An Application of Immersive Virtual Simulation Technology in Maintenance

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Immersive virtual simulation is a new design, development and evaluation method of integrated product and processing strategies, which using VR, multidiscipline simulation and scientific visualization technologies. The virtual human can operate in hazardous environment instead of the real person. This article introduces a method that use motion capture software (Shape Recorder) and virtual simulation software (DELMIA) to build immersive virtual maintenance simulation system, which not only can help analyze the maintenance data and product, but also allows the users operate the virtual product as like as the actual product. With the help of the simulation system, we can analyze the comfort of the user's action. At last, we will give the application of this immersive virtual simulation system.

1. Introduction

The rapid development of the virtual reality technology makes a big progress in immersive virtual simulation (Michel Dureigne, 2004). A virtual human agent (here after referred to as an agent) is a humanoid whose behaviors are inspired by those of humans (Meyer, J.A., 1994). Virtual humans have been used in many applications. Thorisson's(1997) interactive guide, Gandalf, gives solar system tours. USC's Institute for Creative Technologies created virtual experiences to train soldiers in interpersonal leadership (R.W. Hill Jr., J. Gratch, S, 2003). Just VR (A. Manganas, 2004) allows a medical trainee to work with a virtual assistant to assess and treat a virtual victim. Balcisoy (2000) created a system where users play chess against a virtual human augmented to the real world. The Human Modeling and Simulation Group at the University of Pennsylvania (2002) use virtual humans for task analysis and assembly validation. The Virtual Class-room (A.A. Rizzo, 2005) uses virtual teachers and students to assess attention and social anxiety disorders. However, connecting motion capture software and virtual simulation software to simulate the real man in the maintenance is not study seriously.

Maintainability is a discipline that has become more importance over the past 30 years as military systems became more complex, support costs increased, and defense budgets decreased. It is also important in the commercial sector, where high levels of maintainability are increasingly becoming an important factor in gaining customer loyalty. Different textbooks and other reference documents define maintenance in slightly different ways. One such definition (Blischke and Murthy, 2011) is the following: "Maintenance consists of the different functions (or activities) necessary to keep a system in, or restoring it to, an acceptable state (or operating condition)."

In the engineering application, the artificial maintenance exposes lots of problems. Firstly, in dangerous situations, the workers are easy to be injured. Secondly, in the design stage, the maintenance persons don't know whether it is convenience to be maintained when the machine is malfunction. In order to solve these problems, the immersive virtual technology is introduced in the maintenance. With the help of the immersive virtual maintenance, the workers can avoid the dangerous situations, the maintenance characters can be considered in the design stage, and the money can be saved because of many maintenance activities being simulated by the immersive virtual technology.

In this paper, we will apply the technology, integrating the motion capture system and the virtual simulation software, in the equipment maintenance.

2. The motion capture system and the virtual simulation software

2.1 The ShapeRecorder and DELMIA

ShapeRecorder is a portable and durable motion capture system. Freedom from studios and cameras combined with its robust design make ShapeRecorder ideal for use in the field, classroom or just about anywhere. Because of its Wireless capabilities, ShapeRecorder can be operated away from the computer that receives the motion capture data. ShapeRecorder conforms to fit almost any size person, and no special suit is required.

DELMIA (Digital Enterprise Lean Manufacturing Interactive Application) is a virtual simulation software designed by Dassault Company in France. DELMIA's Digital Manufacturing Products and Solutions allow manufacturers in any industry to virtually define, plan, create, monitor and control all production processes. From early process planning and assembly simulation to a complete definition of the production facility and equipment, DELMIA assists companies to achieve maximum production efficiency, lower cost, improve quality and reduce time to market. With DELMIA, we foresee the problems early and can correct the design, confident that when it will be built, it will not generate errors.

