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An Interactive Motion Capture System with a Large Workspace Haptic Device in Human-Scale Virtual Environments

Woong choi, Seung Zoo Jeong, Naoki Hashimoto, Syouichi Hasegawa, Makoto Sato

Precision and Intelligence Laboratory,
Tokyo Institute of Technology
4259 Nagatsuta, Midori-ku, Yokohama, 226-8503, JAPAN
{wchoi, jeongzoo, naoki, hase}@hi.pi.titech.ac.jp, msato@pi.titech.ac.jp

Abstract

Creating interactive motion with existing motion-capture systems is difficult because it requires a precise preparation of the real environment. In order to resolve such a drawback, we propose a new interactive motion capture system that combines the existing motion capture system with a haptic device and a human-scale virtual environment. As our system has built virtual environment with haptic elements, it is very useful for generating a natural-looking motion data like interaction in the real world.

Key words: Motion Capture, Haptic Device, Human-Scale, Interactive Human Motion, Virtual Environment

1. Introduction

In order to represent more real and detailed motion of human in the computer graphic animation, many professional animators have used motion capture systems. However, the motion capture system that depends on the performance of actor, which has a difficulty in creating interactive motion. Moreover, it requires preparing the object and environment of real world. To resolve such a disadvantage or troublesome, we propose a new interactive motion capture system that combines the existing motion capture system with a haptic device and a human-scale virtual environment. Especially, our system is very useful for generating a natural-looking motion data like interaction in the real world. This combination method is based on using motion capture system with haptic device. When we use two different type devices, we come up against unexpected problems. At first, there is a problem that we could ensure an enough workspace and an actor's freedom. So as to make actor move freely, we use the wireless motion capture system with magnetic sensors [1]. Second, this magnetic type motion capture system is sensitive to metal. So, we established haptic device without frame bar. This produce satisfactory results that

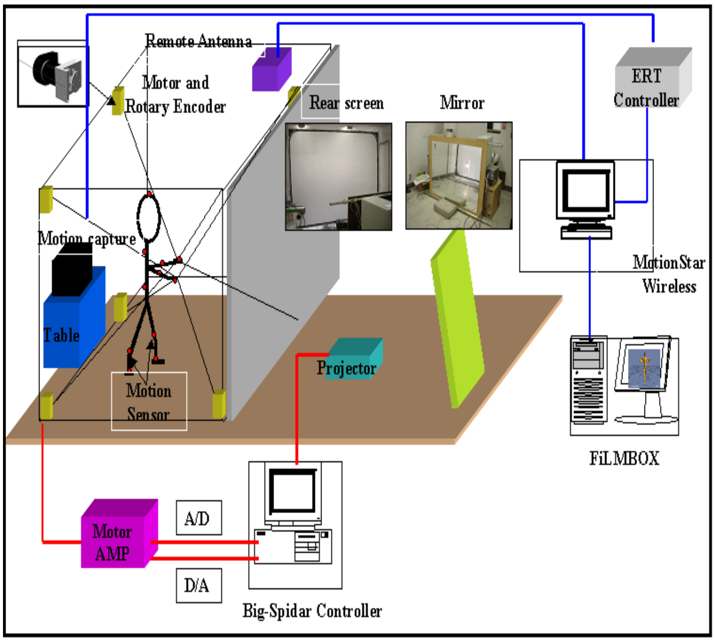

Fig. 1 Interactive Motion Capture System

make use of limited space effectively, and keep away a metal influence relatively.

A scaleable workspace haptic device in human-scale virtual environments can be classified into either non-portable (grounded on earth) or portable types (grounded on the user). Various non-portable haptic devices have been developed, but their workspace is small and restricted. As well, the weight and the bulk of the mechanical attachments are clearly perceived by the user [2]. In contrast, portable haptic device seem to have more potential, especially for use in a larger workspace, because the user can walk around freely within that area, and the workspace follows him [3]. Some portable haptic devices have been developed. The hand-wearable types, the Rutgers Master and CyberTouch have been proposed [4][5]. But portable haptic device is difficult to put magnetic sensors on the user's body. Magnetic motion capture system is easily affected by a metal.

