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Development of Affordance based Human Motion Synthesizing System

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Abstract

A human motion synthesizing system has been developed for generating various kinds of human motions flexibly as 3 dimensional computer graphics in virtual environment. This system is designed based on the idea derived from the concept of affordance. The idea is that the entire algorithms and the information necessary for synthesizing a human motion should be composed in the object database which is an archive for the virtual object's information. This design methodology makes it possible to make a new algorithm for synthesizing a human motion available without reconstructing the human motion synthesizing system. In this paper, how to apply the concept of affordance to design the human motion synthesizing system and the overall configuration of the developed system are described.

1. Introduction

Recently, computer technology has been developing remarkably so that Virtual Reality (VR) technology has been emerged and various kinds of studies have been made to construct training environments in virtual environment[1][2]. On the other hand, the studies have been made on modeling the operator's behaviors for plant operation and machine maintenance by using Artificial Intelligence[3][4]. In this study, the authors aim at developing a new training system which is realized by combining the VR technology and the Artificial Intelligence.

The authors call the training system "Virtual Collaborator" and have made studies such as [5][6]. The Virtual Collaborator provides an artificial instructor who has a human-shaped body and can listen, talk, think, behave and collaborate with real humans. The artificial instructor helps a trainee learn complicated tasks by instructing and demonstrating them in a virtual space. In our previous study[5], a prototype Virtual Collaborator has been developed in which the artificial instructor can behave just like a plant operator in the control room of nuclear power plant. But some problems have arisen at developing the advanced Virtual Collaborator with which the trainee can collaborate with the artificial instructor through bi-directional communication[6].

Firstly, it is very difficult to synthesize various kinds of the artificial instructor's motions as 3 dimensional computer graphics in real time. A human has a lot of joints such as neck, shoulder, elbow, wrist, waist etc. and each joint has from one to three degrees of freedom (DOF). So a human has a large number of posture variables. To synthesize the human motion, all of the joint's angles must be specified. Numerous algorithms for synthesizing human motions can be found in literature[7][8][9], but all of them are limited to use for synthesizing a particular motion. Therefore, to make it possible to synthesize a new kind of human motion, a new algorithm is needed to develop and to make it available. On the other hand, it is impossible to prepare all the algorithms necessary for synthesizing the artificial instructor's motion by predicting which kinds of motion will be necessary in the future. So it is inevitable to develop a new algorithm whenever a new kind of human motion needs to be synthesized.

Secondly, it is very difficult to execute the training simulation in real time, because the vast computation load is required. To execute the training simulation, it is necessary to synthesize the body motion of the artificial instructor, generate a virtual space as 3 dimensional images and execute the human model simulator as the artificial instructor's brain.

In this study, to solve these problems, the authors developed an Affordance based Human Motion Synthesizing System (AHMSS) which is designed based on the idea derived from the concept of affordance, introduced by psychologist James Gibson[10]. In which follows, described are how to apply the concept of affordance to design a new human motion synthesizing system and how to configure the whole-developed system.

2. The concept of affordance and its application for the system development

In this chapter, the concept of affordance and the principle to design the AHMSS are described.

2.1. Introduction of the concept of affordance

The conventional method of developing a system using computer animation of virtual humans has been a way like this; first what kinds of the virtual human’s motion should be synthesized for realizing the system is decided, and then the algorithms and the data for synthesizing those kinds of virtual human's motion are constructed into the system. This is the way that the surrounding environment the virtual human is located is decided first and then the knowledge about the environment is created and put into the virtual human as the model of environment. Of course, even by this, the virtual human can behave in accordance with the knowledge about the environment. But it is very difficult to prepare all the knowledge in advance about the environment the virtual human could be located in the future. Therefore by this method, it is very difficult to develop the human motion synthesizing system which can synthesize all kinds of the virtual human's motion.

As one solution to this problem, there is the concept of affordance. The affordance was introduced by psychologist James Gibson and he defined the affordance as "a specific combination of the properties of substance and its surfaces taken with reference to an animal." According to this concept, an action of a human is triggered by the environment itself where the human exists unlike the afore-mentioned way of interpretation that the human would behave in accordance with the model of the environment the human already possesses in advance.

