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Application and Research of Kinect Motion Sensing Technology on Substation Simulation Training System

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Abstract: The coming forth of kinect technology has enabled trainers to control cruise and operation in 3D scene by their action, but this technology is not applied to electric power training field yet, as this field includes many electric devices and operation regulations. This paper firstly described the electric operation regulations as one set of operation patterns by using finite state machine technology, subsequently matching the operation information gained by a kinect device to these patterns by using the Dynamic Time Warping algorithm, so that the action type of trainer can be recognized. At the same time, this paper discussed the control of the cruising velocity of a virtual man in 3D scene by enabling action synchronization of the trainer and the virtual man, and the control of the display affect of collision by adjusting the attributes of Unity visualization objects when the virtual man operates an electric device. So, trainers have been immersed into 3D scene of substation and have gained deeper training effect.

Keywords: Dynamic time warping (DTW), Kinect, Pattern matching, Training simulator for substation, Virtual man.

1. INTRODUCTION

In the simulation of power training, students' experience should be strengthened to make them have a deeper impression on learned knowledge. The current power training system may give students a chance to wander in the three-dimensional scene, but they have to move or click the mouse continuously. Microsoft launched the Kinect motion sensing device [1], which is called "the third time human computer interaction revolution" subsequent to mouse and multi-touch technology by media. Applications of virtual reality based on the Kinect technology involve fields such as military, medical treatment, recreation, education and training, for instance virtual pavilion roaming [2], visual equipment simulation [3] and so on.

As power training is related to many facilities and operation norm of the electricity system Kinect should be developed to improve likely problems such as finger fingerprint identification [4], distance sensing and limited rotation angle. Kinect technology has therefore not been applied to power training simulation. This paper combined the simulation of operation norm in power training to make Kinect technology advantageous to the greatest extent. At the same time, based on Unity (mature three-dimensional engine), it uses dynamic time warping and finite state machine technology to establish interactive three dimensional Kinect substation training systems.

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2. SYSTEM ARCHITECTURE

In the new substation simulation training system proposed in this paper, there is no need to wear ancillary equipment or have the aid of a keyboard or a mouse, but it is merely required for Kinect facility. Trainees can make virtual people roam in the three dimensional simulation scenes and complete a part of the actual operation courses, leaving trainees with a feeling of staying in real training world and hands-on operation. Therefore, human computer interaction of this system constitutes common interaction experience based on virtual reality technology and immersive interaction experience based on the Kinect motion sensing technology, as shown in Fig. (**1**).

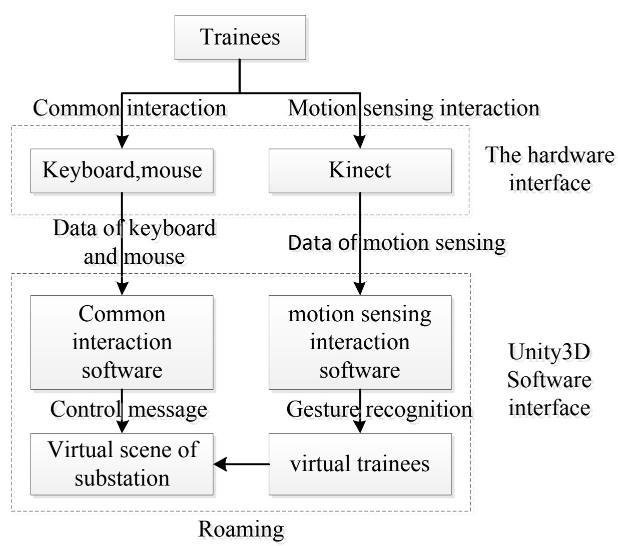

Fig. (1). System architecture.

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Mouse and keyboard and interaction software are common interaction accessories of the training system. Such accessories simulate working condition and processing of normal and broken proposed substation through vivid animation and sound, such as facility tour, operation, and breaker tripping and substation operation condition in rain, thunder and typhoon. Immersive interaction experience consists of the Kinect facility, motion sensing interaction software and virtual trainees. In this section, trainees operate virtual trainees and make them move forward, backward and turn away in virtual substation through the Kinect technology. At the same time, the trainees also operate virtual trainees to open equipment box door, checking connection condition, operation of the functioning switch on switching facility and change in its operation situation.