Therefore, we use the Big-SPIDAR haptic device derived from the original SPIDAR device [6][7]. As shown in figure 1, the Big-SPIDAR delimits cubic frames that enclose a cave-like space, where the actor can move around. The experimental prototype is $15.625m^3$ size ($2.5m \times 2.5m \times 2.5m$). A large screen is located at front side of the device, where a computer-generated virtual world is projected. Such a combination of haptic and visual feedback cues is indispensable element that let the actor' s eyes and hands work to manipulate virtual object. The system is designed so that actor freely moves, is made which force display in the large cubic area can be done easily. Because of no cubic frame of steel and complex mechanism, actor's safety is high. The Big-SPIDAR is the force feedback device that the tension of string was used for. This method is accomplished mainly to apply appropriate tensions to the four strings supporting each fingering worn by the actor. With a physical based computer graphics, we make a virtual object having physical properties the same a real world object in the human-scale virtual environments [8]. When the actor contact with a virtual object using the Big-SPIDAR, the gravity, friction and inertia transmit to the actor. It makes possible a feeling weight motion. The actor is able to performance like manipulating a real object. Therefore, an interactive motion capture system in human-scale virtual environments can capture a realistic motion data and actor's performances that are able to get only in a real world.

2. Architectural framework of designed system

In order to resolve these two problems, we propose a new interactive motion capture system that combines the magnetic motion capture system with a Big-SPIDAR and a human-scale virtual environment.

2.1 Haptic Device: Big-SPIDAR

The device uses tensioned string techniques to track hands position as well as to provide force feedback sensations. The approach consists mainly on applying appropriate tensions to the four strings supporting each fingering worn by the user. The force feedback felt on the user' s hand is the same as the resultant force of tension from strings at the center of the fingering.

In order to control the tension and length of each string, one extremity is connected to the fingering and the other end is wounded around a pulley, which is driven by a DC motor. By controlling the power applied to the motor, the system can create appropriate tension all the time. A rotary encoder is attached to the DC motor to detect the string' s length variation, Figure 2. The set of DC motor, pulley and encoder controlling each string is fixed on the clamp.

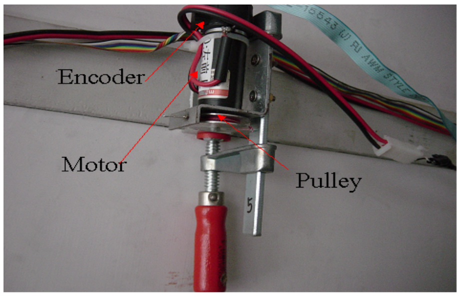

Fig. 2 Motor and rotary encoder

2.1.1 Performance of Big-SPIDAR

The Big-SPIDAR prototype provides two fingerings to be worn by the user on both hands, Figure 3. The fingerings are made of light plastic material and the size can fit to any user. As well, this small device leaves the hand free and easy to put on and off. Although the user can wear the fingering on any finger, middle finger is most recommended. The bottom of this finger is close to the center of hand, and the force feedback applied on this position is felt as being applied to the whole palm. The PC provides a real-time video image of the virtual world. The apparatus of the prototype is shown by Figure 4.

Position Measurement Range: the coordinates origin is set to the center of the framework. The position measurement ranges of all x, y and z in [-1.25m, +1.25m].
Static Position Measurement Error: the absolute static position measurement errors are less than 1.5cm inside the position measurement range.
Force Feedback Range: within the force displayable cubic, force sensation range is from 0.005N (minimum) to 30N (maximum)

