6. CONCLUSIONS AND FUTURE WORK

The initial goal of this thesis was to provide a general technique for the control of complex, statically-unstable 3D bipedal creatures for use in physically-based animation. For simplicity, only cyclic motions were considered. The proposed control formulation meets this goal by discretizing the periodic motion into cycles and simplifying the control through the use of a limited set of control perturbations which are used to stabilize a small set of observed variables.

The approach is general in the sense that the same control technique can be used to control a wide variety of walking gaits for a wide range of control parameter choices. Control of speed and direction for a biped has been demonstrated, as well as parametric variations of a number of walking characteristics. By using simple feedback to drive the parameterized controllers, it is possible to give the animated creature a greater degree of autonomy, providing the animator with high level control. The approach has been demonstrated for walking and limited forms of running, using both a human model and a bird-like robot model. We believe that the technique will also prove to be a suitable approach to animating many other types of periodic behaviours for a wide variety of articulated figures.

While the bipeds are not of full human complexity (which would require about 200 DOFs), they are sufficiently complex that many other forms of control would prove computationally infeasible. Many of the DOFs in the human body cannot act independently, for example, the vertebrae of the spine. The tens of DOFs in our models are sufficient to capture the gross motions of natural bipedal locomotion with reasonable fidelity.

The primary contribution of this thesis is to illustrate that control techniques can be successfully applied to animate creatures of high complexity.

6.1 Future Work

A number of items remain for future work. In particular, improved performance, other forms of locomotion and more natural looking motion remain to be addressed. As well, extension of the control formulation to non-periodic motions and the possibility of automating much of the design process stand out as worthwhile avenues to pursue.

6.1.1 Better Discrete System Models

One of the drawbacks of the current control approach is the high computational expense of reconstructing the discrete system model each cycle. In the case of our bipedal control, this results in a four-fold increase in the time required to generate the final motion. Two reasonable possibilities exist to reduce this cost. Both are based on the reuse of previously computed models rather than blind reconstruction of the model each cycle.

One approach would be to reconstruct the model only when necessary. Once a reasonable limit cycle has been reached, the model parameters determined through sampling remain relatively constant from one cycle to the next. In such cases, a fixed model may be sufficient. By assuming fixed model parameters and monitoring the final RV values for deviations from the limit cycle, it seems likely that direct balance control can be achieved for much of the desired motion. When a limit cycle terminates, for example due to a change in base PCG, a new system model could be constructed.

A second approach might be to construct a general discrete system model which is parameterized with respect to the creature's initial state at the start of a cycle. Such a model could be constructed by generating a number of walks from various initial conditions and recording the model parameters and initial state for each. Once a large enough number of models have been generated, they could be used in the form of a lookup table. Particular models could be chosen using a nearest neighbour approach based on the initial state of the current cycle. The number of different models generated should be sufficiently large to span a reasonable domain of initial states. A general model like this could incorporate varying terrain or other environmental state information in order to allow a wide range of behaviours.

6.1.2 Additional Forms of Locomotion

A number of features need to be added to the system for it to be truly useful as a generic biped animation system. First, other common forms of bipedal locomotion such as skipping and hopping would be necessary, as well as transitions between the various types of gaits. A second desirable feature not yet explored is the ability to generate robust locomotion over varying terrain. Finally, it should be possible to parameterize a controller with respect to various model properties such as mass and dimensions. We believe that it is possible to implement such features within the proposed control structure.

6.1.3 Natural Motion

The motions obtained to date using our technique do not yet represent convincing human motion. This is primarily due to the use of simple base PCGs. One possible way to achieve more natural motion might be to fine tune a suitable open-loop motion based on motion capture data. While we are convinced that more natural looking motion can be attained with a reasonable amount of extra effort, this remains to be demonstrated.

6.1.4 Extension to Aperiodic Motions and Further Generalization

While this thesis has focused on cyclic motions, a similar approach might be suitable for controlling aperiodic motions. Such motions would include standing up, sitting down or throwing a ball at a target. Other useful acyclic motions might include transitions into and out of cyclic motion and dynamic balancing in place, stepping only when necessary. A unified control technique for both periodic and aperiodic motions would be quite useful, since animators typically require the ability to freely move between the two as needed.

6.1.5 Automatic Synthesis

Another possible direction for future work is toward automatic controller synthesis. While the base PCGs, RVs and LPPs for the motions given throughout this thesis were designed by hand, they should ideally be automatically generated. Previous use of pose control has been directed primarily toward such automatic synthesis of motion controllers [vKF94] [vKF94b] [vL95].

Most of these attempts deal with relatively simple, statically-stable creatures. The problem of automatic synthesis of control for statically unstable 3D systems is a difficult one. In [vL95], van de Panne and Lamouret propose the use of external guiding forces to initially generate cyclic PCGs, followed by two subsequent phases which reduce the forces and then attempt to eliminate them respectively. While the motions generated by the second phase are significantly more natural looking than the initial PCGs, they are not fully realistic in the sense that the creature's actuators do not drive the motion unassisted. The final phase, removal of external forces, is not always successful and can be very computationally expensive.

Rather than attempting to directly synthesize the entire PCG in this way, it might be possible to automatically synthesize various control components for our system. The two most likely candidates are the base PCG and the fixed PCG perturbations (LPPs). Base PCGs for various interesting motions might be synthesized using van de Panne's first two phases and then stabilized using the balance control presented in this thesis. LPPs might be synthesized using a more traditional generate, test, and refine process such as that used for simple, statically stable systems.