A tangible interface using 3D printed figures for searching for combat motions of two characters

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***Abstract*—In this paper, we propose a tangible interface using three-dimensional (3D) printed figures to search for the combat motion of two characters, which consist of an attacking motion of one character and the associated defending or avoiding motion of the other character. A key idea is that such combat motion can be identified by the key poses of two characters and spatial relationship between them at the moment of the impact of the attack. Another key idea is that the poses and their spatial relationship can be specified for searching for combat motions by arranging 3D figures of the key poses on a stage. A user of our system can easily search for the combat motion of two characters from a motion database by choosing and arranging the 3D figures. We developed a method for searching for the desired pair of motion from the motion database based on user input. We implemented a prototype to evaluate our approach and conducted a user study to show the effectiveness of our interface by comparing it with a conventional graphical user interface for specifying the same information.**

***Index Terms*—Motion retrieval, 3D printed figures, tangible interface, combat motion**

I. Introduction

In recent years, three-dimensional (3D) computer animation has been used in many types of digital content, such as movies. Motion data are essential for creating 3D computer animation. Because it is difficult to create motion data, there is a demand for reusing existing motion data. However, as motion data are represented by the time-varying joint rotation of an articulated figure and are complicated, it is difficult to search them using a keyword or any other input. Furthermore, even though the associated motion of two or more people, such as combat motion, are often used in computer animation, searching for such associated motion of multiple people is more difficult than searching for the motion of a single person because not only must the motion of each person be taken into account but also the spatial relationship between the motion.

In this study, we develop a tangible interface using 3D printed figures to search for the combat motion of two characters, which consist of an attacking motion of one character and the associated defending or avoiding motion of the other character. A key idea is that such combat motion can be identified by the key poses of two characters and spatial relationship between them at the timing of the impact of the attack, as shown in Fig. 1. Another key idea is that a query of the poses and their spatial relationship can be given by arranging 3D figures of key poses on a stage, as shown in

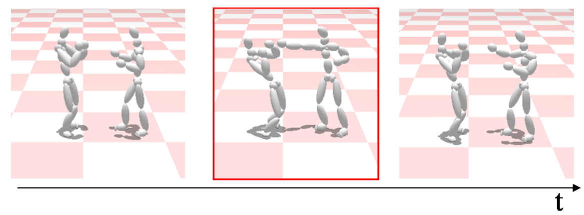

Fig. 1. Keypose of an attacking motion. The moment of impact is used as keyframe.

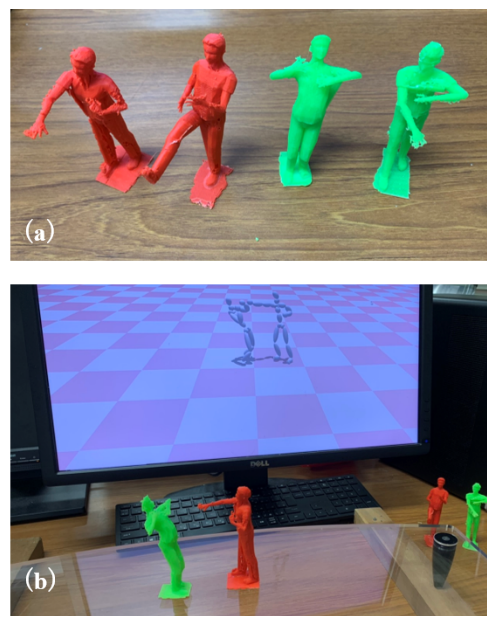

Fig. 2. Created figures (a) and the proposed interface (b).

Fig. 2. A user of our system can easily search for combat motion of two characters from a motion database by choosing and arranging 3D figures. Using 3D printed figures, the user can choose key poses available in the database. Additionally, the user can specify the spatial relationship between figures physically without using a complex graphical user interface. Even a user who is not familiar with conventional animation systems, such as a movie director, choreographer or animator, can use our system to search for existing combat motion.