3. MOVEMENT IDENTIFICATION IN KINECT

Movement of trainees changes the location of responding articulation point. Changes in the articulation point location and their previous location form moving direction vector of this point. This vector is taken as a characteristic vector to identify the movements of the trainees by DTW.

3.1. Identification of Training Action Categories

DTW algorithm is based on the template matching algorithm. The template matching algorithm is used to create a template and classify every action feature data and template, through the similarity of the two to judge the gestures. As the time of some of the same gestures is short, while of some is long, the recognition rate is formulated. DTW algorithm is a pattern-matching algorithm having a nonlinear normalization effect. It uses the characteristic signal to lengthen or shorten until both reach the maximum overlap on the time axis [5], thus realizing the purpose of eliminating the differences between the two space-time representation models.

When executed, limb movements should be simplified into the change of coordinate points in one-dimensional coordinate system first, and then normalization of the changed value is carried out. Through taking the right arm as an example, joint points are studied. If the Node X coordinate obtained later is smaller than the X coordinate obtained before, the value is 1; If the Node X coordinate obtained later is greater than the X coordinate obtained before, the value is -1; When the difference between the two X coordinates of the arm position is within a certain range, then the value is 0. Thus, the right arm's movement sequence is (0, ⋯, 1, 1,1, ⋯, 1,0) or (0, ⋯,-1,-1,-1,⋯,-1,0); the former denotes the right arm waving inward and the latter denotes the right arm waving out. According to the sampling rate of 30 points per second, a lot of feature vectors above can be obtained, their length being 30.

As the literature [6] points out, the continuity of movement is a continuous 1 or continuous - 1 in view of the movement feature vector. Taking the speed of operation factors into consideration, occasionally there will be a zero among them. Thus, if the one-dimensional vector to the reference template R is 30 points, then its value is 1 or -1; if it is 1, this indicates the lifting action; if it is -1, this indicates the drop action. If the feature vector obtained from the samples is T, the similarity degree between it and the reference template R in the i sampling can be measured by the distance between each other $D_i[T_i, R_i]$; the smaller distance indicates the higher similarity degree [7].

Considering that the previous point of the feature vector may be zero, it indicates that there is no action; as the latter point is zero, it can be inferred that the action is being finished. So in DTW algorithm, the Euclidean geometry distance formula is:

$$D_i[T_i, R_i] = \sum_{k=b}^{e} \left| T_{i,k} - R_{i,k} \right| \tag{1}$$

In which, b refers to the number continuously appearing as zero in Ti, e refers to the length of Ti minus the number continuously appearing as zero. Thus, the above normalized feature vectors can be obtained by 30 points per second, and the direction of motion of the joint points can be determined.

3.2. Identification of Simulation Action Semantics

In the simulation plan, the work of training of personnel is described by a simulation task, and when the work is finished, several movement behaviors are involved in training of the personnel. The literature [8] achieved good affect by using the finite state machine to describe wind power system operation state detection. The paper described these actions and logical semantics by using the mathematical models of the finite state machine.

The definition of the finite state machine: namely, a finite state machine (FSM) model can be expressed as a 5-Tuple G=(S,Σ,δ,K,F), where S is a nonempty set of the state; Σ is the corresponding character set; δ is a state transition function, the single value mapping of $S\times \Sigma \rightarrow \mathbf{S}$; K is the initial state; and F is the termination state. Specific to the system involved in this paper, state set S refers to the state of the training of personnel, and the corresponding simulation behavior execution; and the corresponding character set Σ refers to the behavior of the simulation training of personnel; state transition function δ(Si,a)=Sj, Si, Sj∈ S, a ∈ Σ, refers to behavior results of the simulation training of personnel.

