic Legged Locomotion, *Proceedings of SIGGRAPH'91*, pp. 349–356, 1991.
10. SD/Fast User's Mannual, Symbolic Dynamics Inc., Mountain View, California, USA, 1994.
11. M. W. Spong, Swing Up Control of the Acrobot, *IEEE International Conference on Robotics and Automation*, Vol. 3, pp. 2356–2361, 1994.
12. S. Takashima, Control of Gymnast on a High Bar, *Robots and System IROS*, pp. 1424–1429, 1991.
13. van de Panne, M., Parameterized Gait Synthesis, *IEEE Computer Graphics and Applications*, Vol. 6, No. 2, pp. 40-49, 1996.
14. W. L. Wooten and J. K. Hodgins, Animation of Human Diving, *Computer Graphics Forum*, Vol. 15, No 1, pp. 3-13, 1996.