2.2 The analysis of position and orientation

In the GPO (Global Position and Orientation) data format from ShapeRecorder, all limb data is stored with reference to the world coordinate system. All positional data is measured in mm and all orientation data is measured in roll, pitch and yaw orientation angles in degrees, which is shown in Figure 1. The X axis extends outwards in the direction that the person is facing during the homing calibration, the Y axis extends upwards, and the Z axis extends to the person's right during homing. The order of rotation angles is yaw first about the +Y-axis, followed by pitch about the rotated +Z-axis, and then roll about the doubly rotated +X-axis. The default limb position (all rotation angles set to zero) is for a limb extending outwards along the X axis. In other words, if a certain part of human manikin' posture is changed, we can obtain a series corresponding freedom degrees.
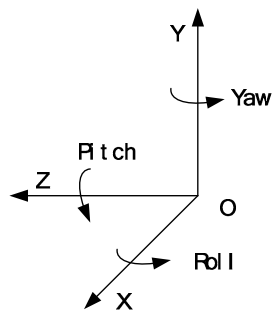

Figure 1: the global coordinate system in ShapeRecorder

The Local coordinate systems are shown in Figure 2. Like the ShapeRecorder, the DELMIA also has its GPO, and all positional data is measured in mm and all orientation data is measured in roll, pitch and yaw, which is shown in Figure 3. But there are some differences between the two systems. Firstly, in the DELMIA, not all limb data is stored with reference to the world coordinate system, the arms' position and orientation is different from the global position and orientation, which is shown in the Figure 4. Secondly, in ShapeRecorder, the orientation angles data are saved in one array, while in DELMIA, the data are saved in two arrays, one for human attitude data and the other is for the orientation and position data.

In the GPO, the X axis extends outwards in the direction that the person is facing during the homing calibration, the Y axis extends to the person's left during homing, the Z axis extends to the upwards. The order of rotation angles is yaw first about the +Z-axis, followed by pitch about the rotated +Y-axis, and then roll about the doubly rotated +X-axis.
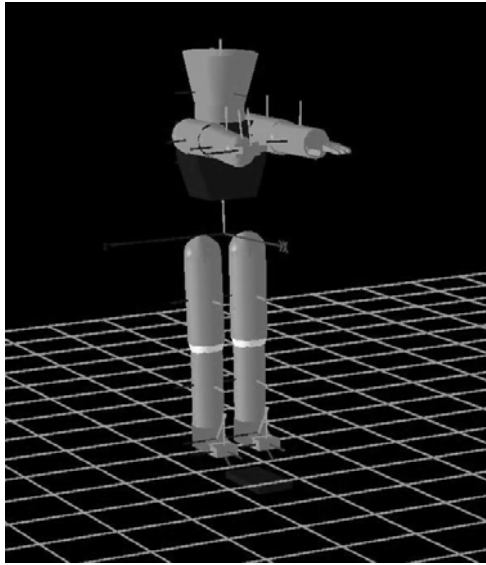
Figure 2: local coordinate systems in ShapeRecorder

In DELMIA, all positional data is measured in mm and all orientation data is measured in roll, pitch and yaw, which is shown in Figure 3. But there are some differences between the two systems. For example, in the DELMIA, not all limb data is stored with reference to the world coordinate system, the arms' position and orientation is different from the global position and orientation, which is shown in the Figure 4.
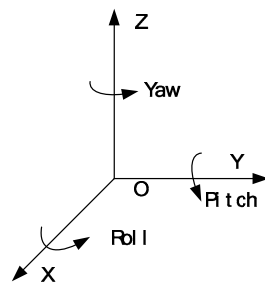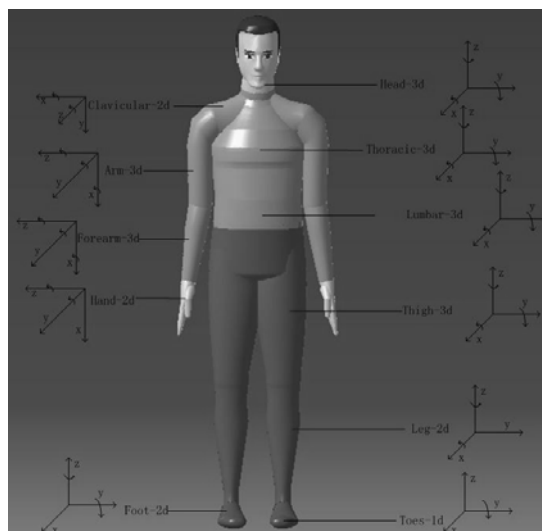

Figure 3: Global coordinate system in DELMIA

Figure 4: local coordinate systems in DELMIA

In the Figure 4, "Head-3d" means the human's head has three DOFs (the degrees of freedom), which are yaw, pitch and roll. We can obtain that the virtual human's thoracic, lumbar, thigh, arm, forearm also have three DOFs, while the clavicular, hand, leg and foot have two DOFs and the toes have only one DOF. The local coordinate systems are not all the same with the global, such as the clavicular, arm, forearm and hand.