Our system uses a motion database, which contains the combat motion of two characters. The key timing for each pair of motion is specified in advance. The 3D figures of key poses of these motion are created using a 3D printer. We develop a method for searching for a desired pair of motion from the motion database based on user input. We define combat motion features that contains the poses of two characters, and the relative position and orientation between them. Based on those features, we also design an evaluation function to evaluate the similarity between user input and each pair of combat motion. We conducted a user experiment to demonstrate the effectiveness of our interface by comparing it with a conventional graphical user interface that specifies the same information. The results demonstrated that, for our interface, the operation time was shorter and the number of trials was smaller than those of a conventional interface.

II. Related Research

Various interfaces have been developed to search for motion. A basic approach is to specify a motion name and search using a keyword [1]. However, using this approach, it is difficult to specify the spatial relationship between poses. An interface was proposed that uses the user's pose acquired using Microsoft Kinect to search for motion [2]. This method requires a large space. Another interface, which uses a doll, was proposed by Numaguchi et al. [3]. The user performs the search by moving the joints of the doll and reproducing the intended motion. However, all these methods cannot specify the motion of more than one person and their spatial relationship simultaneously. Won et al. [4] proposed a method to search for a series of motion of more than two people based on an event graph. However, using this method, it is difficult to specify a spatial relationship. Our interface allows the user to specify the key poses and spatial relationship of two characters using physical 3D figures.

III. Motion database and 3D figures

In this section, we describe the motion database and 3D figures that are created in advance.

A. Motion database

As explained in Section 1, our motion database contains a number of combat motion of two characters, which consist of an attacking motion of one character and the associated defending or avoiding motion of the other character. We assume that these combat motion are created in advance using motion capture or keyframe animation. The motion data consist of the body model and time-varying poses of the character. In this study, we assume that all motion have a similar standard body model; hence, we do not consider the difference between body models. A pose is represented by joint rotation, and the position and orientation of the pelvis.

The key frame for each pair of motion is specified in advance. The key frame is the timing of the impact of the attack, where the limb of the end-effector is moved furthest from the initial posture. Although there are methods for detecting key poses from motion automatically [5], it is still difficult to determine the timing of impact. Therefore, in this study, we manually specify the key frames for each pair of combat motion by visually inspecting them.

For our experiment, we created 60 pairs of combat motion. Our motion database contained four types of basic motion, that is, two attacking motion of punch and kick, and two defending motion of duck and guard. We created 12 combinations of the relative position and orientation for each pair of attacking and defending motion. The combinations included two types of relative distances, which were far or near (approximately 0.9 m and 0.45 m, respectively), and three types of relative orientations, which were facing each other, side or back (approximately $0°$, $90°$and $180°$, respectively) These motion were created using a motion capture device [6]. We manually specified the key frames for all pairs of motion, such as those shown in Fig. 1.

B. 3D figures

A 3D figure was created based on the pose in the key frame of a combat motion. Because the motion data did not contain a shape model, we prepared a deformable shape model that was associated with the standard body model in our motion data. The shape of the 3D figure was generated by deforming the shape model according to the key pose. Additionally, the base of the figure was separately generated so that it covered the positions of the feet on the ground and the center of mass. The figure was scaled to 1/16 of the size of an actual human figure. We used a 3D printer to create physical 3D figures. The colors of the figures are separated for attacking and defending motions.

Because it was not practical to create 3D figures for all key poses of the combat motion in the database, we classified all key poses into groups of similar poses and created a representative figure for each group. The similarity between key poses of attacking motion was measured from the end-effector for attacking and its height. The similarity between key poses of defending motion was measured based on whether the motion was guard or avoid, and in the case of guard, from the end-effector for guarding that was in contact with the attacker and its height.

In our experiment, because our motion data contained only four types of motion, as described in Section III.A, we created four 3D figures, as shown in Fig. 2 (a).

IV. Interface Design

The interface of our system is shown Fig. 2 (b). First, the user selects one figure from the group of attacking figures and another figure from the group of defending figures. The user then places them on the transparent platform. Our system searches for the pair of combat motion that matches the user's query the most from the database and displays the animation on the screen. The user repeats this process until a satisfying result is found.

