Global Dynamics: a new concept for design of dynamical behavior

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Abstract

The global dynamics, a novel concept for design of human/humanoid behavior is proposed. The principle of this concept is to exploit the body dynamics and apply control input only where it is necessary.

Within the phase space of the body dynamics, there are many stable and unstable manifolds coexist. Then if we analysed its structure and obtained a map in sufficient resolution, it may be possible to realise a motion by exploiting stable regions for reducing control input and unstable regions for switching between stable regions.

Also, we expect an emergence of symbols within the dynamics, as the series of points where control input should be adopted. This feature realises higher level description and makes adaptation behavior easier. We are studying from two aspects, the motion capture experiment and dynamical simulation of simple elastic robot. The former supports that above assumption and the latter supports the exploiting the dynamical stability is useful.

1 Introduction

While adaptation is a promising idea to obtain life-like behavior, its methodology may not well established. Especially, if one tries to acquire dynamical behavior, it is still a hard problem.

However, we think that if we know the dynamical nature of the body dynamics, it becomes easier. In the present work, we would like to propose a concept, the “global dynamics”. (Kuniyoshi and Nagakubo, 1997) (Yamamoto and Kuniyoshi, 2001) This concept is to exploit the body dynamics (e.g. (McGeer, 1990) (Pratt and Pratt, 1998)) and apply control input only where it is necessary (e.g. (Linde, 1999) for walking) for general human/-oid motion, as will be explained.

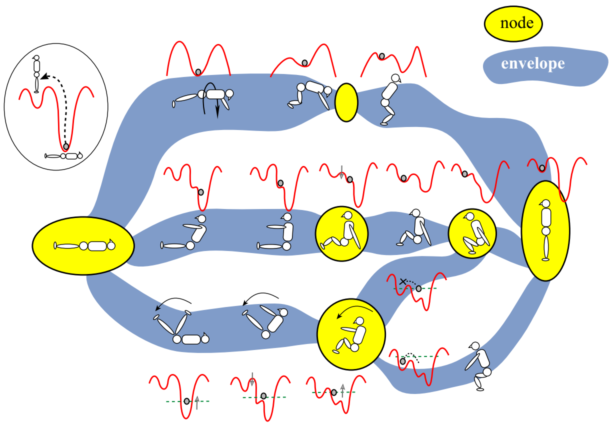

Figure 1: schematic representation of the global dynamics

2 Global Dynamics

A schematic diagram is shown in fig.1. This picture describes possible trajectories of the rising motion. The postures and schematic energy landscape (grey line) are snapshots of each trajectories. With a help of this figure, our theory and assumption for general property of phase space of human body dynamics is described as follows. (note: from now on, we discuss mainly on human(-oid) behavior, but our discussion is not limited to it and widely applicable to other dynamical body behavior where following assumption is valid.)

First, in the phase space, the trajectory is not completely unstable and most part of it is dynamically stable. Such stable region may have finite volume and it is called *envelope* (light shaded area). Within each envelope, control input is not necessary or minimised. Note that the envelopes are articulated and discreet transition between each motion pattern is suggested. This differentiation of patterns is reported by van Sant (van Sant, 1988) and we have also confirmed by ex-

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periment described in the next section.

Second, when above assumption is true, external control input is applied only to move the system across between envelopes. We call such unstable regions *nodes* (bordered circle in the figure). Then it become possible to describe the behavior in “node-to-node” manner, since one should care control only near the nodes. In other words, symbolic coding can be possible. This feature enables higher level description. Hence make adaptation behavior easier.

Using the global dynamics, we expect it becomes easy to construct a model or a real robot that can acquire human-like behavior in adaptive manner. Because once detail map of body dynamics is made, the cost of adaptation is largely reduced.

To establish the concept of global dynamics, we are studying from both sides of numerical simulation and motion capture experiment. They are described later in this paper.

3 Motion Capture

By motion capturing, we have measured actual human motions. Currently we are focusing on the rising in dynamical way. We ordered to subjects to rising from spine position swing up the legs without twisting or using hands.

Extracting the joint angles from captured data, trajectories are analysed. Since human behavior is not precise, in a superimposed plots of trajectories, they converge only important regions. In fig.2 a superimposed plot of 11 trials is shown, as a relationship of joint angles between the knee and the ankle. As we expected, diverse trajectories are shown. Their diversity is thought to reflect the volume of envelope. When the leg is swung up in lying down position, the trajectories are diverse because of trivial stability of the whole body. On the other hand, at the final stage, when the center of gravity is within the feet area, the volume of envelope is small and trajectories converge. While this plot is taken from the trials of single subject, we believe this property is common.

We have also measured trajectories in different condition. For rising, we gave description to put the feet 30cm outward when the subjects contact their feet on the ground. Under this condition, support transfer from hip to feet is difficult and only dynamical rising is possible. If we only compare trajectories of two different conditions (i.e., natural and restricted contact point) in the dimension of joint angle, difference is not obvious. Actually, in fig.2, trajectories of both conditions are superimposed.

