PONYO-PONYO!

Kazuyoshi Tagawa
Intelligent Modeling Laboratory,
the University of Tokyo
http://www.tagawa.info

Koichi Hirota
Graduate School of Frontier Sciences,
the University of Tokyo
k-hirota@k.u-tokyo.ac.jp

Michitaka Hirose
Graduate School of Information Science and Technology
the University of Tokyo
hirose@cyber.t.u-tokyo.ac.jp

Abstract

In this demonstration, haptic interaction with dynamically deformable object using novel deformation model and data compression method is presented. As we used a measurement-based method called 'impulse response deformation model (IRDM) and a data compression method, real-time haptic rendering of dynamically deformable and complex object become possible.

1. Introduction

As an approach to real-time simulation of haptic interaction with deformable object, we proposed a measurement-based method called 'impulse response deformation model (IRDM), in which deformation of object shape is computed by convolving temporal sequence of interaction force with pre-computed response of model to impulse force[1]. Although, IRDM has an advantage that its computation cost of interaction force is independent of model complexity, it requires huge amount of memory to store impulse response data corresponding to combination of all input and output degrees of freedom.

In this demonstration, as an approach to solve this problem, a compress method of the impulse response data is introduced and used. Key idea is to substitute similar impulse response waveforms by modification of smaller number of representative waveforms.

2. Overview of Impulse Response Deformation Model

IRDM is a linear model where deformation of object in response to affecting force is defined by using impulse re-

sponse, or temporal sequence of deformation after an impulse force is applied on the object.

Let us suppose that the impulse response of node j in response to force on node i is given as $r_{ij}(t)$. If a sequence of force $f_i(t)$ is applied on node i, then the resulting deformation $u_{ij}(t)$ on node j is computed by

$$u_{ij}(t) = \int_0^{\inf} r_{ij}(s)f_i(t-s)ds. \tag{1}$$

To apply digital signal processing, the formula must be transformed into discrete representation. Also, the duration of impulse response is limited by a finite time T.

$$u_{ij}[t] = \sum_{s=0}^{T-1} r_{ij}[s]f_i[t-s]\tau, \tag{2}$$

where bracket indicates that the value inside is index of time step rather than continuous value, and τ is the duration of discrete time step.

Because of linearity of IRDM, displacement on each node is computed by summing up displacement that is caused by forces on all nodes. Consequently, deformation of entire model is defined by:

$$u_j[t] = \sum_{k=0}^{N-1} \sum_{s=0}^{T-1} (r_{kj}[s].f_k[t-s])\tau. \tag{3}$$

In case when user interact with the model and touch on some nodes, these nodes are forced have displacement boundary condition; displacement values are given by the user, and current interaction force on these nodes are unknown. All other nodes are free nodes where no external force is currently applied. Since the total number of unknown values is N, all unknown force and displacements are determined by solving the above equation[1].

It should be noted that, in interaction using usual haptic device, the number of nodes on which displacement boundary condition is applied is limited in each time step. This nature of interaction is beneficial to reduce computation cost.

3. Overview of Data Compression Method

It is anticipated that impulse responses on two closely located nodes become similar each other. Also, it is anticipated that responses of a node to affection of impulse forces on closely located nodes become similar each other. This nature of impulse response data led us to the idea that those similar impulse responses data can be substited by, or approximate generated from, representative data of limited number(Figure 1); the reduction of the number of impulse response data directly contribute to reduction of gross data size.
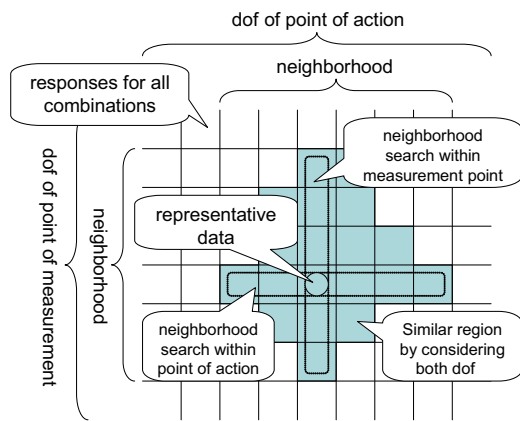

Figure 1. Concept of our approach

Dynamic deformation of elastic object can be viewed as propagation of elastic wave. Since the wave travels with limited velocity and attenuates with time, it is probable that time deilay and amplitude of impulse response becomes different depending on the location on the object, even if the form of response is similar each other. This suggests that more efficient substitution will become possible by introducing these two paprameters in the approximation algorithm. Continuity of displacement is another feature of deformation. This feature is thought to be retained by interpolating impulse response data among several representative data on closely located nodes.

4. Experiment

Compression algorithm was experimentally applied to a set of impulse response data of an object model, and resulting compression ratio was evaluated.

The object model consists of 2421 tetrahedral elements and 690 nodes, among which 359 nodes are on the surface of the model that consists of 1796 triangular patches(Figure 2); since each node has 3 dof along Cartesian axis, the total dof of the model is 359×3, and total number of impulse response data is $(359 \times 3)^2$.

Impulse response data of the object model was computed by dynamics analysis using a commercial FEM analysis software (Altair Engineering, RADIOSS); response of entire object model in response to impulsive force on all dof of the model, respectively, computed. The resulting data was recorded in a format of 500 samples at an interval of 2 ms (i.e. duration of 1 s), although the simulation was performed at a time step of 0.1ms. Computation time of the simulation was approximately 13 hours using a PC with Pentium 4, 3.0GHz. Height of the model is 20cm, Young's modulus and density were assumed to be $2.0 \times 10^3 \; N/m^2$ and $110 \; kg/m^3$, respectively.

Total size of impulse response data is approximately 2.16 GB if it is stored uncompressed float-type array.

Table 1 shows the result of compression, where threshold of correlation coefficient was changed among 0.80, 0.85, 0.90, and 0.95. As the threshold becomes small, compression ratio was improved.
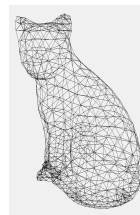

Figure 2. Cat model   Figure 3. Experimental system

Table 1. Compression ratio.

Threshold of correlation coefficient	0.80	0.85	0.90	0.95	original
Number of representative data	12974	26582	59109	158231	-
Number of non-representative data	1146955	1133347	1100820	1001698	-
Compression ratio	1.1%	2.3%	5.1%	13.6%	100.0%
Data size(GB)	0.02	0.05	0.10	0.29	2.14

5. Conclusion

Overview of our methods which are used in our demonstration are introduced.

References

[1] K. Tagawa, K. Hirota, and M. Hirose. Impulse Response Deformation Model: an Approach to Haptic Interaction with Dynamically Deformable Object, Proc. IEEE Haptic 2006, 209-215, 2006.