

# Web-based Customization and Motion Simulation of the Omni-directional Wheelchair

Ban Wang

College of Electrical Engineering, Zhejiang University, Hangzhou, China  
Email: banwang@zju.edu.cn

Weihua Zhou and Jifeng Guo

College of Electrical Engineering, Zhejiang University, Hangzhou, China  
Email: Zhouwh1928@163.com and gjf@zju.edu.cn

**Abstract**—A wheelchair with omni-directional wheel is introduced in this article. Two kinds of omni-directional wheel, Mecanum wheel and Trans wheel, are illustrated and their motion principles were analyzed. Virtual Reality Modeling Language (VRML) is adopted to implement the real-time customization and motion simulation. In the real-time customization process, the color of some parts of the wheelchair can be altered, and the shape of components can also be replaced via the customization panel. By using this methods, the omni-directional movements such as longitudinal, lateral and rotary motion can be emulated via the simulation panel. In this way, clients can participate in the design and get a wheelchair according to their individual requirements, which will give them a deeper and more impressive feeling about the wheelchair's special motion functions.

**Index Terms**—omni-directional, Mecanum wheel, Trans wheel, VRML, customization, motion simulation

## I. INTRODUCTION

With the accelerating development of aged tendency of population and rapid growth in the number of the disabled caused by diseases or injuries, the wheelchair with good performance for the aged and disabled is attracting more and more attention from the society. Lots of researches on wheelchair have been made at home and abroad, including wheelchair for recovery, climbing stairs, and multifunction (see, in Ref.[1]). It's necessary to design a wheelchair with the feature of easy-walking, convenient-use, and small-radius-swerving for the reason that the wheelchair is often used in a relatively narrow and small room. The omni-directional wheelchair introduced in this paper can just meet the requirements above well. The wheelchair with four omni-directional wheels has many motion forms, such as longitudinal motion, lateral motion, and rotary motion. The differences between the user's characters, interests and self-conditions cause various requirements when come to the omni-directional wheel-chair. But, with the application of the Virtual Reality technology, the problems will be solved well, by which the requirement that clients want to have their wheelchairs custom-made

can be met well, and the designers in different places can accomplish their designs and simulate on-line via the internet, beneficial to both the customs and the designers. We use VRML to put the omni-directional into the virtual world.

## II. INTRODUCTION OF VIRTUAL REALITY TECHNOLOGY

Virtual Reality (VR) technology has the features of virtuality beyond reality. It is a new computer technology with the development of multimedia technology, real-time 3D graphics making technology, interactive multi-sensor technology and high-resolution show technology, etc. It can create lively 3D virtual circumstance and users can enter the virtual circumstance merely by particular equipment. Images display equipment is the key external equipment to generate stereo vision effect which includes light valve glasses, 3D Projector and helmet mounted display. VR technology is an integration of several technologies and the key techniques and research contents of it are:

### *Environment Modeling Technique*

That is a modeling technique in virtual environment with the purpose of getting 3D data from actual 3D environment and modeling virtual environment via the 3D data according to the application requires.

### *Synthesis of Stereo Sound and Stereoscopic Display Technique*

It can eliminate the correlation between the direction of sound and the movement of the user's head ,meanwhile generates real-time 3D graphics in a complex scene.

### *Tactile Feedback Technique*

The users can operate virtual object directly and have a true feeling of the reaction force on the scene.

### *Interactive Technique*

Human-computer Interaction in virtual reality is far beyond the traditional mode with keyboard and mouse.

### *System Integration Technique*

System integration technique is very important since there are a lot of perceptive information and models included in virtual reality.

It requires users to adapt to the computer in the fore passed man-machine interface, but with the help of VR technology, people can communicate with the computer like dealing with things in daily life which will let people free from the complex task of operating the computer and it has important significance for taking advantages of information technology's potential adequately.

Nowadays with the development of computer technology VR Technology has been applied to many fields such as scientific and technological development, commerce, medicine, entertainment, education and aerospace. So virtual simulation (see, Ref.[5]), virtual teaching, virtual assemble, virtual scene, virtual products show, virtual E-commerce and virtual parts library will change our daily life in the near future.