To detect the types of figures and their placement on the platform, our system uses AR markers, which are placed on the

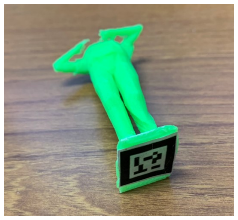

Fig. 3. AR marker on the base of 3D figure.

base of the figure, as shown Fig. 3. The ID numbers, positions and orientations of the markers are recognized from the image from the camera that is placed under the transparent platform using the ID numbers that are assigned to the 3D figures in advance. The recognition of AR markers will be implemented using the ARToolKit software library [7]; it is not implemented in our system yet.

V. METHOD FOR SEARCHING FOR COMBAT MOTION

In this section, we describe our method for searching for combat motion based on the combat motion feature and an evaluation function between the feature from the user's query and the feature from each pair of combat motion in the database.

A. Feature definition

The combat motion feature contains the ID numbers of the key poses of attacking and defending figures F_{pa} and F_{pd}, respectively. It also contains the relative horizontal position F_x and F_z and relative horizontal orientation F_o of the attacking figure relative to the defending figure for the key poses, as shown in Fig. 4. The range of relative orientation F_o is between $-180°$ and $180°$, and becomes $0°$ when the two figures face the same orientation.

The feature values for pairs of combat motion in the database are computed from the position and orientation of the pelvis in the key poses. First, the key poses are projected on the ground to obtain the horizontal positions and orientations of the two poses. Relative horizontal positions F_x and F_z and orientation F_o are then computed. ID numbers F_{pa} and F_{pd} are specified for each pair of combat motion.

The feature values for user input are computed from the ID numbers, positions and orientations of two AR markers in the same manner. Because the size of figures is scaled down to 1/16, the relative position is scaled up to 16.

B. Evaluation Function

The evaluation function computes the distance between the feature from each pair of combat motion $F_{pa}, F_{pd}, F_o, F_x, F_z$ and the feature from the user's query $F'_{pa}, F'_{pd}, F'_o, F'_x, F'_z$. Because the components of the feature are in different units, we compute the weight sum of these components, as described in the following.

The smaller the distance between two feature values of each component, the closer the two features.

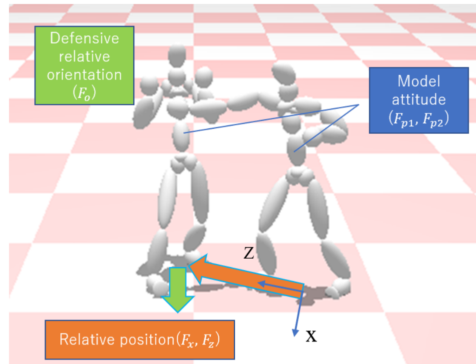

Fig. 4. The poses, and the relative position and orientation of the keyposes of combat motion are used as feature.

1) Distance between pose ID numbers: Distance V_{pa} between two pose ID numbers F_{pa} and F'_{pa} is computed as

$$V_{pa} = \begin{cases} 0 & (\text{if } F_{pa} = F'_{pa}) \\ 1 & (\text{otherwise}) \end{cases} . \quad (1)$$

Distance V_pa is also computed from F_{pd} and F'_{pd} in the same manner.

Because we currently use a limited number of figures, and their poses are completely different, we simply evaluate whether two poses are the same. To consider many figures that contain similar poses, the similarity between poses should be evaluated using a method such as in [8]. This extension will be considered in our future work.

2) Distance between orientations: Distance V_o between two relative orientations F_o and F'_o is computed as

$$V_o = \begin{cases} |F'_o - F_o| & (\text{if } |F'_o - F_o| < 180) \\ 360 - |F'_o - F_o| & (\text{otherwise}) \end{cases} . \quad (2)$$

The angular distance is computed to be between $0°$ and $180°$.

3) Distance between relative positions: Distance V_c between two relative horizontal positions (F_x, F_z) and (F'_x, F'_z) is computed as

$$V_c = \sqrt{(F'_x - F_x)^2 + (F'_z - F_z)^2}. \quad (3)$$

4) Overall Distance: Distance V between two features is computed as the weighted sum of all components:

$$V = \alpha V_{pa} + \alpha V_{pd} + \beta V_o + \gamma V_c, \quad (4)$$

where α,β and γ are scaling parameters.