Fig. 3 Finger grip

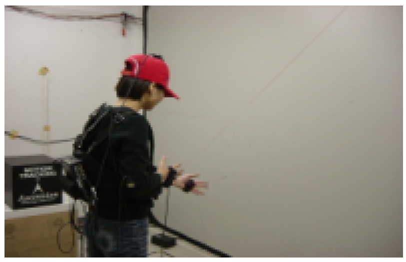

Fig. 4 Apparatus of Big-SPIDAR

2.2 Motion capture system

Fig. 5 MotionStar wireless

We need to ensure a real-time motion data and an actor's freedom in the human-scale virtual environments. Therefore, we use the wireless motion capture system with magnetic sensors [1]. As shown in figure 5, the Ascension Technology MotionStar wireless system is based on magnetic sensors moving in a magnetic field around their source. Orientation and position data is acquired through the sensors within their magnetic field (2.4 meters around the magnetic field source). The 'static accuracy position' is about 0.3-inch RMS at5-ft range, and 0.6 inch RMS at 10-ft range. The 'static accuracy orientation' is 0.5° RMS at 5-ft range, and 1.0° RMS at 10-ft range. The connection with the system is made through the network, using a specific communication protocol defined by Ascension Technology.

In the human-scale virtual environments, the user that wears motion sensors interacts with virtual object using Big-SIDAR. A wireless motion capture system in human-scale virtual environments can capture a realistic motion data and actor's performances that are able to get only in a real world. Motion capture system captures a user's motion in the interacting. The motion data is saved in the designed database and data applied for a virtual human.

2.3 Human-scale virtual environments

We make a virtual object having physical properties the same a real world object in the human-scale virtual environment. When the user contact with a virtual object using the Big-SPIDAR, the gravity, friction and inertia transmit to the user.

2.3.1 Haptic rendering

The haptic controller calculates the force presenting to the user based on the interpolated feature of the virtual object and measured finger of user. In the human-scale virtual environments system, spring-damper model is employed and the force generated is proportion to the penetration of the finger. The force presenting to the user can be represented as following.

Δt : The update period of the haptic controller

f_j : The force presented to user

k_p, k_d : Spring and damper coefficient

C_j : Dinger position of the user

D_i : The nearest point to the user's finger in the area of outside of all planes

$$f_j = k_p(D_j - C_j) + k_d \frac{((D_j - C_j) - (D_{j-1} - C_{j-1}))}{\Delta t}$$

During the cycle of the virtual world, the haptic controller integrates the force given from the user to the virtual world. The amount of the force given by the user can be considered equivalent to the amount of the force generated by the haptic controller, and the direction of the force is opposite. The force integration is represented as following.

F_i : Force integration, which is sent to the virtual world at the i th update of the virtual world.

$$F_i = \sum_{j=0}^{n-1} f_{n(i-1)+j}$$

The virtual world updates the motion of the virtual object based on the received force integration. In the constructed system, virtual objects are treated as solid object. Following represents the update of the motion of an object.

m : The mass of the object

I : The matrix of inertia (3×3matrix)

t_i : The position of the center of the gravity

v_i : The velocity of the center of the gravity

w_i : The angular velocity of the object

p_i : The position where F_i acts on

$$v_i = v_{i-1} + \frac{1}{m} F_i$$

$$I_i w_i = I_{i-1} w_{i-1} + ((p_i - t_i) \times F_i)$$

Haptic display makes possible a feeling weight motion in the human-scale virtual environments. The user is able to act like manipulating a real object.

3. Process of motion data using the designed system

Products using any variety of capture techniques can deliver hierarchical or point independent data. Hierarchical data such as that supplied in Biovision's BVH format describes motion in terms of rotations based on a pre-defined skeleton.

The other side, non-hierarchical data describes only the location of points. It tune the captured data to user freely, but it can require extra set-up time to fit character. Besides captured data types mentioned above, there is some motion data types of the motion capture device development manufacturer, the standard data type haven't been still unified completely.

These days, in an effort to standardize on a common representation for humanoids the Web3D Consortium defined the Humanoid Animation Specification (H-Anim) for VRML. They specify a fixed topology and a naming convention for the articulated structure as well as tools for adding an outer mesh, the skin or directly cloth. Because we want to program in C code with good compatibly, and lighter than java, we aren't yet going to consider this H-Anim form. And despite XML is very strong in a versatile data transport form. Because it is poor as a data storage and access format, we selected database (SQL) relational databases that are tuned to quickly and reliably query complex data.