Generally speaking, there are many kinds of VR technology such as desk-oriented VR technology, immersive VR technology, augmented VR technology and distributed VR technology (see, Ref.[2] for more), etc. But we can just do some project with the application of desk-oriented VR technology, because of the limitation of our available instruments. So I will introduce 3 kinds of desk-oriented VR technologies below and then do some comparison among them.

#### A. VRML

VRML is the core of 3D Web technology characterized by virtual reality. It allows the user to describe an existing or imaginary scene and put it in a virtual 3D scene. VRML has strong programming ability with the supporting of java and JavaScript and it makes the control of graphics and animation more convenient. VRML can be used to create lively 3D virtual scene which can change the state of 2D picture and implement 3D animation effect. It can break the limitation of interaction between Internet and client. HTML can just stay on stage of plane design, let alone dynamic interaction because it doesn't support display of 3D image and stereo sound. But VRML regard human behavior as the subject and it create an accessible and participational world and it is a new technique that related with multi-media communication, Internet, virtual-reality, its aim is to build a kind of mutual 3D multimedia on Internet. The three important functions of VRML are as followed (see, Ref.[3] and Ref.[4]):

*Interactivity*: it means the operable level of referring to objects in virtual scene and the natural level of getting feedback from the scene.

*Immersion*: it means the truth of existing in virtual scene as the protagonist for the users.

*Imagination*: it means human beings can develop their creativity and imagination well with the help of VRML.

#### B. Java3D

Java3D is application programming interface which used to develop 3D graphics and application based on web. A new technical realization scheme of view model based on view platform and input device model is

proposed. We can browse the whole virtual scene by changing the position and direction of view platform. It not only provides high-level Constructor Function which is used to model and operate 3D objects, but also can build virtual scene with different complexity by using the Constructor Function.

#### C. Open GL

Open GL is a desk-oriented CAD system which can model the virtual world with technique of drawing 3D graphics and people can observe the virtual world in display on which people can control the viewpoint freely. This technology is also a kind of VR technology in a sense and the 3D modeling is built by computers, but the complexity and reality of model is limited by the computing capability of the computer.

Java 3D and Open GL are comparatively more professional than VRML, so developers must be good at using C/C++ or Java. Therefore as an amateur developer I will do the project by using VRML instead of Java 3D and Open GL.

### III. BRIEF INTRODUCTION OF OMNI-DIRECTIONAL WHEEL

An omni-directional wheel has three degrees of freedom including the rotation of the wheel, the rotation of the roller and the rotation of the contact point between the wheel and the ground. Omni-directional wheel has a variety of forms and according to the angle between the wheel and the rollers we can divide them into two kinds that is Mecanum wheel and Trans wheel. Mecanum wheel, or called Sweden wheel, is a relatively mature omni-directional wheel(see, for instance, Ref.[6] and [7]) .It consists of a spoke and many small rollers fixed around the spoke, with the angle between the wheel and the rollers represented by  $\gamma$  (usually  $45^\circ$ ). Trans wheel is actually a special case of Mecanum wheel, that is the case of the angle between wheel and rollers represented by  $90^\circ$ .Orthogonal wheel and conical wheel belong to the category of Trans wheel.

The Mecanum wheel and two kinds of Trans wheel (orthogonal wheel and conical wheel) used in wheelchair are shown in Fig.1, Fig.2and Fig.3.



Fig.1 Mecanum wheel



Fig.2 Trans wheel



Fig.3 Conical wheel

IV.MOTION ANALYSIS OF THE OMNI-DIRECTIONAL WHEELCHAIR

Firstly, how a single wheel under ordinary circumstances influence on the motion of the omni-directional wheelchair will be analyzed. As shown in Fig.4 (see, Ref [8]), point  $O$  where the coordinate system of the wheelchair will be established is assumed as the centroid of the wheelchair and point  $O'$  where the coordinate system of the wheel established is assumed as the centre of mass of the wheel.  $\beta$  is defined as the angle between the roller's slide speed and the head face of the wheel. The orientation of the  $x'$  axis with respect to and  $x$  axis is represented by  $\alpha$ .  $v_1$  is the component of the wheelchair's speed at the  $x$  axis, and so  $v_2$  at the  $y$  axis. The components of absolute displacement from  $O$  to  $O'$  are  $S_1$  and  $S_2$ .  $\varphi'$  is the angular rate of rotation for wheelchair.  $\sigma$  is the rotation rate of rollers. According to the formula of speed's decomposition and combination, we can get some equations followed:

$$\begin{aligned} v_1 &= \sigma \cos(\alpha + \beta) + r\theta' \cos \alpha - l\varphi' \sin \gamma \\ v_2 &= \sigma \sin(\alpha + \beta) + r\theta' \sin \alpha + l\varphi' \cos \gamma \end{aligned} \quad (1)$$

$$\begin{aligned} \sin \gamma &= s_2 / l \\ \cos \gamma &= s_1 / l \end{aligned} \quad (2)$$