3. Immersive virtual maintenance simulation system

3.1 The rotation matrix

The two kinds of data, the position vectors and DOFs, can be use to determine the positions and gestures of the virtual human in DELMIA. The position vector is constituted by 12 sub-vectors, where 9 of them denote the direction of the component coordinate system under the global coordinate system, and the left 3 sub-vectors indicate the origin of the component coordinate system under the global coordinate system. For the definition of global coordinate system and local coordinate system is different from ShapeRecorder to DELMIA software, the 3 position sub-vectors can be described as $i(9) = x_0, i(10) = -z_0, i(11) = y_0$, the next 9 sub-vectors can get an array to represent the DOFs.

$$\begin{bmatrix} i(0) & i(3) & i(6) \\ i(1) & i(4) & i(7) \\ i(2) & i(5) & i(8) \end{bmatrix} = \begin{bmatrix} \cos\gamma_0\cos\beta_0 & -\cos\gamma_0\sin\beta_0\sin\alpha_0 - \sin\gamma_0\cos\alpha_0 & -\cos\gamma_0\sin\beta_0\cos\alpha_0 + \sin\gamma_0\sin\alpha_0 \\ \sin\gamma_0\cos\beta_0 & -\sin\gamma_0\sin\beta_0\sin\alpha_0 + \cos\gamma_0\cos\alpha_0 & \sin\gamma_0\sin\beta_0\cos\alpha_0 + \cos\gamma_0\sin\alpha_0 \\ \sin\beta_0 & \cos\beta_0\sin\alpha_0 & \cos\beta_0\cos\alpha_0 \end{bmatrix} \quad (1)$$

In order to get α', β', γ', which denote the upper right arm's three DOFs, It's necessary to obtain the rotation matrix that can be depicted as formula 2.

$$T = \begin{bmatrix} \cos\gamma'\cos\beta' & -\cos\gamma'\sin\beta'\sin\alpha' - \sin\gamma'\cos\alpha' & -\cos\gamma'\sin\beta'\cos\alpha' + \sin\gamma'\sin\alpha' \\ \sin\gamma'\cos\beta' & -\sin\gamma'\sin\beta'\sin\alpha' + \cos\gamma'\cos\alpha' & -\sin\gamma'\sin\beta'\cos\alpha' - \cos\gamma'\sin\alpha' \\ -\sin\beta' & -\cos\beta'\sin\alpha' & -\cos\beta'\cos\alpha' \end{bmatrix} \quad (2)$$

4. Data transformation

Get the GPO data from ShapeRecorder and save the data from in arrays, then calculate the motion data, and at last assign the converted data to DELMIA. We give the specific steps of the data conversion as follows.

Step 1. Get the GPO data from the motion capture software.

We choose Shape Recorder as the motion capture software, and analysis the data output. Shape Recorder has two kinds of data output mode, one is the real-time output, and the other is file output. Here we choose the real-time data output. There are four kinds of data output format, which are GPO, C3D, BVH and Motion Builder, here we choose the GPO. What's more, we should set the UDP socket's property, such as the IP address, port number and so on.

Step 2. Capture body movements and transmit the real-time data of motion capture.

There are two ways to get the human motion data, one is the staff put on the motion capture equipment to get the real-time data, and the other is the prerecorded data. Both of the two methods are feasible and send data through UDP socket.

Step 3. Receive and temporarily save the data from the motion capture software.

Receive the data in the UDP socket manner, and save the data in the form of an array. In order to facilitate record, we name the array as gpo array. The array contains 235 data, which is from gpo(1) to gpo(235).

Then, we create another two arrays to save the converted data. We named the two arrays as Array OPV and Array iAxisComponentsArray. The opv is used to save the data of human attitude data and the iAxisComponentsArray is used to save the orientation and position data. The opv array contains 137 data, which is from opv(0) to opv(136). The iAxisComponentsArray array contains 12 data, which is from iAxisComponentsArray(0) to iAxisComponentsArray(11).

