Chapter 9 CONCLUSION AND FURTHER WORK

# 9.1 Conclusion

This work presents a novel method for synthesizing character motions dynamically following the biological principle.

For Animation, it provides a computational efficient method for adaptive motion synthesis.

However, the new animation technique is not the only object; the underlying new perspective of biological motor control may be of more value.

The research starts with a careful comparison of biological animals and artificial machines.

The discovery is that although artificial systems can move in a manner similar to biological animals, the control principles are very different.

This is because such artificial control methods cannot be scaled up to the complexity of biological systems.

Also the robust stability, energy efficiency and computation constraints imply that the biological systems must have adopted different control approaches.

This research takes this inspiring finding as the key research question.

We think that the control difference may be the crucial reason for the artefacts of current CMS methods and also the key obstacle in CMS is not the lack of algorithms or powerful computers, it is the misunderstanding of the biological motor control system. To improve CMS, we need a better control idea.

This thesis propose the new motor invariant theory, which is a very different idea about biological motor control.

Based on the finding in biological research, MoIT proposes that the questions of control and planning motion trajectory can be transformed into the questions of the manipulating the topology and symmetry of natural dynamic system. This new viewpoint provides a new but powerful way to understand natural motion and control. Since natural dynamics is governed by the body and environment, the new theory captures the characteristics of in the intensive body-environment interactions from the beginning. Unlike the other theory that contradicts with biological finding, the new theory complies with the biological facts and is informative in details.

In theory, it provides valuable information to understand the moving animal; in practise, it provide a method that is simple and computational efficient.

With this theory, motions that are unstable and challenging from traditional perspective can be synthesized with simple control. The bipedal walking example in chapter 6 shows that methods based on the new theory generates stable, adaptive, efficient and natural looking motion. In Chapter 7, we shows even the transitional motion can be physically synthesized adaptively by methods of the same framework.

However, currently the new theory is far from sound and mature. The principle can be scaled to system of any complexity, for attractor and the symmetry property of natural dynamics are common.

However, since topology and symmetry are recent developments in mathematics, tools for analysing topology and symmetry are not sufficiently powerful.

Except for certain cases, analyzing the topology or symmetry of general dynamic systems remains a difficult mathematical problem. Chapter 8 provides some idea of based on approximation or working around, but more research work is needed.

## 9.2 Further Work

Motor Invariant Theory is not an improvement of existing CMS techniques, it is a different paradigm. This thesis does not explore the full implication and potential of the new born theory. There are rooms for improvement, new techniques to developed and even new questions to be answered. This section summarizes several potential topics that may interest computer graphic or biological research communities.

## 9.2.1 Stable Templates For Motion Primitives

Research in this thesis starts from unstable system, stability is enhanced by adding control effort. Motor control is a complex task. In many cases, it is impossible to model all the control efforts that turn an unstable system into stable ones.

An alternative method is to start from a stable system and modify its shape to match the observation. Such methods may lose the details of motion but provide better stability and controllability. For games or film production, this idea may be important; animator requires controllability and stability over physical realistic. For characters performance acrobat, the characters must not fall even dynamic system is unstable in nature.

## 9.2.2 More Types Of Symmetry

More type of symmetry will generate more type of transformation that can be applied to the adapt motion. All the group actions adopted in this research are linear transformation group, which are easy to compute. But the types of transformation are very limited. Exploring more types of symmetry may provide a different adaptation schemes and may expand the theory to different motion primitives.

• Discrete Symmetry Properties Bipedal motions are synthesized in this research, an interesting idea is whether four or more legs motions can be built based on the bipedal walking strategy.

This can be done by exploring another type of symmetry: discrete symmetry.

For the house hound, the hind leg and font leg will move in synchronization or in anti-phase.