At first, we convert these motion data files to our database files with both hierarchical and independent structure. Then we search motion data of the database using index key such as force value or defined motion classification ID. (See Figure 6)

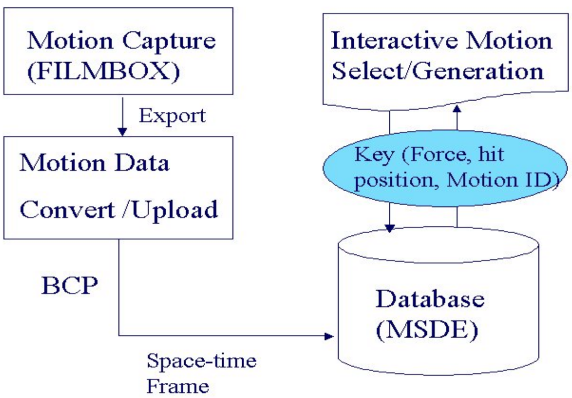

Fig. 6 Implement process of motion database

3.1 Motion Database - RDBMS

We designed a relational database for required motions so that we can simply play them back in our system. The characteristics of relational database are in handling data as more than one table form. Complex data can be simplified respectively if they are divided in more than one table or normalize.

Accordingly, the motion database separates two tables. One is Motion list table that have basic motion information such as total frame number, joint number, end-effectors number, motion classification ID, motion name. The other table includes translation and rotation data of individual joints that is classify by motion ID. Moreover, we express hierarchical elements as using tree level count and end-effectors fields. (See Figure 7)

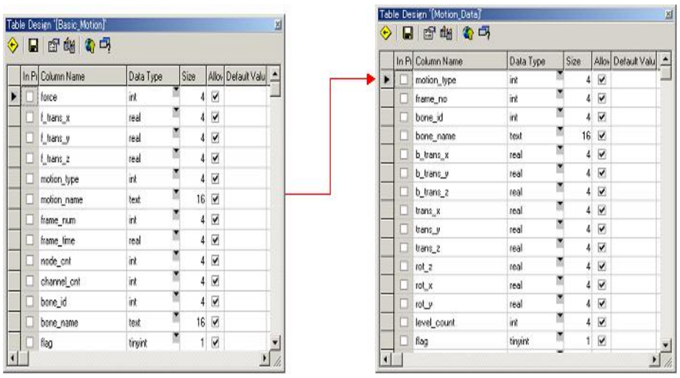

Table Design '[Basic_Motion]'

In Pi	Column Name	Data Type	Size	Allov	Default Valu
☐	force	int	4	☑	
☐	f_trans_x	real	4	☑	
☐	f_trans_y	real	4	☑	
☐	f_trans_z	real	4	☑	
☐	motion_type	int	4	☑	
☐	motion_name	text	16	☑	
☐	frame_num	int	4	☑	
☐	frame_time	real	4	☑	
☐	node_cnt	int	4	☑	
☐	channel_cnt	int	4	☑	
☐	bone_id	int	4	☑	
☐	bone_name	text	16	☑	
☐	flag	tinyint	1	☑	

Table Design '[Motion_Data]'

In Pi	Column Name	Data Type	Size	Allov	Default Valu
☐	motion_type	int	4	☑	
☐	frame_no	int	4	☑	
☐	bone_id	int	4	☑	
☐	bone_name	text	16	☑	
☐	b_trans_x	real	4	☑	
☐	b_trans_y	real	4	☑	
☐	b_trans_z	real	4	☑	
☐	trans_x	real	4	☑	
☐	trans_y	real	4	☑	
☐	trans_z	real	4	☑	
☐	rot_z	real	4	☑	
☐	rot_x	real	4	☑	
☐	rot_y	real	4	☑	
☐	level_count	int	4	☑	
☐	flag	tinyint	1	☑	

Fig. 7 Structure and Relation of two Motion Table

3.2 Searching motion data – SQL Query

As for the strong point of SQL, and it is not to depend on data that it can be used by many data base control packages. In other words, a user doesn't need to worry about the details to the data of the physical way of accessing it. Our designed database can be searched motion data by various keys using this SQL Query. At first, we get basic motion information from motion list table. Motion list table is indexed by force value that corresponds to user's repulsion from Big-SPIDAR. If so, this force value is search key that classify motion, and define a motion ID from motion data.