Transfer function δ includes the movements of two legs and two arms. It specifically involves lifting leg, drawing back leg, lifting arm, dropping arm, swinging arm to the left and swinging arm to the right; while both hands movement, in particular refers to rotating hands, clenching fists, outstretching five fingers, bending fingers and straightening fingers.

Character set is the behavior show of the transfer function δ, including walking, stopping, turning, bending, lifting arm, dropping arm, turning hands, clenching fists, outstretching fingers and the fingers bending and straightening. The transfer function δ is used to control the state change, such as, arm turning left or turning right to control behavior show of the training staff that Σ stands for; when training of personnel turns left, it can be shown by rotating the arm to the left, or when training of personnel turns right, it can be shown by rotating the arm to the right.

Through using the finite state machine to describe the process of equipment installation as shown in Fig. (**2**), the training of personnel needs to go to the equipment first, including walking forward, turning, standing upright, squatting and operating several states.

"Lifting Leg": this body movement means that the forward and upright states all move to forward state; "Arm Translation": this body movement makes forward status move to turning state; "Standing Leg": this body movement makes forward or turning state move to the upright state; “Arm down": this body movement makes the upright state move to the squatting state; and "Arm Up": this body movement makes the squatting state move to the upright state; "Rotating hands, Clenching fists, Outstretching fingers": these palm movements make training of the personnel enter the operating state until completion.

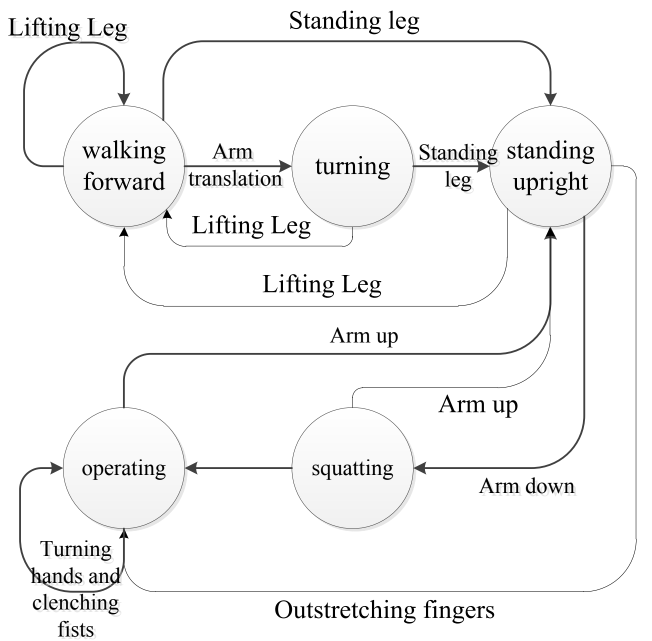

Fig. (2). Examining-repairing syntax state machine of device.

4. REALIZATION OF KINECT AND CONVERTING STATION ALTERNATIVE SIMULATION TRAINING SYSTEM

As Unity virtual reality technology is widely applied [9, 10], the application of Unity for electronic power training to build a simulative field is also required to make the virtual man walk freely and operate in a 3D simulative field. Hence, we need to actualize the wandering control and real field operation control of the virtual man. This study designed two alternative controlling schemes: remote control and in-field operation.

4.1. Remote Control Alternation

Remote control alternation design refers to realization of the functions that the training personnel control to make the virtual man move forward, backward, turn left, turn right and stand in place. Taking control of virtual man’s movement as an example, if we want to realize the movement of the virtual man, three steps should be completed as follows: a. Design controlling actions of the training personnel. b. Play relevant animations. c. Let the virtual man move forward, backward or turn around in a particular pace. The completed controlling actions are shown in Table **1**:

Table 1. Corresponding relation of actions and cruise tasks.

Gesture and Action	Remote Action Task
Step in place (Left first, once)	Move forward
Step backward (right first, once)	Move backward
Keep left arm in same level with shoulder (Continuously)	Turn left
Keep right arm in same level with shoulder (Continuously)	Turn right
Wave left hand to breast(once)	Cease walking

At first, the walking control is completed. And combined with already walking animation, the remote control of virtual man is finally completed in the simulative field according to the control flow graph (Fig. **3**).