Combining (1) and (2):

$$\theta' = a_1 v_1 + a_2 v_2 + a_3 \varphi' \quad (3)$$

and

$$\begin{aligned} a_1 &= \sin(\alpha + \beta) / r \sin \beta \\ a_2 &= -\cos(\alpha + \beta) / r \sin \beta \\ a_3 &= a_2 s_1 - a_1 s_2 \end{aligned} \quad (4)$$

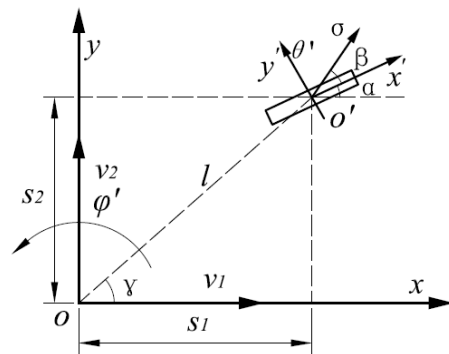


Fig.4 The establishment of the axis system

Generally speaking, there are two optimal layout forms of the Mecanum wheels (see, Ref.[9] and Ref.[10]) as shown in Fig.5. Considering the stability of the wheelchair, we choose the second layout form which includes four Mecanum wheels as our scheme for wheelchair. So we just analyze kinematics of wheelchair with four omni-directional wheels.

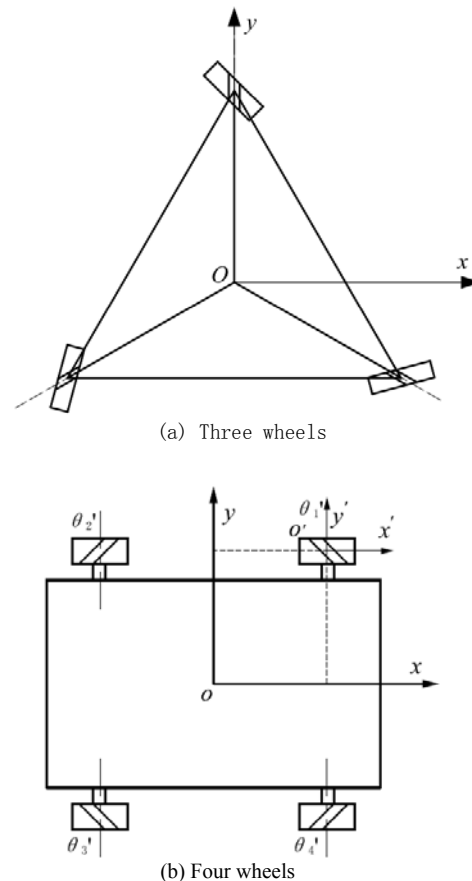


Fig.5 Two layout forms of the Mecanum wheels

In the second layout form, for wheel 1, we can know that  $\alpha = 0^\circ$ ,  $\beta = 45^\circ$  and we can get formula followed from formula (3):

$$\theta_1' = \frac{1}{r}[v_1 - v_2 - (s_1 + s_2)\phi'] \quad (5)$$

So the angular velocity value of other 3 wheels can be got in the same way which expressed in matrix form is:

$$\begin{pmatrix} \theta_1' \\ \theta_2' \\ \theta_3' \\ \theta_4' \end{pmatrix} = \frac{1}{r} \begin{pmatrix} 1 & -1 & -(s_1 + s_2) \\ 1 & -1 & s_1 + s_2 \\ 1 & -1 & -(s_1 + s_2) \\ 1 & 1 & s_1 + s_2 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \\ \phi' \end{pmatrix} \quad (6)$$

A conclusion can be drawn from formula (6) that the wheelchair will move according to the route desired by adjusting the rotation of the four Mecanum wheels.