Moreover, we made simple stored-procedures of motion ID in order to keep primary key's consistency of two tables. Therefore, if motion ID happens a transaction in basic table, data of motion table can be transacted simultaneously in server or client.

3.3 Skeleton model

Real humans have so many degrees of freedom that virtual models frequently omit some of them. We use a simple skeleton model that is a hierarchically organized set of joints, and this set is animated by local rotation matrix. (See figure 8)

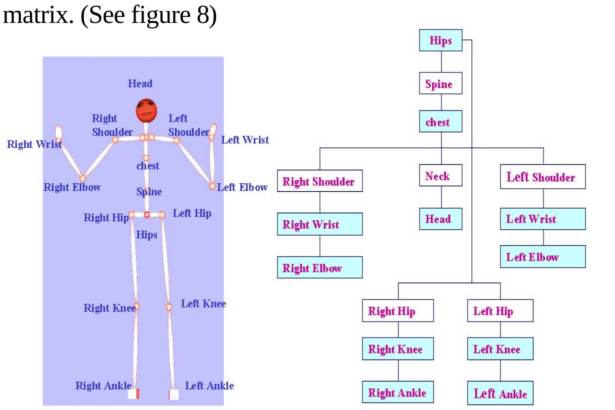

Fig. 8 Example of a simplified skeleton and the corresponding hierarchy. The shadow area of right chart indicates joints that are captured by 11 magnetic sensors.

We developed motion view program that draw and animate model in reading motion data through ODBC. The program is coded in C++ and OpenGL. We added interactive functions to control a simple skeleton model with ball-shaped joint. Our program makes these functions use easily as keyboard or mouse: Viewpoint or camera control, individual joint selection, direct kinematics, face texture mapping, and end-effectors generation, Full Screen toggle. In near future, user will be able to interact with virtual human of adaptive type, which is projected in human-scale screen.

4. Experiments and application

An experimental system had been constructed. The human-scale virtual environments used here is Big-SPIDAR using tensed strings. A PC with Pentium 400Mhz is used for managing virtual world, controlling haptic interface, and rendering computer graphics.

The virtual object is constructed with a 3D physical model: the gravity, collisions, and frictions in the virtual object are also taken in to consider. In the human-scale virtual environments, a user's motion is capture by MotionStar wireless. We get the real-time motion data from an interactive motion capture system to database PC using the motion capture software. The interactive motion data is saved in the designed database and data applied for a virtual human.

4.1 Experimental task

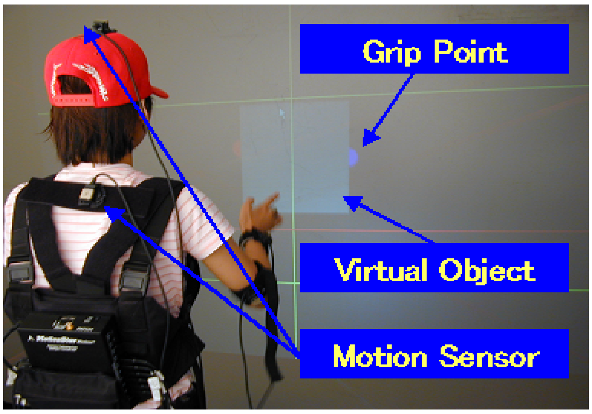

Fig. 9 Picture of the experimental task

An experiment had been carried out and showed the effectiveness of the proposed system. The experimental task was as following. As shown in figure 9, we had an experiment which tracing objects to verify the validity of an interactive motion capture system.

Tracing objects prepare a cube and wall. Real cube is 27000cm^3 size (30cm×30cm×30cm) and 3kg. Wall is 2m^2 size (1m×2m) and a pedestal under wall. A Virtual cube and wall is made by a size and weight the same a real objects. Only once, user's motion data is captured without practice. We capture actor's motion that trace an imaginary objects (cube, wall), a virtual objects and a real objects in turn using an interactive motion capture system.