Step 4. Calculate the motion data.

We convert the gpo data, which is from the step 3, into the data that DELMIA can use, and store the data in the opv array and iAxisComponentsArray array. Denote one group of GPO data correspond to the hip part of the virtual human in ShapeRecorder with $\{x_0, y_0, z_0, \alpha_0, \beta_0, \gamma_0\}$, one group of GPO data

correspond to the upper right arm with $\{x_1, y_1, z_1, \alpha_1, \beta_1, \gamma_1\}$ and one group of GPO data correspond to the right shoulder with $\{x_2, y_2, z_2, \alpha_2, \beta_2, \gamma_2\}$.

With the aim of eliminating the influence caused by the DOFs of DELIMIA and the definition of Euler angles in Shaperecoder, it needs to deduce the rotation matrices by Euler angles $\alpha_1, \beta_1, \gamma_1$ of the upper right arm and Euler angles $\alpha_2, \beta_2, \gamma_2$ of the right shoulder, and transform these matrices in some certain corresponding way to get the ultimate matrices which can be shown as formula 3.

$$
S = \begin{bmatrix}
\cos\gamma_2 \cos\beta_2 - \sin\gamma_2 \cos\alpha_2 \sin\beta_2 & \sin\gamma_2 \cos\alpha_2 & \cos\gamma_2 \sin\beta_2 + \sin\gamma_2 \sin\alpha_2 \cos\beta_2 \\
-\sin\gamma_2 \cos\beta_2 - \cos\gamma_2 \sin\alpha_2 \sin\beta_2 & \cos\gamma_2 \cos\alpha_2 & -\sin\gamma_2 \sin\beta_2 + \cos\gamma_2 \sin\alpha_2 \cos\beta_2 \\
-\cos\alpha_2 \sin\beta_2 & -\sin\alpha_2 & \cos\alpha_2 \cos\beta_2
\end{bmatrix}^{-1}
$$

$$
\times \begin{bmatrix}
\cos\gamma_1 \cos\beta_1 - \sin\gamma_1 \cos\alpha_1 \sin\beta_1 & \sin\gamma_1 \cos\alpha_1 & \cos\gamma_1 \sin\beta_1 + \sin\gamma_1 \sin\alpha_1 \cos\beta_1 \\
-\sin\gamma_1 \cos\beta_1 - \cos\gamma_1 \sin\alpha_1 \sin\beta_1 & \cos\gamma_1 \cos\alpha_1 & -\sin\gamma_1 \sin\beta_1 + \cos\gamma_1 \sin\alpha_1 \cos\beta_1 \\
-\cos\alpha_1 \sin\beta_1 & -\sin\alpha_1 & \cos\alpha_1 \cos\beta_1
\end{bmatrix} \quad (3)
$$

Then let $T = S$, the DOFs of the upper right arm component of the virtual human can be deduced as α', β', γ'.

Step 5. Assign the converted data to DELMIA.

DELMIA provides a series of functions, which can be invoked to calculate. The function that can operate the human attitude data is different from the function that can operate the human orientation and position data.