α, β and γ are determined from the ratio of the range of feature quantities of the database. The scaling parameters α,β and γ can be determined based on the distribution of features in the motion database. In our experiment, we used $\alpha = 150$, $\beta = 1.25$ and $\gamma = 1$.

VI. EXPERIMENTS AND DISCUSSION

A. Design of Experiment

To evaluate the effectiveness of the proposed system, we compared our interface with a conventional GUI-based interface. Four subjects who had no experience of computer

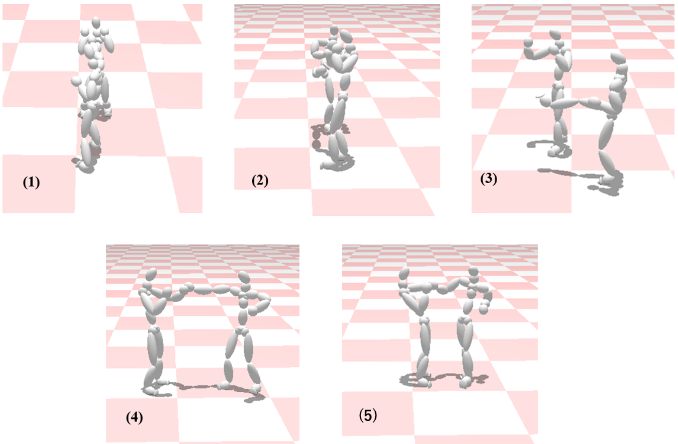

Fig. 5. Five target pairs of combat motion used in the experiment.

animation participated in our experiment. We chose five targets of combat motion from 60 pairs of motion in our database so that they included different combinations of poses, relative positions and orientations (Fig. 5). During the experiment, a target pair of combat motion was presented and the subjects were asked to search for target motion using our interface and the GUI-based interface. We measured and evaluated the required operation time and the number of trials until the subject found each target motion for each interface.

Because the module for recognizing the AR marker was not implemented, we used the Wizard of Oz method. A human operator interpreted the subject's query and input the same query using the GUI-based interface. We manually measured the time taken for the subject to select figures and arrange them on the platform as the operation time for our experiments. Therefore, there were small marginal errors in the measurements.

B. GUI-based interface

We implemented a conventional GUI-based interface for comparison. The user specified the same information used for our 3D figure interface using a mouse and keyboard. When the user selected a figure on the screen, handles for manipulating the horizontal position and orientation were displayed. The user moved and rotated the figure by dragging the handles. The types of figures were switched by pressing the associated key on the keyboard.

C. Experiment results

The average of the experimental results for the four subjects is shown in Table I. In the experiment, because the figure-based interface was input manually using the Wizard of Oz method, there was a slight measurement error in the result. Overall, the operation time for our figure-based interface was shorter than that of the GUI-based interface. The number of trials for our figure based interface was also smaller than that of the GUI-based interface. The results indicate that our method was effective in searching for the intended combat motion from the database.

TABLE I
EXPERIMENTAL RESULTS.

Interface	Figure-based		GUI-based	
Taget motion	Time	No. of Trials	Time	No. of Trials
1	8.2	1	29.4	1
2	5.5	1	29.6	1.5
3	8.0	1.5	30.1	2
4	11.7	1	7.3	1
5	6.3	1	12.2	1.5
average	7.95	1.1	21.73	1.4

Two subjects failed to find the expected motion on the first trial with the figure-based interface for the target motion 3 (Fig. 5 (3)). This is probably because two poses were placed in diagonally opposed positions, as shown in Fig. 5 (3), and the subjects were unable to reproduce the relative position and orientation using the 3D figures. The four subjects also required a longer operation time to use the figure-based interface for the target motion 4 (Fig. 5 (4)). This is probably because the initial arrangement of figures in the GUI-based interface was close to the arrangement of the key poses in the target motion.

VII. Conclusion

In this paper, we proposed a tangible interface using 3D printed figures to search for combat motion of two characters. Our experiments demonstrated the effectiveness of our interface. In future work, we will apply our system to a large number of actual combat motion and conduct a user study.

Future work will also include the automatic detection of key poses in pairs of combat motion and an extension of the distance function to consider the similarity between poses.

VIII. ACKNOWLEDGMENT

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