When this way of thinking would apply to the development of the human motion synthesizing system, the algorithms and the data for synthesizing the virtual human's motion should be composed not in the virtual human's brain but in the virtual objects located in the virtual environment. And the algorithms and the data should be transferred from the virtual object to the synthesizing system at the time when they become necessary.

For example, a floor affords "walk-on-ability" to the virtual human if the floor is large enough and smooth enough. In this case, the algorithms and the data for synthesizing the walking motion should be composed not in the synthesizing system but in the database which describes the information about the floor. In other words, the necessary information for synthesizing the virtual human's motion should not be composed in the synthesizing system but in the database which describes the information about the virtual objects such as the 3 dimensional shape, texture and so on.

As mentioned above, by composing all the information necessary for synthesizing the virtual human's motion into the virtual object, there are some advantages as follows:

(1) Because it becomes possible that all the information related to one virtual object could be put together being separated from the other virtual object, it is easy to add a virtual object into the virtual environment.
(2) By editing the database for the virtual objects, it is possible to make an algorithm for synthesizing the virtual human's motion available without reconstructing the system.
(3) Because the algorithms and the data for synthesizing the virtual human's motions can be constructed separately for each virtual object which is the target of the virtual human's motion, the workload to construct them can be distributed to plural system developers.

Based on the discussions mentioned above, the authors make it the first policy of the system design that the algorithms and the data necessary for synthesizing the virtual human's motion are composed in the database not for the virtual human but for the virtual objects.

2.2. Introduction of the concept of mixing two kinds of affordances

If the distance between a cup and a chair is short enough, a human can grasp the cup while sitting on the chair. In this way, a human can perform an action which relates to two different objects at the same time. But a human does not know how to perform an action toward all combinations of objects in the world. In this case, considering the basic concept of affordance, it could be interpreted as that both the cup and the chair afford the motion "grasp a cup" and the motion "sit on a chair" respectively, and the both affordances are mixed together into the one affordance "grasp a cup while sitting on a chair".

In this study, to make it possible to synthesize the mixed motion with the AHMSS, the authors suppose that a human does not accept the affordance uniformly; the degree of the affordance intensity varies according to every part of the human body. For example, a cup affords the motion "grasp a cup" strongly toward the arm while weakly toward the other part of the body. And a chair affords the motion "sit on a chair" strongly toward the legs and the hip while weakly toward the rest. If the distance between a cup and a chair is short enough, a human accepts the affordance from both of the cup and the chair. And because the degree of the affordance intensity from the cup is stronger than that from the chair, the arm performs the action "grasp a cup". Likewise, because the degree of the affordance intensity from the chair is stronger than that from the cup, the legs and the hip performs the action "sit on a chair". All together, the human acts "grasp a cup while sitting on a chair".

Based on the concept of mixing of affordances as mentioned above, the authors make it possible to synthesize the mixed motion with the AHMSS. Concretely, the authors introduce the concept of the weighted average which was proposed by Douglas[11]. The weighted average is the numerical value which represents the priority of the human motion over the other motion and it is set to each joint of human's body. In the AHMSS, the weighted average is prepared to every action the virtual objects can afford. For the further details of how to mix the motions by using the weighted average, please refer the author's published paper[12].

3. Requirements

In this chapter, the requirements the AHMSS should satisfy as a system for synthesizing the virtual human's motion are described. In this study, in consideration of the design principle derived from the concept of affordance mentioned in chapter 2 and the situation the AHMSS is used as a component of the advanced Virtual Collaborator, the authors designed the AHMSS to satisfy the following 6 requirements:

(1) Both of the virtual human's motion and the virtual object's movement can be synthesized at the same time.