When it comes to Trans wheels, there are also two optimal layout forms (see, Ref.[11]-Ref.[13]) as shown in Fig.6. We certainly chose the second layout form which includes four Trans wheels as our scheme.

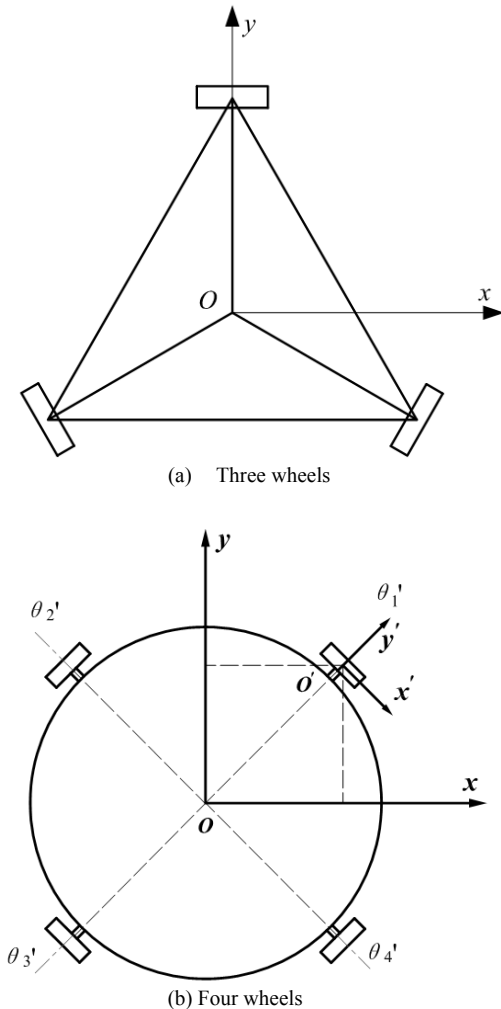


Fig.6 Two layout forms of the Trans wheels

In the second layout form, for wheel 1, we can know that  $\alpha = -45^\circ$ ,  $\beta = 90^\circ$  and we can get formula followed from formula (3):

$$\theta_1' = \frac{\sqrt{2}}{2r}[v_1 - v_2 - (s_1 + s_2)\phi'] \quad (7)$$

So the angular velocity value of other 3 wheels can be got in the same way which expressed in matrix form is:

$$\begin{pmatrix} \theta_1' \\ \theta_2' \\ \theta_3' \\ \theta_4' \end{pmatrix} = \frac{\sqrt{2}}{2r} \begin{pmatrix} 1 & -1 & -(s_1 + s_2) \\ 1 & -1 & s_1 + s_2 \\ 1 & -1 & -(s_1 + s_2) \\ 1 & 1 & s_1 + s_2 \end{pmatrix} \begin{pmatrix} v_1 \\ v_2 \\ \phi' \end{pmatrix} \quad (8)$$

A conclusion can be drawn from formula (8) that the entire wheelchair will move according to the route desired by adjusting the rotation of the four Trans wheels.

#### V. THE WHOLE DESIGN OF CUSTOMIZATION AND SIMULATION SYSTEM

VRML can only build simple models because of its disappointing 3D modeling function. As for some complex models like the omni-directional wheel-chair, some specialized software for three-dimensional modeling such as PRO/E will be needed. We can have the assembly drawing of the omni-directional wheelchair saved as the type of wrl file, and then lead it out, finally get a primary VRML file. Considering the convenience for the programming of customization and motion simulation later, some optimized measures are needed to be taken to deal with the primary VRML file, such as DEF definition and USE citation, useless plane, points and viewpoints cancellation in the process for transforming formats, files entirely making and points renaming and so on, which will decrease the VRML files' size greatly. Programming of real-time customization and motion simulation system will be finished by using sensor node and Javascript in the VRMLPad editor. Besides, to meet the customs' needs for browsing on line, Dreamweaver, a software for making web pages, can be used to combine VRML files and web pages, and then upload the files to the web sever when finished (see, for instance, Ref.[14]). To display a VRML world from the web or off your hard disk, you will need a VRML browser, topically configured as a plug-in for a Web browser. Microsoft and Netscape each include a VRML browser plug-in standard in their Web browser distributions. The VRML browser reads your world files, interprets their syntax, and builds a 3D virtual world, then draws that world into a rectangular region on a Web page. The browser also provides a user interface to let you walk through the virtual world, interact with its content, trigger animations, and listen to 3D sound effects (see, Ref. [15]). Fig.7 shows the process of realizing the whole system:

