

A Data-driven 3D Animation System for Tele-Rehabilitation

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Abstract - In this paper, a novel data-driven 3D animation system is developed for stroke patients to use remotely at home environments to recover their motor function. This system consists of four main components, namely human motion tracking, data analysis diagram, data-driven arm animation, and text-driven speech animation. It also contains an expert database and transmission of data files over the Internet. Both patients and therapists can use this system to compare 3D mimic animation with historical case studies of normal and abnormal motions. We have evaluated this system using several simulations: (1) 3D arm rendering in different movement patterns, such as reach, drink, and reach-flexion; (2) data analysis using the diagrams; (3) giving an evaluation and suggestion by the digital human model with a speech animation.

Index terms - data-driven animation; tele-rehabilitation; data analysis; motion evaluation.

I. INTRODUCTION

In the Europe, as well as USA and other developed countries, stroke is the most common cause of permanent disability. Therefore, a lot of people live with moderate to severe disabilities as a result of stroke [1]. Economic pressures force these patients to return to their homes quickly after the initial rehabilitation programme in hospitals. However the evidence shows that the potential for improving motor function may last a number of years after stroke [3, 9]. Hence, it is necessary for patients to continue some rehabilitation programmes in their home environments using some forms of assistive technology.

In recent years, home-based rehabilitation has evolved as a viable alternative way for stroke patients to do exercises and recover their motor ability at their own homes. The potential benefits associated with the home-based rehabilitation programme are the convenience and low cost for patients and their families [2], as well as huge cost saving for national health services.

In this paper we present a data driven 3D animation system for tele-rehabilitation of stroke patients. The system can provide a controlled and motivating environment that is very cost effective. The capability of the proposed system includes several key features: (i) to provide a data-driven 3D

animation interface to play arm movements. (ii) to display the diagram of data analysis. (iii) to enable a digital human model on the screen to give an evaluation and suggestion to patients according to the data analysis diagram as a therapist normally does; (iv) to transmit the data file from patient homes to computers at a care centre via the Internet so that therapists can monitor the progress of patient rehabilitation at home and give some remote instructions immediately.

The remainder of this paper is structured as follows. Section 2 describes some related works. The system architecture is presented in Section 3. Section 4 presents some experimental results to show the feasibility of the proposed system. Finally, Section 5 concludes the research and presents some ideas for future work.

II. RELATED WORK

Developments in medical rehabilitation research over the past 25 years have enhanced rehabilitation engineering technologies for seating, cushioning, and positioning [10]. Specially, in stroke rehabilitation, patients may learn how to move, talk, think and care at their homes. These technologies enable patients to build their strength, coordination, endurance and confidence. In recent years, a large number of studies have demonstrated the efficiency of home-based stroke rehabilitation. For example, the work of Goncharenko et. al. [11] emphasizes the use of "history units" - recordings of simulation parameters and patient's motions during the post-rehabilitation analysis of human performance. Through analyses of patient's performance and behaviors, therapists try to improve and adapt the therapy models to better fit the personal needs of each patient who did the training of rehabilitation at home environment.

Nair et. al. [12] created a low-cost tool for diagnostic and rehabilitation of people with upper limb dysfunction due to muscular dystrophy and stroke. Moreover, Jadhav et al [13] have developed a home-based haptic tele-rehabilitation system that focuses on the virtual driving environment and series of exercises to serve as an integrated diagnostic and therapeutic tool for upper limb motor rehabilitation. It facilitates effective visualization and quantification of the patients' motions and associated pathologies as he or she follows a prescribed series of exercise. The therapist can use the remotely collected data to replay the patient's exercise session on a digital human

model.

However, although some systems provide the interactive remote visual monitors and multimedia facilities, most of the systems require physiotherapists and careers online all the time. This may be difficult if therapists are too busy to talk with the patients sometimes. Thus the patients can not get feedback soon when they need, which may influence their mood and the effect of the home-based rehabilitation.

In our project, a digital human model can mimic a therapist to give some useful feedback to patients in real time. The evaluation and suggestion by the digital human model are based on an expert database, so the patients seem heard many experts' instructions immediately after their exercise, although they do not know who the experts are. This system can improve patient compliance and better recovery performance at home.

III. SYSTEM ARCHITECTURE

Our data-driven 3D animation system is divided into a number of functional blocks: motion tracking sensors, 3D animation, data analysis diagram, and evaluation and suggestion by a digital human model. The role of each component is elaborated in the following subsection. The organization of our animation system is illustrated in Fig. 1.