To develop the advanced Virtual Collaborator as a personalized interface, it is necessary for the artificial instructor not only to communicate with real humans by gestures but also to manipulate virtual objects with his both hands. So it is necessary to synthesize not only the virtual human's motion but also the virtual object's movement. In this study, the authors make it possible to use the algorithms not only for the virtual human's motion but also for the virtual object's movement.

(2) It is possible to make a new algorithm available for synthesizing the virtual human's motion without reconstructing the system.

In the AHMSS, as mentioned in chapter 2, the information necessary for synthesizing the virtual human's motion is composed in the object database for the virtual object which is the target of the virtual human's motion. This system structure makes it possible to add a new algorithm to the AHMSS without reconstruction. But there are a lot of cases where the same algorithm or the same database is necessary for synthesizing the different motions. Therefore if the algorithm or the database itself is composed in the object database, the same algorithms and the same databases should be composed in the system. Then in this study, an algorithm database which is an archive of the algorithms is introduced into the AHMSS and only the name of the algorithm and the database for synthesizing the virtual human's motion is composed in the object database.

(3) It is possible to synthesize the motion of the virtual human who performs an action toward two objects at the same time.

In accordance with the concept of mixing of affordances mentioned in chapter 2, the weighted average for all joints on each action is prepared and the virtual human's motions are mixed according to the weighted average in real time.

(4) The users of the AHMSS indicate the kind of the virtual human's action via a terminal.

In the advanced Virtual Collaborator, the AHMSS synthesizes the virtual human's motion in accordance with the indication of the Human Model. But the Human Model has not been constructed yet, so the AHMSS is designed that the indication to the virtual human is given from the user via a terminal.

(5) The AHMSS can synthesize the virtual human's motion and the virtual object's movement in real time.

To realize the advanced Virtual Collaborator as a personalized interface, it is necessary to update the virtual environment fast enough so that the user does not feel incongruous by looking the artificial instructor's motion. In this study the authors aim at developing the system which can update the virtual environment from 10 to 20 times per second. Concretely, the authors designed the AHMSS to realize the parallel and distributed processing by separating the computational load into 3 processes of computation: the virtual human's motion, the virtual object's movement and the generation of the 3 dimensional images of the virtual environment.

(6) The 3 processes can be executed on the different computers.

In the AHMSS, it is possible to share the information among the 3 processes mentioned above by using a socket communication. By this system structure, it becomes possible to execute a right process on a right computer. For example the process for calculating the virtual human’s motion which computation load is very high is executed on the workstation which capacity of calculation is large, while the process for generating the 3 dimensional images of the virtual environment which drawing load is very high is executed on the graphics workstation optimized for generating 3 dimensional images.

In the AHMSS, the 3 processes are executed on the 3 different workstations which are connected via network.

4. System configuration

In this chapter, the configuration of the AHMSS is described. As shown in Figure 1, the AHMSS consists of 3 subsystems: Main Process, Virtual Space Information Server, Virtual Space Drawing Process and 4 databases: Object Database, Human Database, Algorithm Database for Human Motion Synthesis and Algorithm Database for Object Movement Synthesis. The subsystems are executed on three kinds of workstations: Server workstation, Main workstation and Graphics workstation, which are connected via network. The details of the subsystems and the databases are explained below.

(1) Algorithm Database for Human Motion Synthesis and Object Movement Synthesis

The Algorithm Database for Human Motion Synthesis and Object Movement Synthesis are archives of the algorithms for synthesizing the virtual human's motion and the virtual object's movement respectively. These algorithms are developed as the programs which can be executed on a unix workstation independently of the other algorithms and subsystems.

(2) Main Process

The Main Process consists of Command Interface, Motion Mixer, Database Interface, Algorithm Controller and Communication Interface.

The Main Process accepts commands from the user via the Command Interface and selects appropriate algorithms from the Algorithm Database in accordance with the commands and starts the algorithms as external processes. Then the necessary information for synthesizing the virtual human's motion and the virtual object's movement are sent to the processes via shared memory and the calculation results are returned to the Main Process. The Motion Mixer mixes two kinds of the virtual human's motions in accordance with the prepared weighted average as mentioned in section 2.2. The Main Process sends the results to the Virtual Space Information Server.