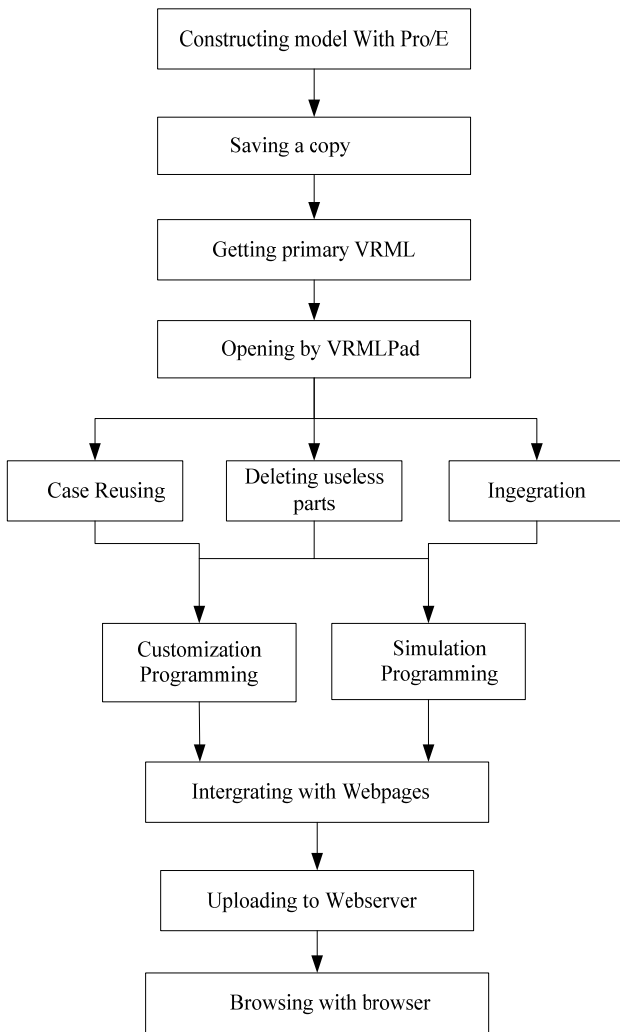


Fig.7 The process of realizing the whole system

VI. THE REALIZATION OF INTERACTIVE CUSTOMIZATION

The way of implementing the wheelchair’s real-time customization is to click the corresponding buttons for the purposes of changing the seat’s color and replacing the forms of the omni-wheels. The nodes used in the scene consist of fields and events. The value of the fields is restricted by models created by the node and the present states of the scene. A field marked with the eventIn or eventOut tag can participate in the event-driven VRML execution model. An event may be sent from one nodes’s eventOut to another nodes’s eventIn field if a route exists. On the other hand, events will enable the node to receive signals from outside or send out signals to outside. The node would change its original value according to the signals received from other nodes via the eventIn and change the values of other nodes by sending out its signals via the eventOut. We can figure out the hierarchical relation among some modeling nodes (see, Ref.[16] and Ref.[17]) from Fig.8 in detail.