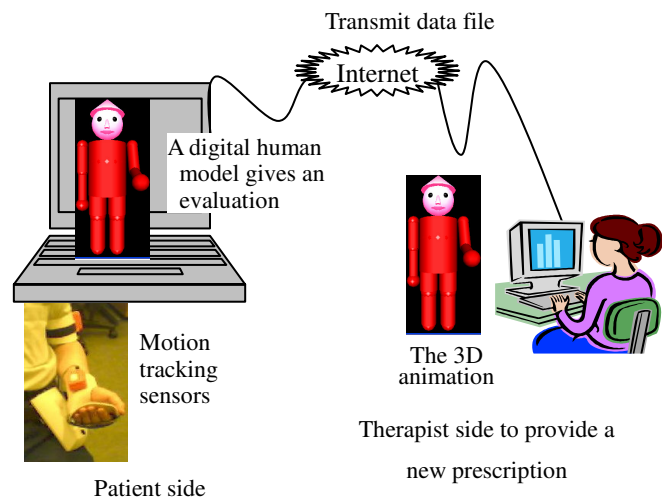


Fig. 1 System architecture

A. Motion Tracking Sensors

The motion tracking and data recording module is used to track the arm movements of a patient and record the position and rotation of wrist, elbow and shoulder joints of arm to a data file. The data file is used to drive 3D animation and draw data analysis diagrams. In addition, the data file is transferred from the patient to the therapist via the internet. In this way, the therapist can “observe” the movement virtually in hospital and monitor the patient’s improvement in home based rehabilitation, and then determine whether patients need to change the rehabilitation scheme.

This module is based on two MTx inertial sensors that are

developed by the Xsens Dynamics Technologies Netherlands. It consists of sensor fusion and optimization techniques to support post-stroke rehabilitation programs. It is implemented in Visual C++. There is a Bluetooth wireless connection between the computer and two MTx sensors via a small box worn on the waist. The wireless connection allows the subject to carry out motion exercises freely. The two inertial sensors are placed on the lower and upper arms in order to determine the position of the patient’s arm (see the motion tracking sensors in Figure 1). Each sensor consists of a tri-axial accelerometer, a tri-axial gyroscope, and a tri-axial magnetic sensor. It measures drift-free 3D orientation as well as kinematic data: 3D acceleration, 3D rate of turn (rate gyro) and 3D earth-magnetic field data of the patient’s arm, of which real-time 3D arm movements can be reconstructed with 3D demonstration. The motion tracking algorithm applied in this system is illustrated in Figure 2.