(3) Virtual Space Information Server

The Virtual Space Information Server manages the information about virtual environment such as the location and posture of the virtual human and the location and orientation of the virtual objects. The Virtual Space Information Server sends these informations to the Main Process and the Virtual Space Drawing Process by their requests. And these informations are updated in accordance with the calculation results from the Main Process.

(4) Virtual Space Drawing Process

The Virtual Space Drawing Process generates 3 dimensional images of the virtual human and the virtual objects in real time in accordance with the information about the location and posture of the virtual human and the location and orientation of the virtual objects from the Virtual Space Information Server.

(5) Object Database

The Object Database stores the information about virtual objects located in the virtual environment. As shown Figure 2, the Object Database includes various kinds of the information about virtual objects such as virtual object's name, 3 dimensional shape, the action name the virtual object affords, the algorithm name for synthesizing the virtual human's motion, the algorithm name for synthesizing the virtual object's movement and so on.

(6) Human Database

The Human Database stores the information about the virtual human located in the virtual environment, such as

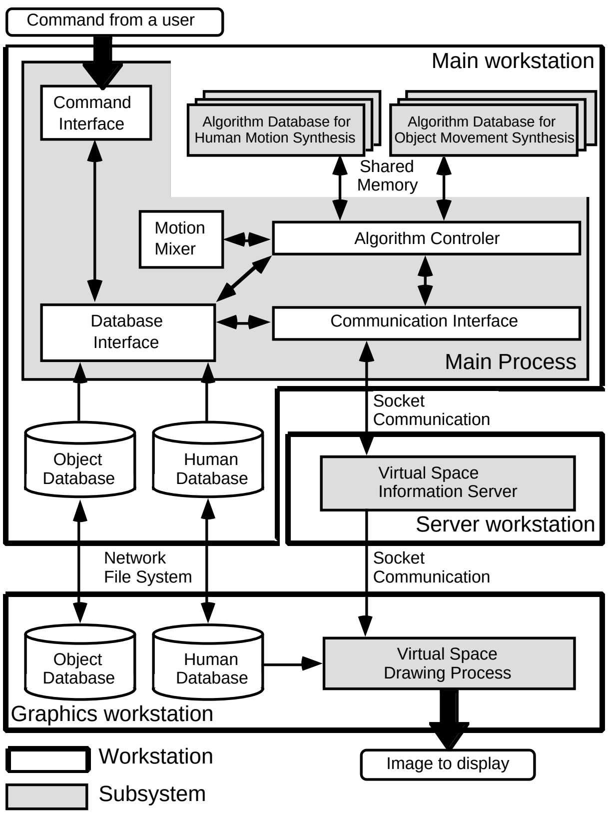

Figure 1 Configuration of the AHMSS.

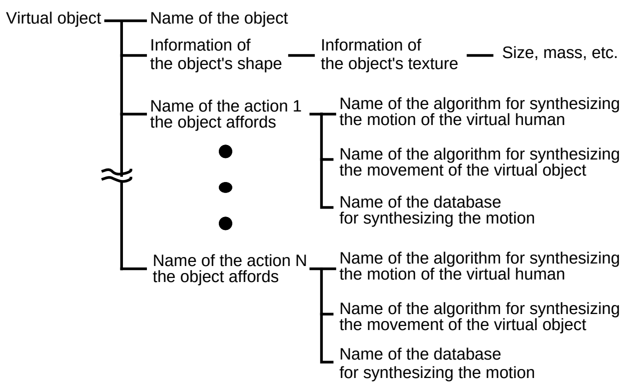

Figure 2 The structure of the Object Database.

3 dimensional shape of the virtual human's body, textures, the weight and the length of the body parts and so on.

The procedure for synthesizing the virtual human's motion in accordance with the indications from the user is shown in Figure 3 and summarized as follows:

Step1 The user allocates virtual objects and a virtual human into the virtual environment.

Step2 The user indicates the virtual object which is the target of the virtual human's action.