• Non-linear Symmetry from Structural Parameter Turning Non-linear symmetry preserving transformation will generate more type of adaptation. Since non-linear transformation is more difficult to find, it remains questionable how a biological system perceives it and applies it for motion adaptation. However non-linear transformation is suitable for modelling the transformation resulting from tweaking system parameters. For the idea of structural stability we know the results of tweaking system parameters are equivalent to having a one-one mapping transformation. Further research result from non-linear transformation may potentially completely solve the motion re-targeting problem

• Symmetry of Partial Differential System

All the methods developed are for ordinary differential equations, which is good enough for rigid body dynamics. In fact the topological property and symmetrical property also apply to partial differential equations. A famous example in physics is the Lorenz transformation group and Maxwell equation.

Symmetries of partial differential equations are important for they may extend the control strategy to control the motion elastic body or locomotion in fluid.

Such motion are more expensive are little addressed by current CMS methods.

To exploring more types of symmetry, reformulating the form of equations may ease the task. Current dynamic equations are based a fix coordinates frame. It is helpful to formulate the equations in the coordinate free manner or in the local frame.

## 9.2.3 Transform the Motion Capture Data

For computer animation, even methods for simulation high dimensional characters are proposed. It may be impractical to synthesize all types of motions by procedure method. An alternative method is to use dynamic simulation to modify motion capture data, which is well addressed in many researches in computer graphic community

Based on the idea of topological equivalence, motion primitive of different persons or motions of different situations should have the property of topological equivalence. In state space, there should exist a one to one mapping transformation function. Motion

Data can be converted into the state space and transformed by one-one mapping.

We can use the low dimensional model to find the one to one mapping relationship, which is applied to transform the high dimensional motion capture data. Potentially, this method may retain the motion details and involves little computational work.

## 9.2.4 Muscle Actuation

In the thesis, control effort is applied directly to each DOFof the mechanical system.

In biological research, this process is not so direct. Neural system generates some chemicals which affects the material properties of muscles. And force is generated　as an indirect side effect.

The question muscle actuation is untouched in this research, but with a second thought, MoIT also provides an alternative idea of muscle action. Transformation is the reason for applying control effort, the actuation of muscles can be calculated directly from the transformation, without caring about the force generated. From this perspective, muscle actuation can be easier than calculating the forces.

For the simple mass spring system, offset can be implemented by changing the rest length parameter d. Speed action can be implemented by changing the stiffness K. and energy scaling can be achieved by adjusting the stiffness K and then restoring it.

The reason is transformation can be achieved by two methods. Either control effort or by changing the system parameters.

For biological system, the method of changing parameters may be better for it will help motor control system get rid of the necessary feedback and computation. In fact most of control effort in the thesis is potential energy shaping, which only involves modifying the potential energy. If muscles are modelled as spring, then potential energy shaping can also be achieved through modifying spring parameters.

The complex muscle structure may provide a mechanism for fine turning the deformation of the phase portrait and the attractor can be changed into any possible shape. This idea may propose a conjecture for further biological research. For graphic research, incorporating muscles in this manner will have no effects on motion synthesis or computational work. The potential benefit is that the parameters of muscles can affect the skin deformation.

## 9.2.5 Perception based Dynamics

Motion perception is a high level capacity; it is based upon our object recognition ability and our dynamic reasoning ability. And many physiological questions in computer graphics may finally conclude with the recognition and perception research in neural science. The introduction of a motion synthesis method also touches the question of dynamic motion perception and encoding problem in intelligence. The topological equivalence and symmetry may also provide an understanding of the perception problem.

Based on the idea of topology equivalence, neural system may not need to encode the details of dynamic system; neural system can form an analogous dynamic system in our brain that is analogy to the real dynamics. Such model will lack the details accuracy, but get the qualitative properties right.

Based on the idea of symmetry, neural system may store some experience and the symmetrical property of dynamics in memory. Our brain may verify dynamics by transforming our experience to match observation.

We are still not sure which method is better, but both of methods are more practical for our brain than forming a symbolic equation solving the differential equations numerically. Maybe a new dynamic simulator can be designed to test this hypothesis.

Dynamic simulator can be build upon the topology and the symmetry property.

Animator can specify animation by specify its attractor and the transformation being applied. If the hypothesis is true, even the method will generate physically inaccurate results, audience will not notice it.