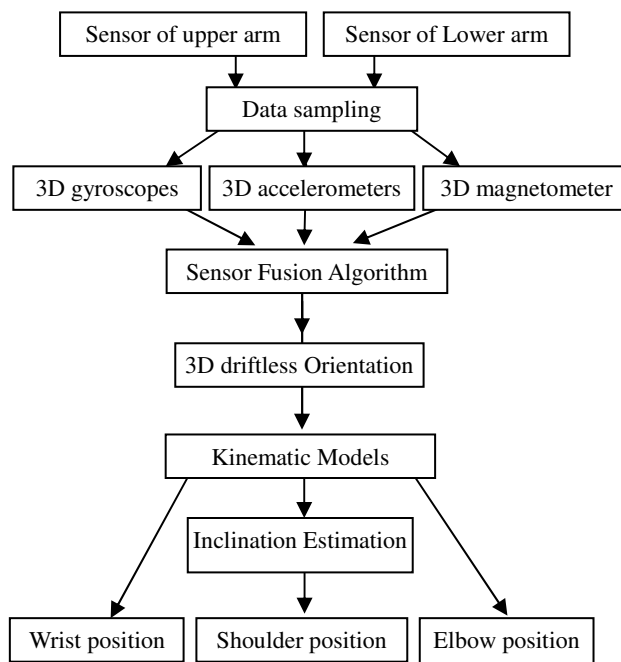


Fig. 2 Motion tracking algorithm

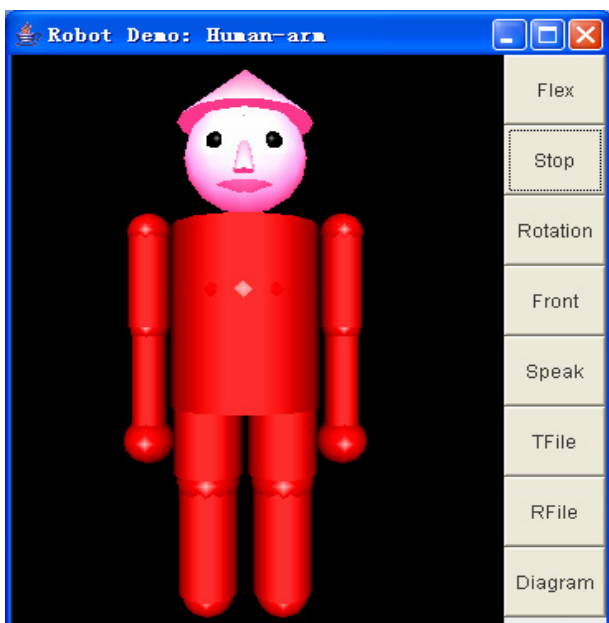
In order to estimate the position of the patient’s arm, we use a sensor fusion algorithm to accurately calculate absolute orientation in three-dimensions from the miniature rate of turn sensors (gyroscopes), accelerometers and magnetometers in real time. A Kalman filter is used here to compute the position of the shoulder, elbow and wrist joints based on kinematic models and the inclination of the upper-arm. In our model, shoulder and elbow joints have six degrees of freedom (6 DOFs) in total.

B. 3D Animation

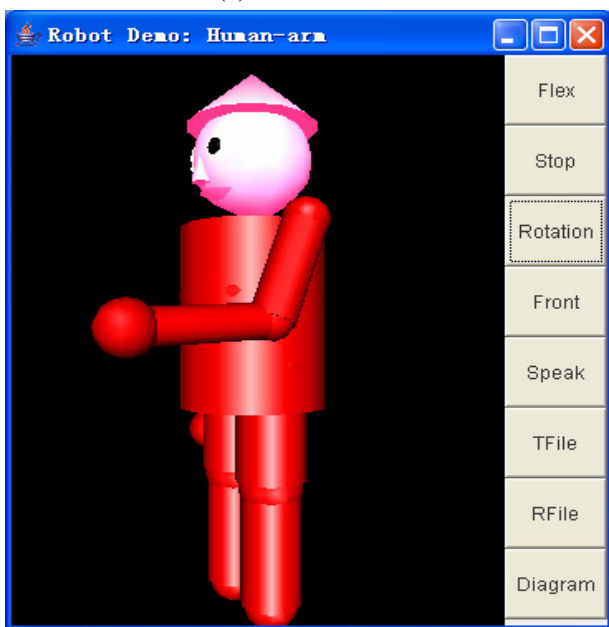
In tele-rehabilitation, both therapist and patient need to remote communicate and monitor with each other. Although the real-time remote monitor is very useful in the tele-rehabilitation, it requires both therapist and patient to be

online at the same time. This may be not realistic, because a therapist can not monitor every patient all the time. Hence, the animation is a flexible and necessary means to reconstruct patients' movements for the remote rehabilitation. A 3D animation enables therapists to display collected arm motion data off-line.

In addition, therapists and patients can compare the 3D mimic animation of a patient's movements with historical case studies of normal and abnormal motions. They can then evaluate the efficiency of rehabilitation schemes.



(a) Front



(b) Rotation

Fig. 3 Main interface of 3D animation

Figure 3 shows the main interface of the 3D animation.

This module generates the arm moment by a digital human model with a data-driven 3D animation, where the data file comes from inertial sensors fixed on the patient's arm. We implemented the animation system based on Java and Java3d. The system can animate the arm motion from different angles by clicking the buttons: Front and Rotation.

In order to represent the data-driven 3D animation, we read the data from the data file into a temple array, and then group it into three groups as follows:

$$WP = (W_x, W_y, W_z)$$

[1] Wrist Position (WP) represents the wrist movement.

$$EP = (E_x, E_y, E_z) \cup FR = (\varphi_{fr}, \theta_{fr}, \psi_{fr})$$

[2] Elbow Position (EP) and Forearm Rotation (FR) represent the forearm movement.

$$SP = (S_x, S_y, S_z) \cup UR = (\varphi_{ur}, \theta_{ur}, \psi_{ur})$$

[3] Shoulder Position (SP) and Upper-arm Rotation (UR) represent the upper arm movement.

