Study and Design of Virtual Laboratory in Robotics-Learning

Fei MA* and Rui-qing JIA

School of Mechanical Electronic & Information Engineering
China University of Mining & Technology (Beijing), Beijing, China
*Corresponding author

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Abstract. With the development of virtual reality technology, more and more virtual laboratories are used in the fields of education and scientific research. Many famous universities and scientific research institutions at home and abroad have carried out a lot of research on the virtual laboratory, but most of them stay in the design of some simple experiments and the development of specific functions. This paper is expected to focus on using virtual reality technology to embody the teaching process of Robotics. Through the analysis of the theoretical framework and development approach of virtual experimental technology, a general method is developed to build a virtual laboratory in Robotics-Learning. By contrasting the implementation methods of various virtual experiment techniques, the virtual laboratory technology software framework is established. The effectiveness of the proposed method is verified by the establishment of a three-link robot virtual laboratory. Thus, teaching content could be displayed in the virtual world completely. All these can be used either in college education or training to acquire knowledge about robotics and mechanical.

Introduction

A virtual laboratory is a kind of virtual experiment teaching system, which is based on VR (Virtual-Reality) technology[1]. It is a digital and virtual form of the real teaching laboratory. With the characteristics of low construction cost, short cycle, and low complexity, the virtual laboratory will play an important role in the remote teaching, remote experiment, remote training and long-distance display in the future[2]. It is becoming the key application of VR. However, the virtual laboratory has not been well applied to university teaching and research work in various specialized disciplines so far. It generally appears in the teaching process only as an adjunct to doing an experiment. For this phenomenon, there are several reasons: 1. Due to lacking integrity and popularity, virtual reality technology can only be developed and used by some professional researchers. 2. The development of virtual laboratories used for specialized disciplines is of high difficulty that is proportional to the complexity of the specialized subject generally. 3. The validity and authenticity of virtual experiments are often doubted by some users. Based on the above several reasons, the virtual laboratory is in a very embarrassing position. On the one hand, many researchers study the application of virtual laboratory in various fields just making a little effect. On the other hand, educators are plagued by the low teaching quality caused by the complexity of specialized disciplines and difficulties of teaching experiments. Why don’t we solve the two problems together? Researching a set of the virtual laboratory used for specialized disciplines is not only to solve the teaching problem of specialized disciplines but also to expand the application field of the VR. In addition, it is a good opportunity to improve the development of key technologies of the virtual laboratory. Therefore, it is imperative to develop a set of the virtual laboratory which is used to the teaching of specialized disciplines.

Robotics combines computer technology, cybernetics, mechanics, information and sensing technology, artificial intelligence, bionics and other disciplines, is a very active contemporary research and development. Robot research in the world has been more than half a century of history so far. The emergence of robots on human production and life had a significant impact, and therefore obtained considerable progress[3]. Robotics has become a new discipline with interdisciplinary and interdisciplinary. Its core is intelligent technology and the extension covers mechanical, electronic, communication, control, biology and other disciplines and technologies. It is highly permeable,
innovative and practical and contains a wealth of educational elements. The application of robotics in education shows unparalleled educational value and development prospect. The interdisciplinary integration of robotics provides a good platform for training wide caliber, high-quality and compound engineering talents \[4\].

It’s expected to develop a virtual laboratory system of robotics for mechanical engineering students. As the break through point, teaching methods of the virtual laboratory used for specialized disciplines are established and related technologies are researched. It promotes the development of virtual reality technology and the teaching level of specialized disciplines ultimately.

**Literature Review**

Many scholars at home and abroad have carried out extensive and deep research on the virtual laboratory in the field of teaching. Yuchuan Chen and Qing Hu, in Dalian University of Technology, established a virtual laboratory environment for the mechanical experiment. Based on the environment, users can use virtual machine tools to do mechanical testing and avoid the risk of the actual experiment \[5\]. David C. Schwebel and Virginia Sisiopiku did the children's safety training and education through the establishment of a virtual reality system \[6\]. Kurt V and Choppella RA conducted a research on the establishment of a virtual laboratory framework and proposed a framework called DISCOVER which was designed to reduce the cost of learning to build a virtual laboratory \[7\]. Andersen PT and Mikkelsen SA made a comparison between the virtual simulation training and the traditional realistic training on mastoidectomy \[8\]. Özden Karagöz and Ahmet Zeki Saka set up a virtual laboratory based on 7E learning model for the experiment of physics and chemistry in middle school \[9\]. Zhang Lixia and Liu Guangran studied the environmental arrangement as well as facilities placement and other issues of virtual laboratory facilities in the 3D environment. The purpose is to make the user in the virtual laboratory have a more good sense of immersion \[10\].