Part of controlling program is shown as follows:

```
void Update ()
{
transformValue=Vector3.forward*    Time.deltaTime*0.05f;
//Set the walking speed
if(sw.pollSkeleton())
  {
  floaty_LeftKnee=sw.bonePos[0,
  (int)Kinect.NuiSkeletonPositionIndex.KneeLeft].y;
  //joint data
  floaty_RightKnee=sw.bonePos[0,
  (int)Kinect.NuiSkeletonPositionIndex.KneeRight].y;
  //joint data
  if (y_LeftKnee >=( y_RightKnee+0.1))
  //The left knee high over the right knee
        {
        upLeftKeen=true;
         //Enter the second round of judgment
       }
        if(upLeftKeen==true  &&  y_RightKnee  >=(
        y_LeftKnee+0.1))
        //The second round of judgment: The right knee
        high over the left knee
   {
         upLeftKeen=false;
         anima-
  tion.Play(animation["KinectMan_Walk"].clip.name);
```

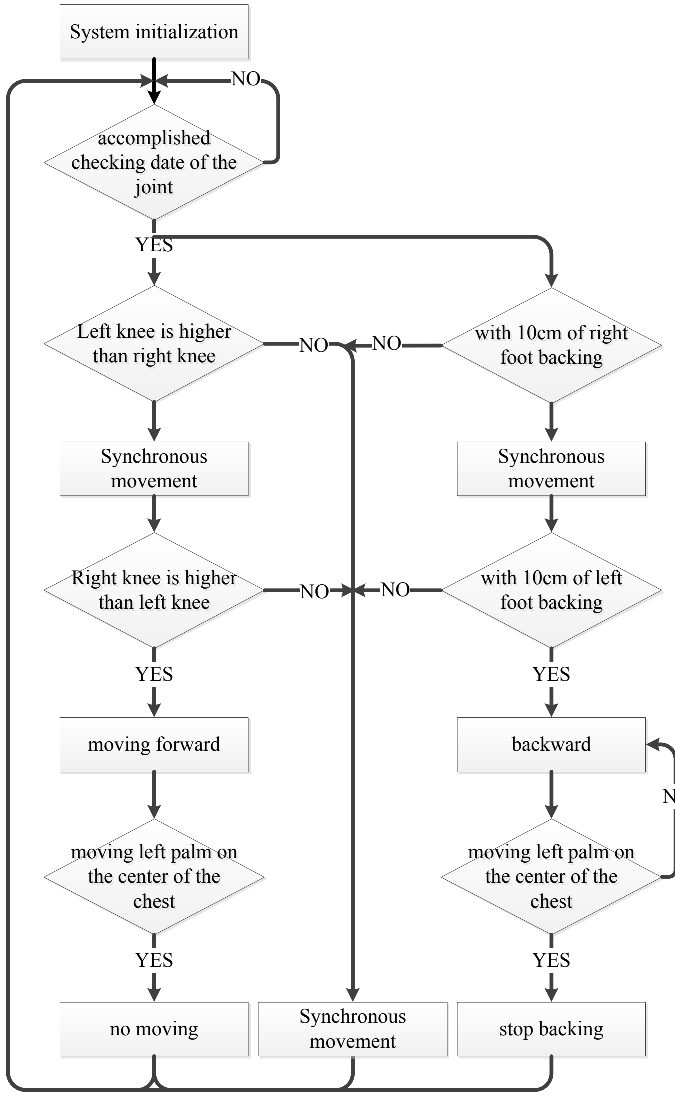

Fig. (3). Processing procedure of virtual man cruise.

```
    //Play the walking animation
            ManMoveForward=true;
            //Set forward state
            }
            if (ManMoveForward == true)
    {
            this.transform.Translate(transformValue,Space.Self
    );    //Forward
            }
    }
}
```

The next step is to control the virtual man to turn around. The virtual man's turning around can be divided into two sorts: turning at a standstill or turning in walking. To realize the above turning functions and make them conform to normal human walking habits, the virtual man's continuity and speed should be guaranteed when turning around. To achieve the two functions, the article adopted the way that let the virtual man turn around in its own axis and in angular velocity at 5 degree per frame and take the continuity of two kinds of turning around states into consideration, which conform to human's normal demand and action habits.