However, if we take the dimension of velocity into account, the difference become clear. In figs. 3 and 4, relationship between head speed and joint angle of the ankle are shown. Note that there is obvious difference in the trajectory pattern between fig.3 (no restriction) and fig.4 (with restriction). This implies the importance of evaluation of phase space (i.e., not configuration space). Hence the use of the phase space (i.e., dynamical aspect of the global dynamics) is shown.

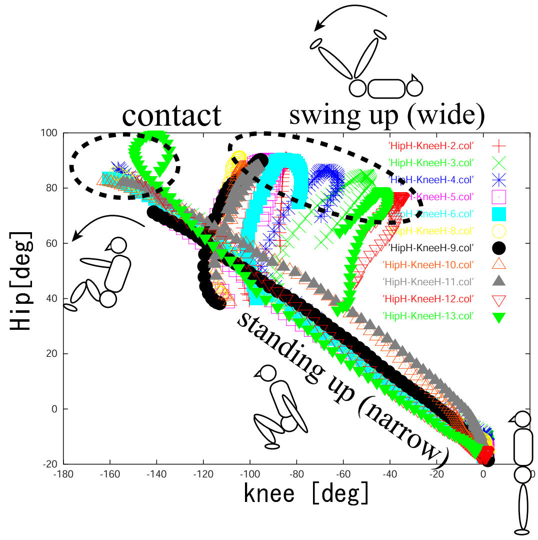

Figure 2: superimposed plot of relationship between the hip and the knee. Note that both are joint angles.

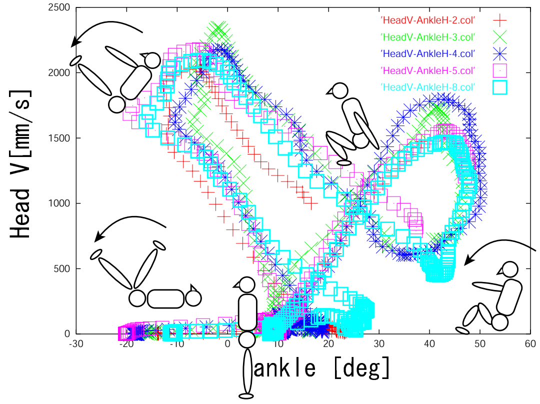

Figure 3: superimposed plot of relationship between the head speed and the ankle (angle). Without restriction of place to foot contact.

The differentiation of two patterns corresponds division of envelopes in the lower right in fig.1. Still this diagram is a schematic one, but we believe it is possible to extract such diagram from experimental data.

4 Dynamical Simulation

In numerical simulation, we are evaluating merits of elastic body. By simulation of a simple robot with springy joints (see fig5), so far we have shown two features.

One is that vibration damping is trivial, which required highly tuned filter method for conventional method in robotics (e.g., (Hirai et al., 1998)). The reason is that elastic elements can store kinetic energy. Also, since human body can be regarded as inverted (nonlinear) pendulum and the oscillation energy can be distributed to each modes to avoid resonance and

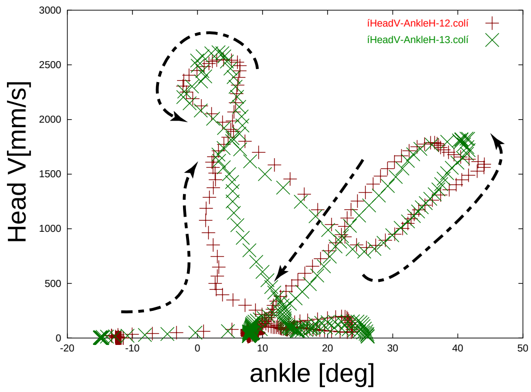

Figure 4: superimposed plot of relationship between the head speed and the ankle (angle). Place to foot contact is restricted 30cm outwards.

amplitude can be kept small in total.

In figure6, an example of oscillation damping is shown. In this example, external oscillation is applied for 5 secs and damping of oscillation is evaluated by plotting trajectories of center of gravity. While oscillation does not decay when the neck spring is stiff (gray line), decays faster when the neck spring is soft (black line). It is important to note that amplitude of the neck is bigger in the latter. Then the damping occurs through transportation of oscillation energy and the total energy does not dissipate at once but kept as a small oscillation of each joint.

The other is that a method to use the energy obtained by above phenomenon. We have shown that instantaneous tightening of strength of the spring can transport its energy to others. In fig. 7, by tightening the ankle, the body falls down. In the figure, external perturbation is adopted until time 5 and the body is oscillating. By tightening the ankle (i.e., spring constant is raised 10 times), the oscillation energy is delivered to the upper body and upper body swings.