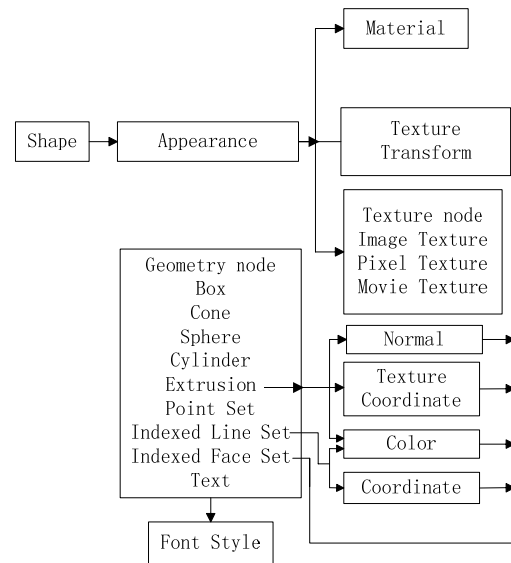


Fig.8 Hierarchical relation between modeling nodes

The way of only using the VRML’s own nodes can’t successfully meet the needs of finishing real-time customization without the JavaScript. We can use JavaScript to compile some specific functions and then combine them with the nodes of the sensors with the help of the eventIn and eventOut of the VRML’s own sensors. Script node doesn’t create any modeling, so it can’t be seen in the virtual world. Script node can be used as the children node in any Group node, but it doesn’t depend on the system used and choice of children node. Take the real-time replacement of the wheel forms as an example and we can see that many VRML sensor nodes, such as Touchsensor node, Timesensor node and Switch node are used. In the process of modeling, three kinds of omni-directional wheels including Mecanum wheels, orthogonal wheels and conical wheels are built up. The displays of the sub-points of these three scenes can be altered by changing the value of whichChoice after setting these three kinds of omni-directional wheels as the sub-points list of the scene of the Switch node. We can use JavaScript to compile some functions and set the eventOut of the Touchsensor as an input. The forms of the wheels in the display will be changed after changing the value of whichChoice. The grammar of Switch node (see, Ref.[18]) is shown as Fig.9.

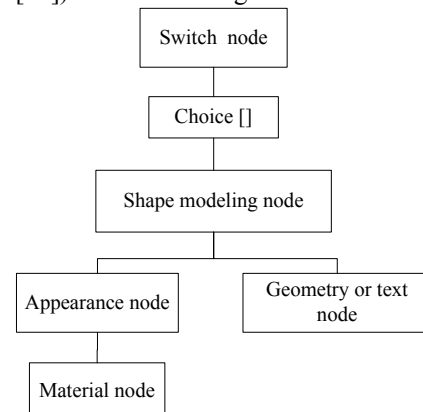
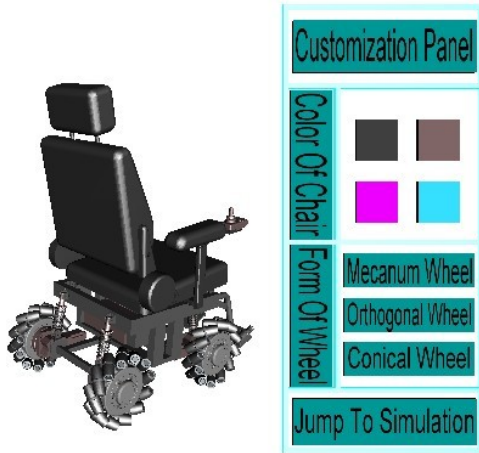


Fig.9 Grammar of Switch node

Three different appearances of wheelchair are shown in Fig.10:



(a) Wheelchair with Mecanum wheel



(b) Wheelchair with orthogonal wheel



(c) Wheelchair with conical wheel

Fig.10 The real-time customization of wheelchair

### VI. THE REALIZATION OF MOTION SIMULATION

Totally, four motion forms, that is forward or backward motion, leftward or rightward motion, oblique motion and in situ rotation in the system, which can be put into simulation. The wheelchair's motion simulation would be seen by the customers when they click the corresponding simulation button. Touchsensor node, Timesensor node, PositionInterpolator node, OrientationInterpolator node and Collision node are used. Not only the rotation of wheels and rollers should be set respectively, and their harmony should be taken into consideration for the special of the omni-directional wheelchair. Rollers will rotate only when they contact the ground. Meanwhile the time when the rollers will rotate is related to the rotation of the wheel. We can use the Collision node to find out whether the rollers contact the ground. Compared to customization, OrientationInterpolator node and Collision node were added to motion simulation. Because of some key programs of customization given before, the grammar of Collision node is just shown as followed:

```
Collision {
  addChildren          #eventIn SFNode
  removeChildren      #eventIn SFNode
  children             #exposedField SFBool
  collide              #exposedField SFBool
  proxy               #SFVec3f
  bboxCenter          #SFVec3f
  bboxSize            #SFVec3f
  collideTime         #SFVec3f
}
```

The grammar of OrientationInterpolator node is shown as followed(its hierarchical relation with other node is shown in Fig.11):

```
OrientationInterpolator
{
  key[]                #value of time
  keyvalue[]          #value of position
}
```

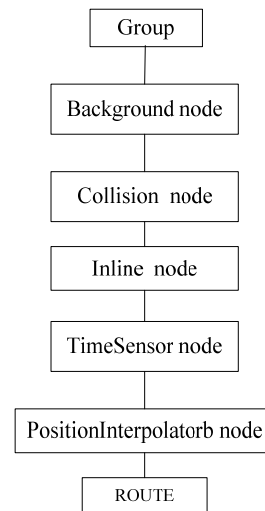


Fig.11 Hierarchical graph of OrientationInterpolator

Fig.12 shows the flow-process diagram of simulation and Fig.13 shows the motion simulation of the wheelchair.