After assignment, the virtual human's motion in DELMIA is as same as the human in ShapeRecorder, which is shown in Figure 5.
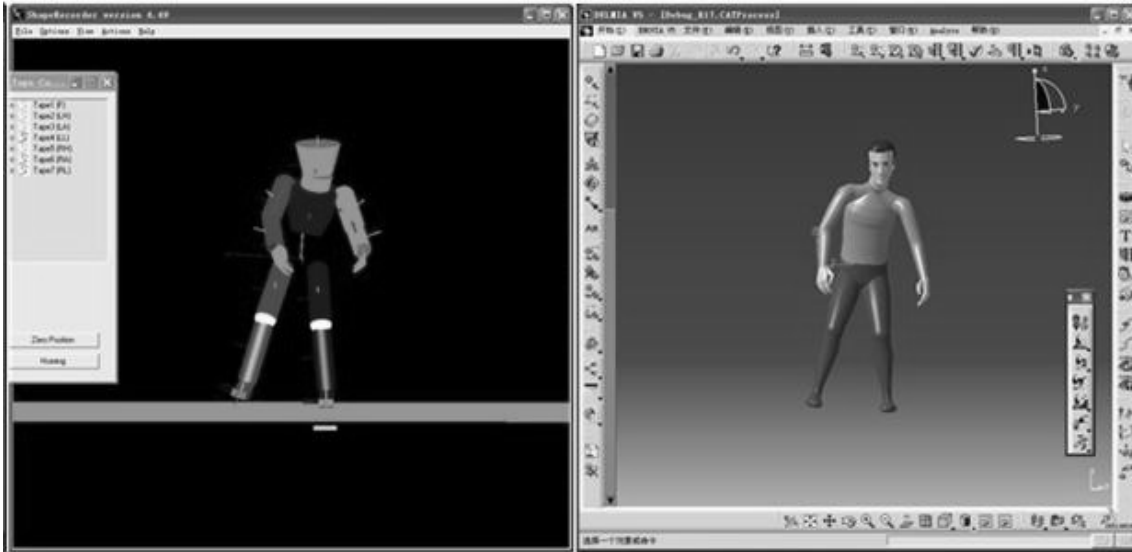

Figure 5: the example of the virtual human control

Step 6. Repeat step 2 to step 5.

Repeat step 2 to step 5, until the motion capture system do not send the data to the DELMIA.

5. Case study

In the lab, the researcher puts on the motion capture system (ShapeRecorder), wears the 3D helmet glasses, and immerse in the virtual environment, which is shown in Figure 6. In the virtual environment, the maintenance personnel can do maintenance tasks, such as maintenance space, visibility, accessibility, and applicability of the repair tools.
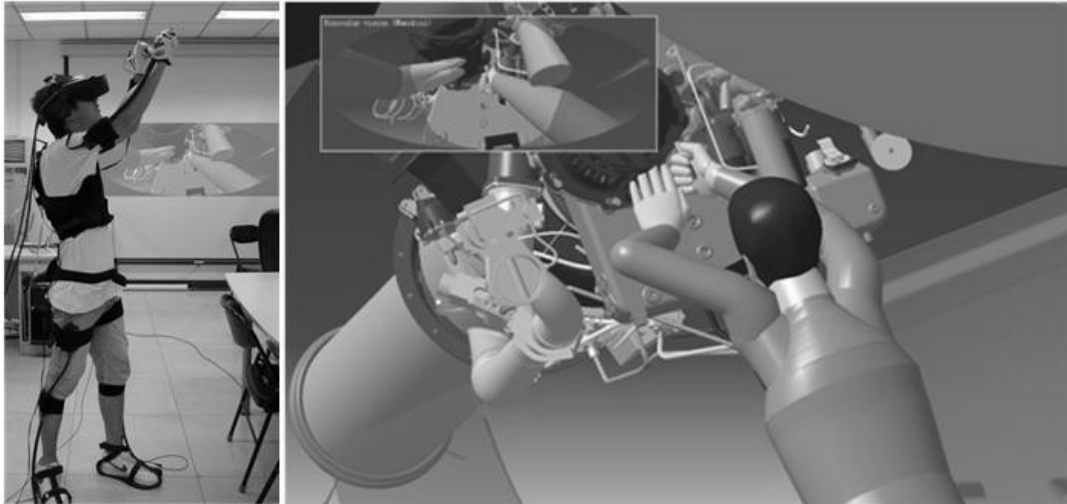
Figure 6: the practical application of the simulation system

What's more, it can also make the maintenance design no longer totally dependent on the physical prototype or equipment. When the maintenance factors are considered in product design, the possible maintenance design defects could be discovered and recommendations for design improvement could be indicated. Then it is possible to modify the original designation while designing to avoid troubles and economic loss caused by re-designation of the physical prototype or equipment.

6. Conclusion

The virtual simulation software DELMIA has powerful simulation and analysis functions, while the motion capture system ShapeRecorder has accurate motion capture capabilities. Using the two systems to build immersive virtual maintenance simulation can help the maintenance personnel operate the virtual product as like in the real scene. With the help of the simulation system, the maintenance personnel can avoid dangerous maintenance operate, and the money can be saved, and furthermore, developing a working platform to train and enhance the workers abilities in maintenance and supportability field will be taken into account.

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