It can be seen that many scholars have put a high attention to the importance of the virtual laboratory and the huge role that would be played in the field of education in the future. Virtual laboratory researches made by most scholars are still stuck in the virtual tools and virtual training. A complete set of the virtual laboratory which based on specialized disciplines is still lacking fully development.

**System Design and Key Solution**

**The Development of Virtual Laboratory Technology**

The development way of virtual laboratory system is the integration of virtual experiment technology, simulation technology, and test technology. Virtual experiment technology is not a simple combination of virtual reality technology, simulation technology, and test technology, but a combination of human-computer interaction technology, simulation technology and signal processing technology and other technologies, the formation of technology integration, functional integration of the organic whole. The technology development is shown in figure 1.

**The Theoretical Framework of Virtual Laboratory**

The basic purpose of the virtual experiment is to realize the reuse and sharing of experimental information. The theoretical framework of virtual laboratory includes three organic components:

*Theoretical Part:* Theoretical part refers to the theoretical and scientific problems of the virtual experiments, such as similar theory, object-oriented thinking, information science, management science, cognitive science, computer science, simulation theory and test theory. They are the theoretical basis of the virtual laboratory.

*Technology Part:* Technology is the key technology of virtual laboratories, such as test information modeling technology, three-dimensional modeling technology, human-computer interaction technology, virtual instrument technology, visualization technology, data management technology, computer network technology, realistic graphics display technology and system integration technology. They are the technical foundation of the virtual laboratory.
Application Part: Application refers to the virtual laboratory applications, such as virtual experiments, virtual training, performance testing, simulation experiments. They are the concrete realization and application of virtual laboratory, which directly reflects the significance, function, and value of virtual experiment.

A Three-link Robot Virtual Laboratory
The purpose of this paper is to research a set of virtual laboratory teaching system for Robotics and to summarize the general methods of establishing the virtual laboratory used for specialized disciplines. The effectiveness of this method is illustrated by a planar three-link robot.

Physical model
The physical model of the planar three-link robot is established in SolidWorks and 3DS Max.
Mathematical Model

The establishment and solution of the mathematical model are the important content of virtual laboratory establishment. The general mathematical model refers to the dynamic model of the robot. Here, in order to test the correctness and effectiveness of the method described above, the authors only derive kinematic models.

Robot’s kinematics is an important part of robotics, which is divided into forwarding kinematics and inverse kinematics. It is studied to understand and control the movement of the robot.

**Forward Kinematics:**

![Figure 5. The three-link robot.](image)

The forward kinematic model of the robot is deduced using the DH parameter method. The DH parameters are as follows:

<table>
<thead>
<tr>
<th>Link</th>
<th>( b_i )</th>
<th>( \theta_i )</th>
<th>( a_i )</th>
<th>( \alpha_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>( \theta_1 )</td>
<td>( a_1 )</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>( \theta_2 )</td>
<td>( a_2 )</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>( \theta_3 )</td>
<td>( a_3 )</td>
<td>0</td>
</tr>
</tbody>
</table>

The transformation matrix from frame \( i \) to frame \( i+1 \) is as showed:

\[
T_{i+1} = \begin{pmatrix}
    c\theta_i & -s\theta_i & 0 & a_i c\theta_i \\
    s\theta_i & c\theta_i & 0 & a_i s\theta_i \\
    0 & 0 & 1 & 0 \\
    0 & 0 & 0 & 1
\end{pmatrix}
\]  

(1)

The transformation matrix of end-effector is derived as:
These is the forward kinematics of robot.