4.2 Experimental result

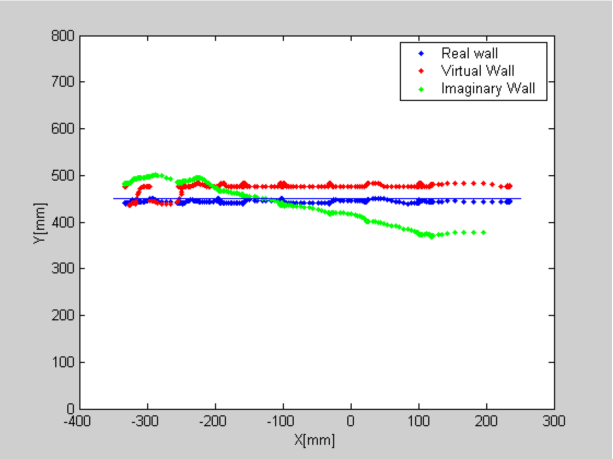

Fig. 10 Motion Data tracing Walls

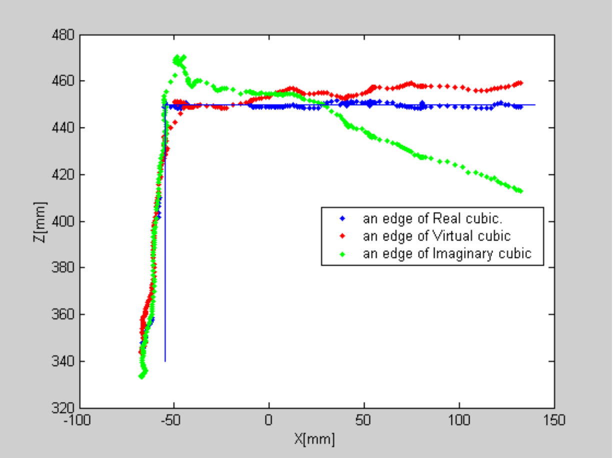

Fig. 11 Motion Data tracing an edge of cubes

Fig.10, 11 showed the motion data where the experimental objects traced. Case of imaginary objects is not good a motion data and user is necessary a motion practice. Case of real objects, a motion data accurately shows the edge of cube and the surface of wall. Case of virtual objects in an interactive motion capture system meets with results much the same a motion data of real objects

The experimental result is showed that virtual objects can use like real objects in an interactive motion capture system. When actor's motion needs objects, it validates an efficiency of an interactive motion capture system

4.3 Application

Fig. 12 Touching a virtual wall

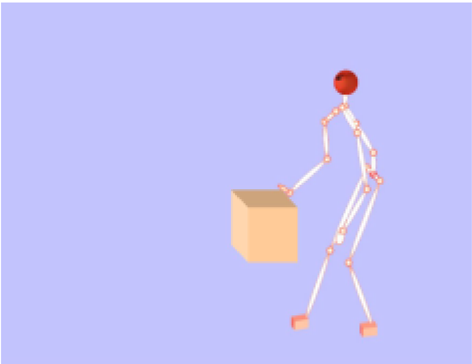

Fig. 13 Touching a virtual cube

We make virtual human that applied by a motion data captured using virtual wall and cube in an interactive motion capture system. Fig 12, 13 is showed that virtual human have an impression that touch a real wall and cube. Motion is natural-looking. The virtual human may use for making human in the virtual city and factory

5. Conclusions

In the study, we proposed a new interactive motion capture system that combines the magnetic motion capture system with a Big-SPIDAR and a human-scale virtual environment. Now, a simple virtual object only makes arrangement, such as virtual cube and virtual wall. In the Big-SPIDAR, the strings may interfere with each other if the user tries to turn around her/himself or cross deeply his hands. But the device is not bulky, and easy to use; Another distinguishing characteristic of Big-SPIDAR, is that the user does not think in terms of manipulating an input device, instead he has a full and direct use of his hands.

Our system improves a weak point of the existing motion capture that a skillful actor and real objects need to capture the motion data. The experiment is showed that a new interactive motion capture system is very useful for generating a natural-looking motion data like interaction in the real world.

A future research is to make a various virtual objects having physical model in the human-scale virtual environments. We save a various motion data on a designed database in real-time and implement virtual human that uses a saved motion data in the network.

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