All fields in Unity are projected on the computer screen by camera, as is the virtual man. Due to the limitation of camera's visual scope, the change of place brings a perspective alternation. The system solution is to let the camera move along with the virtual man at the same pace so that when the virtual man is moving in 3D field, the camera moves simultaneously, bringing an authenticity for the training personnel. The final wandering effect pictures are shown in the following Figs. (**4** and **5**):

4.2. Field Operation Alternation

The field operation alternation actions referred in the article mainly are opening up the equipment and alternating the switch. It has been hoped that the user could get rid of the limitation of the gesture to finish two such actions and

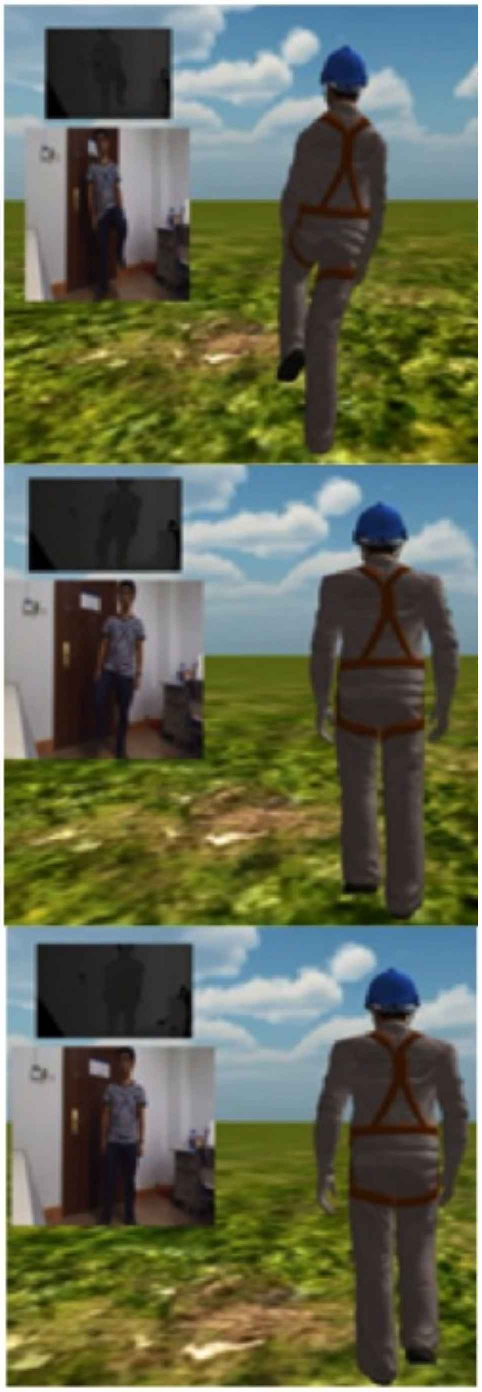

Fig. (4). Virtual man walking forward.

return to the conscious action in order to let the virtual man open the door, approximately conforming to the real action.

When the field operation is to be finished, the training personnel should control the virtual man walk to the front of the equipment in 3D field and touch the door frame or switch. Such action should be similar to real operation, hence the testing should be finished as whether the virtual man's hands have touched the door or switch or not, and the testing as whether there are transformative actions such as opening up door, closing up door, ceasing and connecting when the virtual man has touched the equipment.

Fig. (5). Virtual man turning to right.

The article firstly finished the testing in touching condition by collision detection function equipped with Unity. The function can compute the interrupt function as long as the two rigid objects collide. The function realizes the functions such as opening door or switching off, etc.