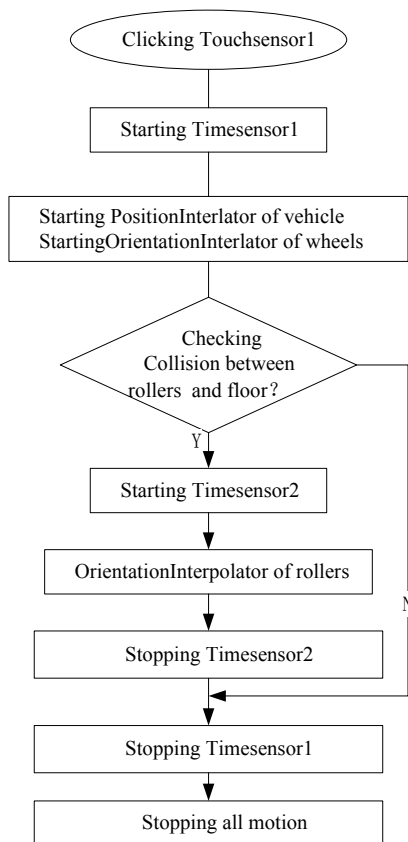


Fig.12 The flow-process diagram of simulation

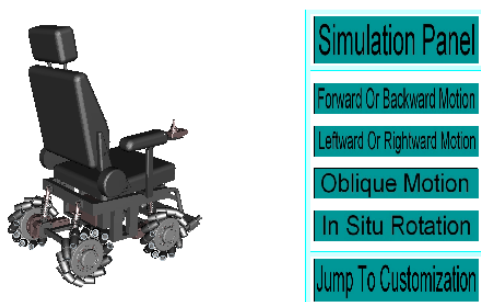


Fig.13 The motion simulation of the wheelchair

VII. CONCLUSION

The real-time customization and motion simulation of the omni-directional wheelchair based on VRML are introduced in the paper. And also the process of completing the whole system including building three-dimension models, finishing the function of real-time customization and simulation function is illustrated in detail. To average clients, they can not only have their omni-directional wheelchair custom-made, and also put the wheelchair into on-line interactive simulation for the features of being well interactive, real-time and simple.

All the features mentioned above give the clients a better knowledge about the wheelchair and make it easy and convenient to popularize the omni-directional wheelchair. The ideas that combining PRO/E and VRML for the products' virtual design will do good to the designs for other products. But there are still some problems (same as mentioned in Ref.[19]):

*Download and rendering time.*

Downloading the world description into the VRML browser takes a long time because there are lots of parts in the wheelchair.

*Multi-user interaction.*

The participants can just communicate with computers in the virtual world, but there is no possibility of interaction between different users in the same world.

*External updates.*

It is difficult to arrange for the world to change in response to external events.

These are the disadvantages of the desk-oriented VR technology. So, next, we intend to apply the immersive VR technology to the omni-directional wheelchair using equipments such as helmet-mounted displays. The participants wear the helmet-mounted displays in which vision and auditory will be isolated from outside world and the system can provide stereo vision and 3D scene with the rotation of head according to different applications. The participants can communicate with the virtual world lively as in the actual world with the help of speech recognition, data glove and data garment. In this way, the participants can personally experience the omni-directional function of the wheelchair and can make choices between many kinds of omni-directional wheelchairs in the virtual world just sitting in front of a computer, wearing the helmet-mounted. This is our future working direction.

ACKNOWLEDGMENT

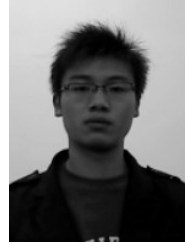
This paper research results of Advanced Driving Lab, supported by Office for Science and Technology of Zhejiang province. The scientific responsibility rests with its authors.