Step3 The system searches the Object Database for the indicated virtual object and shows a list of actions the indicated object affords.

Step4 The user selects an action from the list of actions and inputs the information necessary for synthesizing the virtual human's motion.

Step5 In the case of mixing two actions, repeat Step2, 3 and 4.

Step6 According to the indicated actions, appropriate algorithms for synthesizing virtual human's motion and the virtual object's movement are started. In the case of mixing two actions, 2 algorithms for synthesizing the virtual human's motion and 2 algorithms for synthesizing the virtual object's movement are started.

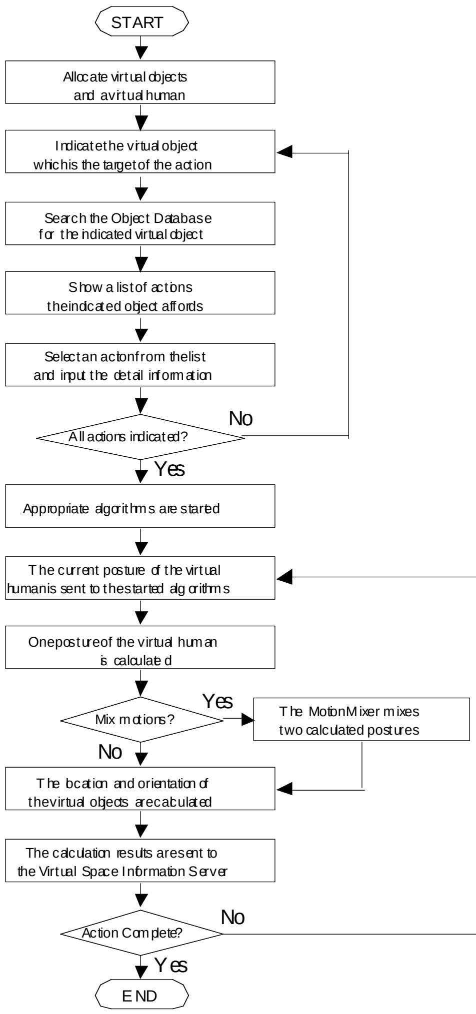

Figure 3 The procedure for synthesizing the virtual human's motion.

Step7 The current posture of the virtual human is sent to the started algorithms for synthesizing the virtual human's motion.

Step8 The started algorithms for synthesizing the virtual human's motion calculate one posture of the virtual human.

Step9 In the case of mixing two actions, the results of Step8 are sent to the Motion Mixer and two postures are mixed according to the weighted average.

Step10 The posture of the virtual human calculated in Step8 or Step9 is sent to the started algorithms for synthesizing the virtual objects' movement.

Step11 The started algorithms for synthesizing the virtual objects' movement calculate the locations and orientations of the virtual objects.

Step12 The results of Step10 and Step11 are sent to the Virtual Space Information Server.

Step13 Repeat from Step7 to Step12 until the indicated action completes.

5. Algorithms for synthesizing the virtual human's motion and the virtual object's movement

In this chapter, the algorithms which have been already developed as the algorithm database are explained.

5.1. Algorithms for synthesizing the virtual human's motion

As the algorithms for synthesizing the virtual human's motion, the algorithm "grasp an object" and "maintain a posture of the arm" have been developed besides the algorithms explained as follows:

(1) Motion capture

This algorithm synthesizes the virtual human's motion by using a sequence of human postures obtained by measuring the motion of a real human with 3 dimensional motion capture system.

(2) Walking synthesis

This algorithm was originally developed by the authors[13] and can synthesize walking motion of arbitrary direction and distance.

(3) Spherical cubic interpolation (Key-framing)

This algorithm synthesizes the virtual human's motion by the way that the motion is recorded as a sequence of key-postures and the computer reconstructs the motion by interpolating intermediate postures from appropriate key-postures.

5.2. Algorithms for synthesizing the virtual object's movement

As the algorithms for synthesizing the virtual object's movement, two kinds of algorithms have been developed as follows:

(1) Open a door

This algorithm calculates the orientation of a door from the location and orientation of the virtual human's arm and simulates the opening and closing of the door.