This phenomenon is adaptable for various quick motions. If we tighten the joints sequentially, e.g., shoulder, elbow, the energy is transported toward end of the limb and high angular velocity is achieved; this idea agrees with the empirical knowledge of baseball pitching. Then it is possible to exploit oscillation energy, by changing parameters.

This method is regarded as an indirect control since we do not control position directly. This feature is important, because indirect control less interfares the body's own dynamical state. Also, we think this method is a good candidate for control method around the node.

5 Concluding Remarks

The global dynamics is a concept that attempts to exploit dynamical feature of the body itself. Combining stable manifolds in the phase space (i.e., "envelopes") and add control input at the "nodes" (i.e., unstable

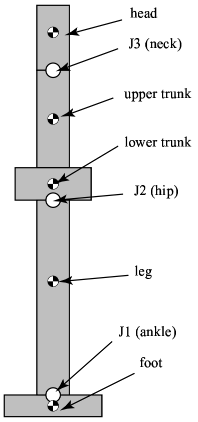

Figure 5: schematic picture of the model robot. Total height is 1.1m

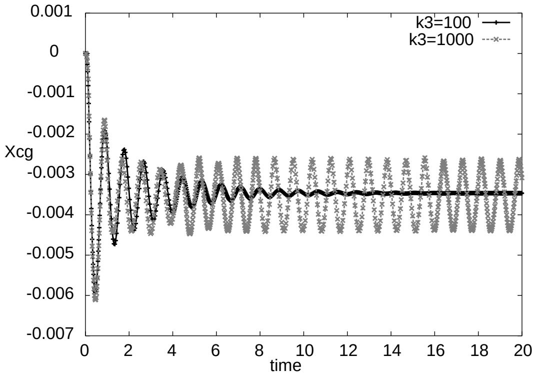

Figure 6: An example of oscillation damping. By varying spring constants, oscillation of the CG is reduced when the soft spring is adopted (black line).

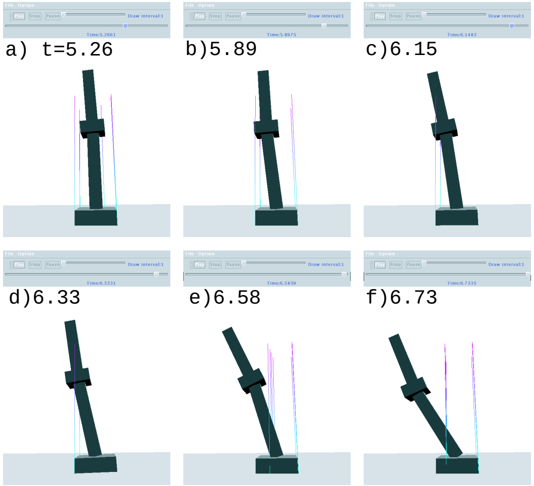

Figure 7: An example of whip-like motion. A series of snapshots after the ankle is tightened. The body falls down by transportation of oscillation energy towards its upper parts.

regions between envelopes). We believe this concept strongly supports to establish adaptation process for human/-oid (or animal) behavior.

In this work we introduce the concept of the global dynamics and show our approaches from two directions – motion capture experiment and dynamical simulation. These two compensate each other and we think the combination of them is very important for the progress of the study.

To know what kind of envelope can be appropriate for a behavior being considered, a map of the phase space is required. The phase space of the real body dynamics is very high: in rough estimation, about 55 dimensions if we assume a Hamiltonian system (27 degree of kinematic freedom is assumed in our body model). Then its high dimensionality and nonlinearity, detail analysis for the whole space is impossible.

Then motion capture experiment is essential for examining which region is really used. The obtained experimental results may lead to realistic version of the diagram shown in fig. 1.

Once mapping is done, the detail analysis by dynamical simulation become possible. While we have shown that that diversification within an envelope (when restriction is adopted), is obvious when velocity is considered, this feature implies that there are many sub-envelopes within an envelope.

We think this feature is a clue for flexibility and possibly adaptability in human/-oid and animal dynamical behaviors. Then we believe it is possible to achieve flexible behavior via exploiting such microscopic (but significant resolution for the task) variation within a motion.

As a further study, integration of motion capture data and simulation study is suggested. Although the parameter and the network of the muscle may be difficult to apply, inverse dynamics can be studied. Also, stability analysis should be done for the detail mapping of nodes and envelopes.

Finally, we would like to state that precision of control, which is usually assumed in robotics, is actually a “hobbling” the dynamics. As our results in simulation shows, soft (therefore inaccurate) body motion has its own stability. Then our concept, the global dynamics, is to harness the dynamics and exploit its rich variety of trajectory to build a motion. The method of controlling around the node is still not yet determined, but an indirect method, e.g., change of parameter seems promising.

Acknowledgment

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