REFERENCES

- [1] LU Tao, YUAN Kui and ZHU Haibing, "Research status and development trend of intelligent wheelchair", Application technology of robot, No.2, pp.1-5, 2008.
- [2] Mendez,R.M. and Tellez,R.Q., "Distributed virtual worlds for collaborative work based on Java RMI and VRML", Groupware, 2000.CRIWG 2000. Proceedings. Sixth International Workshop on. pp.146-149, Oct. 2000.
- [3] ZHANG Defeng, ZHOU Ling. "The application technology of Virtual Reality". Electronic Industry Press. Beijing, Aug.2010.
- [4] ZHANG Jinzhao, ZHANG Jindi and ZHANG Jinrui, "Virtual reality 3D stereoscopic net programming language VRML", Tsinghua university Press, Beijing, 2004.
- [5] Mahmoud, A. H., Clayden, A and Higgins, C., "A comparative study of environmental cognition in a real environment and its VRML simulation (Virtual Reality

- Modeling Language)", Information Visualization, 1999. Proceedings. 1999 IEEE International Conference. Jul. 1999.
- [6] AGLLO J, CARDONA S,VIVANCOS J. "Kinematics of vehicles with directional sliding wheels", Mech. Theory, Vol.22, No.4, 1987.
- [7] ZHAO Dongbin, YI Jianqiang and DENG Xuyue. "Structure and kinematic analysis of omni-directional mobile robots", Robots, Vol.25, No.5, sept.2003.
- [8] Guy Campion, Georges Bastin and Brigitte D Andrea-Novel, "Structural properties and classification of kinematic and dynamic models of wheeled mobile robot", IEEE Transaction on Robotics and Automation", Vol.12, No.1, Feb.1996.
- [9] WANG Yizhi and CHANG Degong, "Layout and motion principle of an multidirection motion system with three Mecanum wheels", World Sci-Tech R&D, No.6, 2008.
- [10] WANG Yizhi and CHANG Degong, "Motion performance analysis and layout selection for motion system with four Mecanum wheels", Journal of mechanical engineering, Vol.45, No.5, May.2009.
- [11] MU Xuegang, ZHU Jin and JIANG Ping, "Research on Structural design and modeling of a three-wheel omni-directional soccer robot", Machinery & Electronics., Vol.5, 2006.
- [12] YAN Guorong and ZHANG Haibing, "A new kind of wheel-model all-directional moving mechanism. Journal of harbin institute of technology", Vol.33, No.6, Dec.2001.
- [13] HUANG Lei and XI Anmin. "Omni-directional wheeled mobile robot simulation and optimization anlysis based on ADAMS", Mechanical Engineering &Automaton, Vol.148, No.3, Jun.2008.
- [14] QIN Jie, WANG Peijun, LUO Shuixin et. "Web-based three-dimensional virtual real-time customization design of bicycle ". Machinery, Vol.36, No.12, Sep.2009.
- [15] Nadeau, D.R. "Building virtual worlds with VRML", Computer Graphics and Applications, IEEE. V.19, Issue: 2. Mar/Apr 1999.
- [16] WU Xiaohua. "The programming of VRML and java". National Defense industrial Press. Beijing, Jun.2008.
- [17] Brady, M., Dima, A., Gebase, L., Kass, M., Montanez-Rivera, C. and Rosenthal, L, "VRML testing: making VRML worlds look the same everywhere", Computer Graphics and Applications, IEEE. Vol.19, Issue: 2. Mar/Apr 1999.

- [18] QIU Ying, LI Weimin and WEI Zhi. "Manipulator simulation and its technology based on VRML", Journal of Machine Design, Vol.26, No.3, Mar.2009.
- [19] Rischbeck, T., Watson, P. "A Scalable, Multi-user VRML Server", Virtual Reality, 2002.Proceedings.IEEE.Aug.2002.



**Ban Wang** received the mechanical engineering degree from Southwest University.

He is currently studying in Zhejiang university for his master degree. His main research interests are in mechanical design and robot technology.



**Weihua Zhou** received the electrical engineering degree from Zhejiang University.

He is currently studying in Zhejiang University for his doctor degree. His main research interests are in drive and control of motor, robot technology and automation technology.



**Jifeng Guo** was born in 1964. He received the master degree of mechanical engineering from Harbin institute of technology and doctor degree of mechanical engineering from Zhejiang University.

He is Professor of Zhejiang university .His current research interests are in automation of production line, control of motor, robot technology and spatial mechanism.