All above three joint positions are represented by three elements of single-precision floating point x, y, and z coordinates in meters. The rotation is represented by three Euler angles in radians. Assume that:

$$\varphi = roll, \text{ rotation around } x$$

$$\theta = pitch, \text{ rotation around } y$$

$$\psi = yaw, \text{ rotation around } z$$

To convert data measured by the sensors into the value of Java3D coordinates, we use the following formula:

$$Position = value.sensors + offset$$

$$Rotation = gain \times value.sensors + offset$$

The offset and gain value are different for each axis, and determined using the data model and sensor calibration. For example, the computed Shoulder Position and Upper-arm Rotation can be converted into Java3D coordinates as follows:

$$SP.J = SP + offset$$

$$UR.J = gain \times UR + offset$$

In the equations above, SP.J and UR.J are the position and rotation value of the shoulder in Java3D coordinates. SP and UR are the position and rotation measured values in sensor coordination frames.

After converting the data measured by sensors into the value of Java3D coordinates, we then use these data to drive the digital human model arm animation in a loop. Thus the animation can show the human arm movements with reality.

In order to represent the data-driven 3D arm animation, data is fetched from a text file into a temporal array TP, and the values of position and rotation for wrist, elbow, shoulder, forearm, and upper-arm from TP are obtained and saved to different arrays separately as Figure 3 shows. Then it constructs the axis-angle matrix for wrist, elbow with forearm, and shoulder with upper-arm by matched arrays. Finally, we

combine the current values of translation and rotation to control the arm movement.

The flowchart of the designed 3D arm animation program is illustrated in Figure 4.

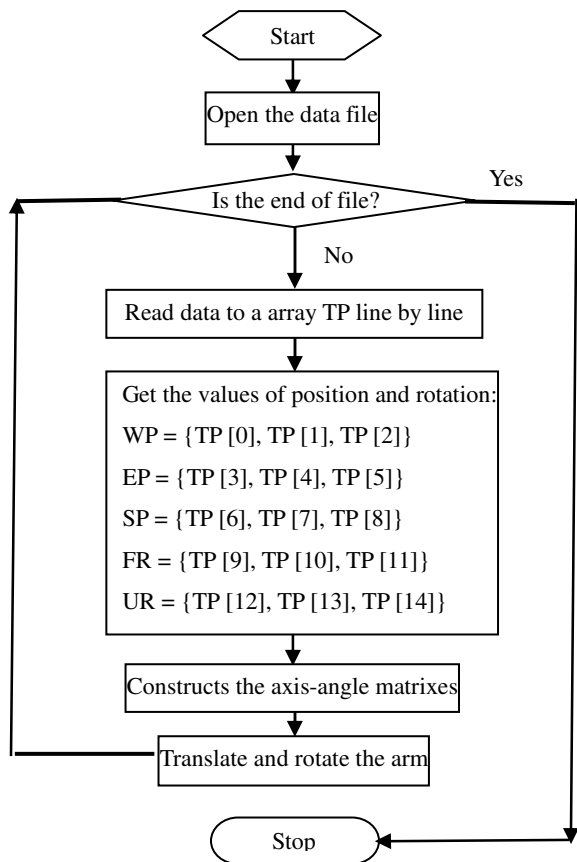


Fig. 4 Flow chart of 3D arm animation

C. Talking with the digital human model

To implement the digital human model talking, speech animation is created with a background audio file. All the background audio files are saved in a database, namely expert database. Our system selects different audio files from the expert database according to different results of data analysis, and then plays this audio file in background; meanwhile the digital human model's speech will be controlled by this audio file to change its shape and size. In this way, the digital human model could mimic therapist talking. Therefore, it is clear that the speech animation is a text-driven animation.

In order to control the text-driven animation, first we need to create a data file from an audio text file, for example, changing the audio text file "OK" to the data file "0.79,0.75", then using this data file controls the speech animation. The speech animation uses a text-driven mechanism for changing its shape and size rather than using a complete phoneme target or pose layering technique. It is easy to implement and provide more flexibility during the animation process, especially when speaking a long sentence or a long paragraph. Figure 4 shows the results of two simulations. More specifically, Figure 5(a)

shows the digital human model says "OK", and Figure 5(b) shows that the digital human model is speaking "you are right".