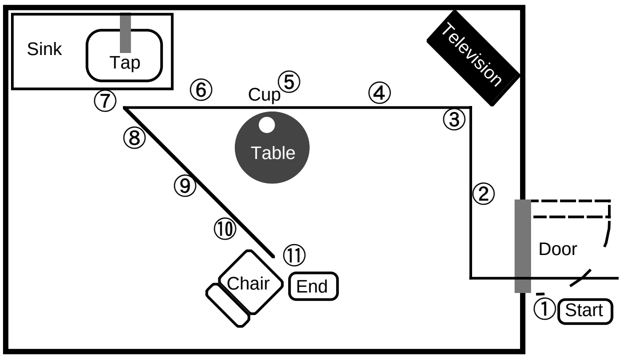

Figure 4 The layout of the virtual room and the movement course of the virtual human.

Time / Action	Algorithm for human motion synthesis	Algorithm for object movement synthesis
① Open a door	Motion capture	Open a door
② Walk to a television	Walking synthesis	
③ Turn on a television	Spherical cubic interpolation	
④ Walk to a sink	Walking synthesis	
⑤ Pick up a cup while walking	Walking synthesis + spherical cubic interpolation	
⑤ Grasp a cup while walking	Walking synthesis + grasp an object	Follow the movement of the arm
⑥ Walk to a sink	Walking synthesis + maintain the posture of the right arm	Follow the movement of the arm
⑦ Turn on a tap	Spherical cubic interpolation	Follow the movement of the arm
⑧ Walk to a chair	Walking synthesis + maintain the posture of the right arm	Follow the movement of the arm
⑨ Drink water while walking	Walking synthesis + spherical cubic interpolation	Follow the movement of the arm
⑩ Walk to a chair	Walking synthesis + maintain the posture of the right arm	Follow the movement of the arm
⑪ Sit on a chair	Motion capture + maintain the posture of the right arm	Follow the movement of the arm

+ : motion mixing

Figure 5 The correspondence between the synthesized motion and the algorithms.

(2) Follow the movement of the arm

This algorithm calculates the location and orientation of an object from the location and orientation of the virtual human's arm. This algorithm can synthesize the movement of the object which is grasped by the virtual human.

6. Example of synthesizing virtual human's motion

In this chapter, as the example use of the AHMSS, how to synthesize the virtual human's motion is described according to the scenario as follows;

Action1 Open a door.
Action2 Walk to the front of a television.
Action3 Turn on the television by pushing a switch.
Action4 Pick up a cup while walking to a sink.
Action5 Pour water for the cup by turning on a tap.
Action6 Drink water while walking to a chair.
Action7 Sit on the chair.

The layout of the virtual room and the movement course of the virtual human are shown in Figure 4. The list of the algorithms used to synthesize the virtual human's motion is shown in Figure 5. The procedure to synthesize the virtual human's motion according to the scenario is summarized as follows;

(1) If there is any algorithm which is necessary for synthesizing the virtual human's motion but has not been developed yet, the user develops the algorithm in accordance with the regulation of the algorithm development. The main regulation of the algorithm development is as follows;
   1. The algorithm can synthesize the virtual human's motion in real time (more than 10 frames/sec).
   2. The algorithm can calculate the posture of the virtual human every one frame.

(2) The user constructs the Object Database for the virtual objects which are the target of the virtual human's actions. For example, for the door object which is the target of Action 1, the user constructs the information as shown in Figure 6.

(3) Similarly, the user constructs the Object Database for the floor, television, cup, tap, chair and so on.

(4) As mentioned in chapter 4, the user inputs the detail information such as an object name which is the target of the virtual human's action, the name of the action and so on.

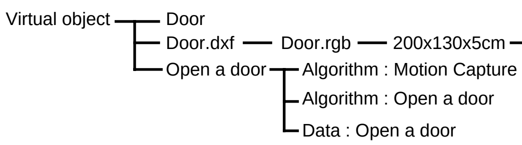

Figure 6 Object Database for the door.