**Inverse Kinematics:**

The orientation of the frame attached to the end-effector with respect to the X1-axis is assumed to be \( \phi \), the position of the end-effector can be specified by the origin of Frame 4, i.e. \((px, py)\):

\[
\theta_1 + \theta_2 + \theta_3 = \phi
\]  

so,

\[
x_w = p_x - a_3c\phi_3 = a_1c_1 + a_2c_{12}
\]  

\[
y_w = p_y - a_3s\phi_3 = a_1s + a_2s_{12}
\]  

one finds:

\[
\Delta = x_w^2 + y_w^2 = a_1^2 + a_2^2 + 2a_1a_2c_2
\]  

so,

\[
c_2 = \frac{x_w^2 + y_w^2 - a_1^2 - a_2^2}{2a_1a_2}
\]  

and,

\[
s_2 = \pm\sqrt{1 - c_2^2}
\]  

so,

\[
\theta_2 = \arctan2(s_2, c_2)
\]  

Thus, \( \theta_2 \) can be obtained.

And

\[
s_1 = \frac{(a_1 + a_2c_2)y_w - a_2s_2x_w}{\Delta}
\]  

\[
c_1 = \frac{(a_1 + a_2c_2)x_w + a_2s_2y_w}{\Delta}
\]  

\[
\theta_1 = \arctan2(s_1, c_1)
\]  

\[
\theta_3 = \phi - \theta_2 - \theta_1
\]  

These is the inverse kinematics of robot.

The relationships between the joint velocities and the corresponding end-effector linear and angular velocities is described by a matrix termed Jacobian, which depends on the manipulator configuration. The Jacobian constitutes one of the most important tools for manipulator characterization. The Jacobian matrix can be extracted as:

\[
J = \left( \begin{array}{cccc}
        e_1 & e_2 & \ldots & e_n \\
        e_1 \times a_{1e} & e_2 \times a_{2e} & \ldots & e_n \times a_{ne}
\end{array} \right)
\]  

For the three link robot, the Jacobian matrix is:
As we known, the relationships between the joint velocities and the corresponding end-effector linear and angular velocities is obtained:

\[
\begin{pmatrix}
\dot{v}_e \\
\dot{w}_e
\end{pmatrix} = J \dot{\theta}
\]  

(16)

Derivation of both sides of the equation, the relationships between the joint accelerations and the corresponding end-effector linear and angular accelerations is obtained:

\[
\begin{pmatrix}
\ddot{w}_e \\
\ddot{v}_e
\end{pmatrix} = J \ddot{\theta} + \dot{J} \dot{\theta}
\]  

(17)

Verify the Mathematical Model

The mathematical model of the robot is derived in the previous section, the following section is to verify it in the Mathematica. The forward kinematics and inverse kinematics are verified in Mathematica respectively.

![Figure 6. Verifying forward kinematics.](image)

![Figure 7. Verifying inverse kinematics.](image)

Three-Link Robot Virtual Laboratory

The mathematical model and algorithm are represented by virtual technology, and the plane three-link virtual laboratory is established as follows:
As show in Fig.10, virtual experiment of three-link kinematics is achieve in virtual environment. For the forward kinematics virtual experiment, the users can input the robot joint angle and get the robot end-effector position and orientation; for the inverse kinematics virtual experiment, the users can input the robot end-effector position and orientation to get the robot joint angle.

Conclusion
According to the theoretical framework of virtual experiment system, a virtual experiment system framework of robotics is proposed, and the realization of the virtual experiment system of robotics is studied. It is not only suitable for the establishment of virtual laboratory of robotics, but also plays an exemplary role in the establishment of virtual laboratory of other disciplines such as mechanical principle and theoretical mechanics. The virtual experiment subsystem and the mathematical model subsystem are implemented under Windows 10 operating system by using Qt software, Ogre3D rendering engine and Mathematica mathematical software, and then the virtual experiment system of robotics is realized by combining the above two subsystem. In the virtual laboratory, the users can observe the movement of the robot in different observation modes and special internal information that can’t be obtained from physical experiments. The user can understand the virtual robot movement quickly, accurately, naturally in virtual laboratory.

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References