(a) She is speaking "OK"



(b) She is speaking "you are right"

Fig. 5 the text-driven speech animations

TABLE I
ROUTINES FOR TEXT-DRIVEN SPEECH ANIMATION

{Convert the text to a data array from the audio text file}

```

Open file ("audiotext.txt");
Char [] tmp; //save the characters of audio text.
Float [] tav[]; //save the ASCII values of characters.
Read ("audiotext.txt") into tmp[];
Int cnt = tmp.length;
  
```

```

For (int i =0; i<cnt; i++) {
  Convert {tmp[i]} into tav[i];
}
Close ("audiotext.txt");
  
```

```

{Play an audio file in background.}
Open file ("audioFile.wav");
Get input stream in = new FileInputStream("audioFile.wav");
Create a object as = new AudioStream (in);
AudioPlayer.player.start (as);
  
```

{Control the speech animation by the ASCII value array}
Construct speechAA = new AxisAngle4f (x, y, z, angle);

```

For (int j=0; j<cnt; j++) {
  speechAA.set (0.0f, 0.0f, tav[j], 0.0f);
  Speech.getTransform (tmpTrans);
  tmpTrans.setRotation (speechAA);
  Speech.setTransform (tmpTrans);
}
  
```

The routines to recognize the text-driven speech animation are described in Table I. Note that some operations on the selection of audio files and audio text files from an expert database are omitted in order to simplify the pseudo code and make it more readable.

Remark: the speech movement is controlled by the ASCII values of characters to change its shape and size, without rotation. So we set the angle of rotation equal to zero about any vector (x, y, z). In addition, in order to match the length between the speech animation and the audio file of background, the speech animation can not read out all characters from the text file of audio. It only gets one character for one syllable to a char array. This means that the code needs to judge the vowel in the text file, then read the previous character to the char array.

IV. EXPERIMENTAL WORK

We first did the motion detection and obtained three groups of data files from testing, which are reaching, drinking and reach-flexion tests. Here we only present the 3D animation experiments since the motion detection experiment and associated results will be presented in a forthcoming paper “An Interactive Internet-based System for Tracking Upper limb Motion in Home-based Rehabilitation”.

A. 3D Animation Display

We use six degrees of freedom (6 DOF) to refer to motion in three dimensional space, i.e. the ability to move translation in three perpendicular axes (forward or backward, up or down, left or right) combined with rotation about three perpendicular axes (yaw, pitch, roll). The arm movement along each of the three axes is independent of each other and also is independent of the rotation about any of three axes. The motion therefore has six degrees of freedom. In fact, these six-DOF data sets come from transmission via P2P communication. The accuracy of our 3D animation depends on two issues: one is the alignment between sensors and Java3D coordinate systems and the other is the real-time rendering of the 6 DOF from a text file (sent from the patients via the Internet).

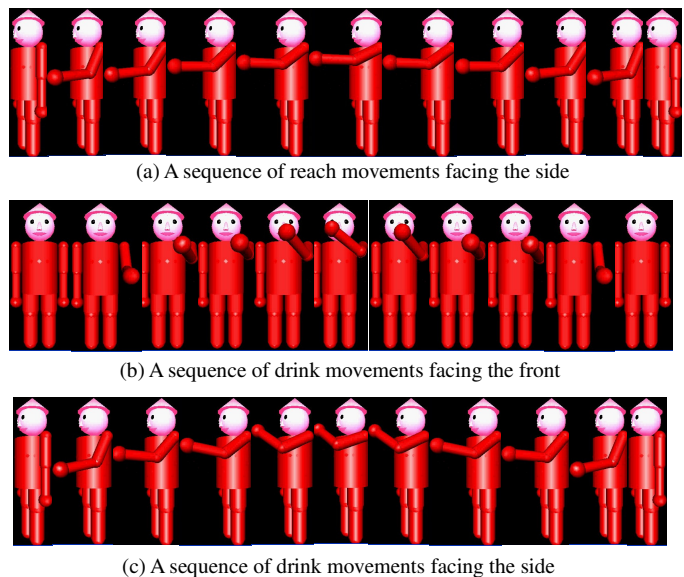


Fig. 6 Some motion sequences: reaching and drinking

Figure 6 shows the results of 3D animation in several different motions. The experiment shows that the animation can represent the arm movement accurately. Figure 6(a) shows the reaching action in which the arm is being extended and flexed. Figure 6(b) and Figure 6(c) shows that the arm is conducting drinking tests from the different view angles, i.e. either facing the front side or facing the right side. It shows that the forearm is stretched and then flexed to touch the mouth. As can be seen, there is no significant drift in the results and the proposed tracking and 3D animation system had good performance at different motions.

B. Data Analysis and Motion Evaluation

Both patients and therapists can obtain the detail of the rehabilitation exercise through the data analysis diagram after a period of arm movements. For example, how many periods the patient did in a fixed time? What is the value of three-dimension position for wrist or elbow joints? And so on. The system can exactly compare the value of the diagrams before and after treatments with historical case studies of normal and abnormal motions, and generate a precise evaluation about the home-based rehabilitation.