(5) Then the objective motion of the virtual human is synthesized.

The constructed algorithms and the Object Database can be reused for synthesizing the virtual human's motion for the other scenarios so that once the user constructs the algorithm or the Object Database, the virtual human's motion can be synthesized easily by indicating the name of the target object and the name of the action the virtual human performs.

Figures 7 and 8 show the example motion synthesis of the virtual human who picks up a cup while walking and drinks water while walking respectively.

In this study, the AHMSS was implemented on a Linux Workstation (Pentium III 700MHzx2) as the Main Workstation, a SGI Octane (R10000 250MHz) as the Graphics Workstation and a SGI O2 (R10000 250MHz) as the Server Workstation. As a result, it was confirmed that the developed system satisfies all the requirements described in chapter 3.

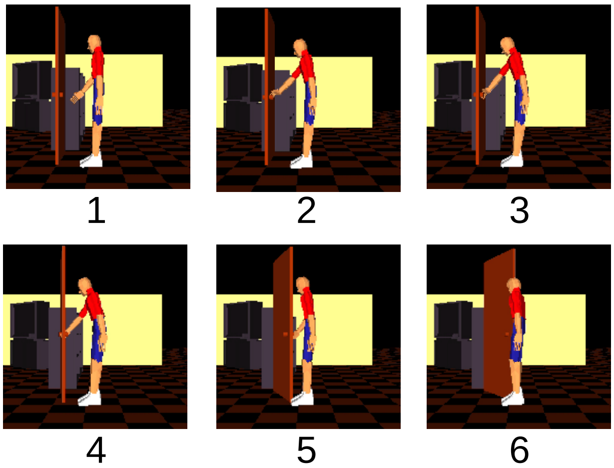

Figure 7 The example snapshots of the virtual human who opens a door.

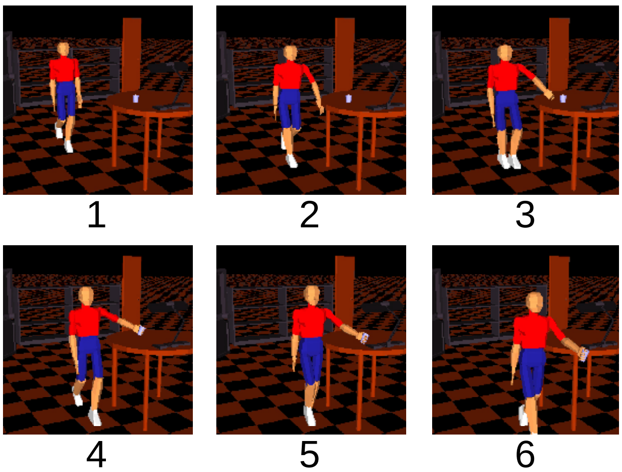

Figure 8 The example snapshots of the virtual human who picks up a cup while walking.

7. Concluding remark

In this study, an Affordance based Human Motion Synthesizing System (AHMSS) has been developed based on the idea derived from the concept of affordance which is one of the important concept in the field of cognitive science. The AHMSS was designed so that the algorithm and the necessary information for synthesizing the virtual human's motion are composed in the object database which is an archive for the virtual object's information. This design methodology makes it possible to add a new kind of the algorithm for synthesizing the virtual human's motion without reconstructing the system. Moreover, by introducing the concept of mixing of affordances, the algorithm for mixing two kinds of actions has been developed. With this algorithm various kinds of the virtual human's motions can be synthesized easily by changing the combination of actions and the beginning time of the mixing.

For the future work, more algorithms for synthesizing the virtual human's motion and the virtual object's movement should be developed because it is necessary to synthesize more kinds of virtual human's motions to realize bi-directional communication between real and virtual humans with the advanced Virtual Collaborator. Moreover, the Graphical User Interface for editing the object database and allocating virtual objects into the virtual environment should be developed.

8. Acknowledgements

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