As the collision detection in unity is used to simulate the physical effect of the two objects colliding in reality, therefore people's hands in contact with the equipment surface can also produce physical collision, and besides, the speed of this contact is also hard to control. However, the collision effect can be very weak only when the virtual man's palms move to touch the equipment surface at a very slow speed, so this method is clearly not feasible. To solve this kind of

Fig. (6). Virtual man opening a device door.

Fig. (7). Virtual man closing a device door.

problem, the solution in this paper is that at the moment when the virtual human's palm comes in contact with the equipment surface, immediately the human hands' rigid body properties are cancelled (cancel the collision effect), and after the state transition of the equipment door or switch has been finished, the human hands' rigid body properties are recovered.

In consideration of the experiment effect, it is found that the distance between the virtual man and the equipment can also influence the final effect. When the training staffs finish one open-door action, the influence of the action continuity, the limitation of human hands' rigid body shape in the unity and the speed of opening the device door may lead to blocking of the device door by the virtual man's hands to some extent and then can lead to collision again, finally affecting the equipment's open-door effect. By controlling the distance between the virtual man and the equipment and adjusting the size of virtual human palm's rigid body shape, this problem can be solved. The actual operation of opening and closing the door is shown in Figs. (**6** and **7**).

In the scene, the virtual man can realize the opening and closing door operation just by waving his hands slightly to touch the device door. Connection and disconnection of switch are similar to the following.

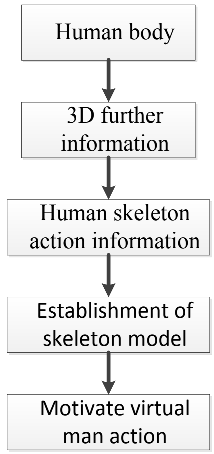

Fig. (8). Real-time acquisition and display chart of human motion.

5. INTERACTIVE SIMULATION EXPERIMENT DATA OF KINECT

Identifying the training staffs' behavior or controlling the virtual man in the 3 dimensional scenes to finish the simulation task on the basis of the kinect finite state machine technology introduced in this paper has been applied to the the actual substation simulation training system. The real-time acquisition and display of human motion are shown in (Fig. **8**).

Fig. (9). Application rendering of the simulation laboratory-kinect.

The system can dynamically catch the guests' somatosensory interaction movement data by the kinect sensor, and then the data can be mapped to the virtual scene to drive the interaction between the virtual human and the virtual scene, realizing somatosensory interaction between the virtual scene and the guests by accurate collision detection of the operational three-dimensional objects in the virtual man body and virtual substation. Fig. (**9**) shows application rendering of the simulation laboratory.

5.1. Recognition Range of Kinect

The operating range set is shown in the following chart. Placing the kinect shot at the point which is 35cm to the ground and 2m to the middle of the 3-dimensional arc curtain, the projection and mapping as well as the sight of the