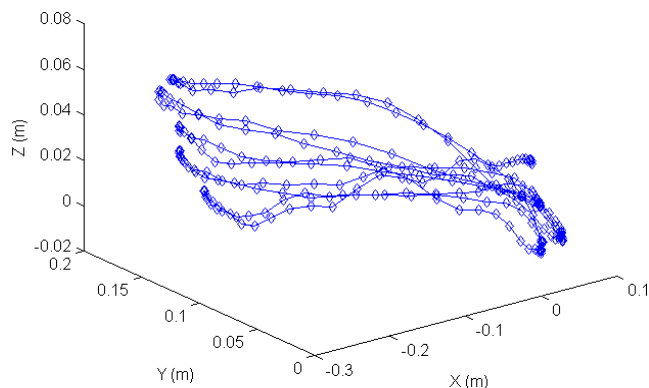


Fig. 7 Data analysis diagrams. (Elbow Position)

In our system, users who want to obtain all diagrams only need to click the button of the diagram in the main interface of the system. Figure 7 shows the elbow position with its values, in which the elbow joint position has the movements of -0.3m to 0.1m along the x-axis and has 5 periods of movements during the human arm motion test.

In addition, if patients want to listen to the motion evaluation from therapists, they just need to click the button of the Speak in the main interface of the system, and then the digital human model will speak the motion evaluation according the data analysis result. For example, in above case, the digital human model will say “well, the maximum value of elbow positions is 0.2m along the y-axis, and finished 5 periods in 20 seconds. Well done”. Figure 8 shows the speech animation. The system can compute all the data and record the motion time, and then save them into a database. It can also combine this data with an audio file that comes from the expert database. The system controls the speech animation via

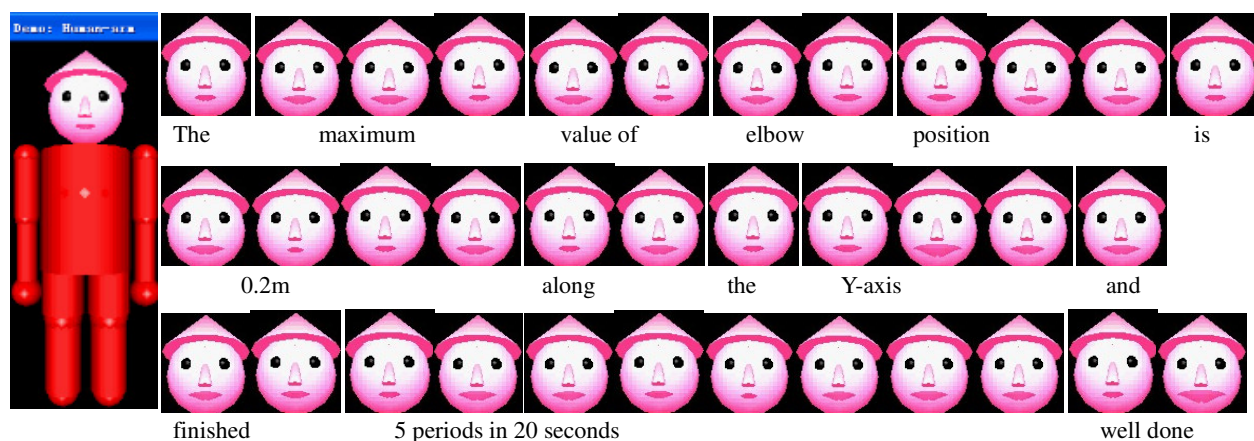


Fig. 8 Speech animation

the audio file. Note that audio is played in background. So patients can obtain the motion evaluation and instructions immediately after the rehabilitation exercise.

V. CONCLUSIONS AND FUTURE WORK

This paper presents a data-driven 3D animation system for a home-based rehabilitation programme. The system provides basic support for motion tracking, data transmission over the Internet, data-driven 3D arm animation, and text-driven speech animation that plays an evaluation dialogue and data analysis diagram. The proposed system was demonstrated by arm reaching and drinking actions in different view angles, as well as a spoken dialogue animation and its performance was evaluated. The system is expected to operate at home environments to improve patient compliance and recovery, reinforced by a digital human model instruction based on the expert database.

Our future work will focus on the improvement of the system accuracy. For the animation part, the natural expression of human body will be added in order to make the face look more attractive. In addition, we will create a concise expert database for data analysis and motion evaluation in collaboration with a number of hospitals and therapists.

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