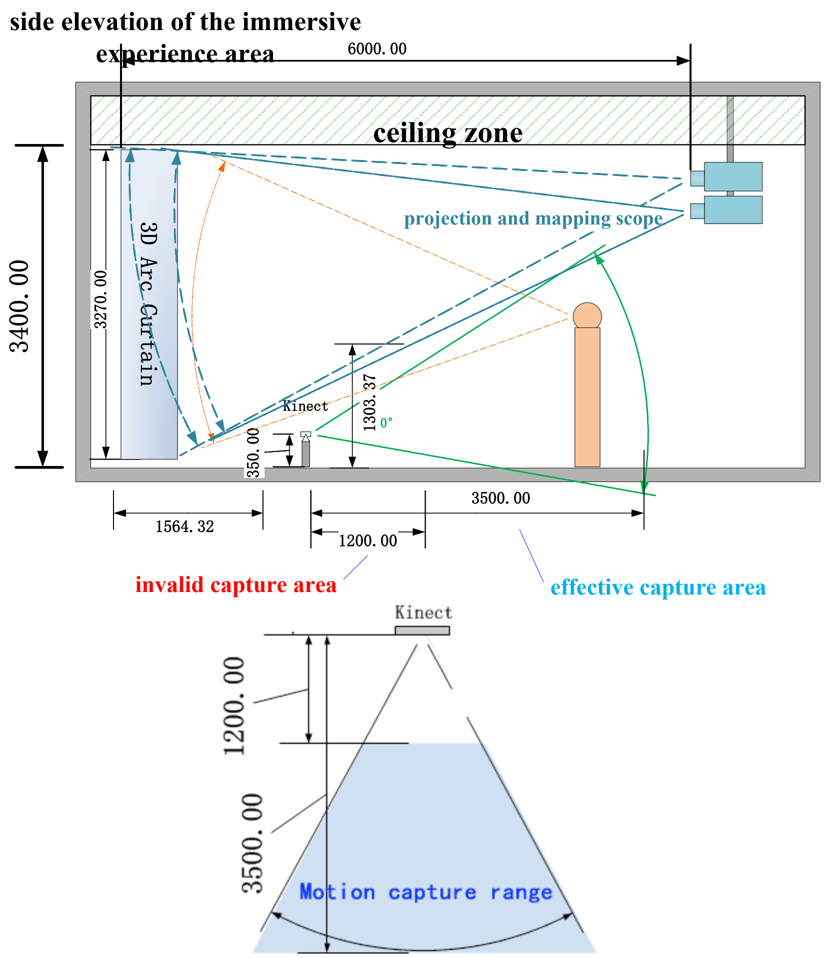

Fig. (10). Kinect capture range.

Table 2. Data on the recognition rate of alternating movements.

Action	Semantic Meaning	Precision %
march on the spot	go ahead	95
backstep	recede	93
left arm and shoulder level (sustain)	turn left	92
right arm and shoulder level (sustain)	turn right	94
swing left hand to the chest	top moving	98
wave hands upwards	Open the door of the box	92
hand forward	Operating button	95
make a fist	close the door of the box	72

operator are not affected, and the operator's action can also be caught correctly. The capture range is shown in Fig. (**10**).

The experiment data show that the best kinect capture range is from 2m to 3.5m. In this range, the action recognition rate is the highest. Outside the range, the action recognition rate falls sharply. The relation between the action recognition rate and this range is shown in Fig. (**11**).

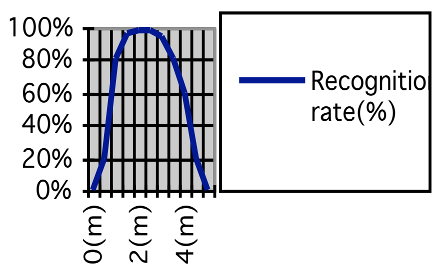

Fig. (11). Curve of the relation between action recognition rate and the range.

5.2. Recognition Accuracy of Kinect Alternating Movements

Considering people's height and weight or other influencing factors, 20 people of different weights and heights were selected and 100 sampling experiments were carried out and finally a set of data on the recognition rate of alternating movements was obtained which is shown in Table **2**.

Thus, it can be seen that the recognition of kinect to large ranged movement is relatively good, but to tiny movements, it is a little bad. In the system design, we should try to avoid this situation.

6. SUMMARY

By the simulation process of operation specification in power training, the finite state machine technology can be applied to describe the simulation task as operational action template set, and then by combining with dynamic time warping, the training staff's action can be matched to the template set to recognize the action behavior of the training staffs, which can drive the state transition of finite state machine in order to make the virtual man in the 3-dimensional scene of the unity finish the simulation task. Then, by motion coordination between the virtual man and the training staffs, the virtual man's roaming speed can be controlled in the three-dimensional scenes such as the transformer substation, and by adjusting the rigid body attributes of the unity objects, the collision effect can be controlled when the virtual man operates the electrical equipment. By the above operations, the purpose of the training staffs to immerse into the three-dimensional transformer substation scene by virtual man can be achieved. It is observed that the training staffs have gained good experience of their training, reinforcing the training effect greatly.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

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