

# **Design and implementation of a real-time control system for industrial robots based on virtual reality technology**

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## **Abstract**

In today's global trend of intelligent manufacturing, intuitive and efficient industrial robot control system is essential to facilitate high-quality automation and intelligent transformation in industry. In order to solve the control difficulties of industrial robots such as complex application environment and high technology integration, virtual reality (VR) technology is widely used because the application is not limited by environment and is characterized of convenient interaction. However, the current applications of virtual reality technology on industrial robots are not able to realize the real-time control of the robot since the Virtual Reality technology is only used during the motion set compiling process, which also increases the difficulty of the interaction between workers and the system. Therefore, this paper aims at proposing a real-time control system of industrial robots based on Virtual Reality technology to achieve efficient human-robot collaboration. The modelling process uses SolidWorks, 3dsMax and Unity3D engine. Then, the operating mechanism of the system is introduced. A practical case is performed and the result shows that the system has obtained the real-time control objective, which can guide the human-robot collaboration process in different scenarios of industrial robots.

## **Keywords**

industrial robot; virtual reality; real-time control; human-robot collaboration

## 1. Introduction

The development of intelligent manufacturing has stimulated the transformation of industry to automation and intelligence. The industrial robots, as important equipment in intelligent manufacturing, are used increasingly widely in industrial production. According to the report of the International Federation of Robotics, the annual global sales value of industrial robot expects an average growth of 12 percent per year from 2020 to 2022 (Heer 2019). The human-robot collaboration and control strategy are key elements to realize high-quality intelligent transformation in industry, since they are associated not only with the production flexibilization (Dröder et al 2018), but also potential risks such as pushing, crushing or clamping during operation (ISO/TS 15066, Berlin; DIN EN ISO 10218 Berlin).

Virtual reality (VR) is recognized to be able to provide visual immersion through real-time simulation and interaction (Burdea et al 2003). These features can effectively solve the control difficulties of industrial robots, which are identified with high integration of technology, complex application environment and high professional operation (Nagy 2019). Moreover, Virtual Reality applications will revolutionize future industry environments with its safe and efficient human-robot collaboration. For instance, Ben F. designed a set of virtual motion simulation system for industrial robots by using Unity3D virtual reality engine, visual motion simulation and remote communication control is able to be realized through this system (Ben 2019); Jiang H.X. developed an integrated control system of 6-DOF spraying robot by using virtual simulation environment modeling technology (Jiang 2011); Mao F.F. et al used 3dsmax software combined with virtual reality technology to build the 3D model of industrial robot and its path tracking control environment in Virtools virtual reality software (Mao 2021) and Crespo et al. used the VR equipment to simulate the operation of industrial robotic arms for task training (Crespo et al 2015). These virtual reality control systems developed for industrial robots aim to realize the robot trajectory planning (Zhang et al 2017) and collision detection (Stotko et al 2019) through VR simulation environment, and then send the motion command to the industrial robot in physical space to realize the control of the robot (Luo and Cao 2010). From the application level, this kind of control system is not able to realize the real-time control of the robot, the planning and compiling process of the instruction set also increases the difficulty of the interaction between workers and the control system.

Considering those studies that has already reached a real-time remote control of industrial robots, S. Khruangsakun et al designed a cyber physical system for real-time web-based control system of a 4-DoF robotic arm (Khruangsakun 2020) and Su Y.H. et al developed a novel manipulation system which is intended for achieving 3D manipulation in a real-time manner using VR technology (Su et al 2019). Khruangsakun's study reach the remote control featured with high precision and low time-delay. However, this system is not applied for a VR interface, thus making the operation only available on PC. Su's study mainly focuses on building a point cloud model of the real environment and integrating it with the virtual one.

Therefore, this paper aims to introduce an intuitive and convenient real-time control system for industrial robots based on VR technology, so that the control process of the robot no longer depends on the programming, debugging on the IPC. The real-time motion control of industrial robot in physical environment can be realized by simply dragging the robot gripper in VR environment. In the second part of this paper, the model of the robot and its working environment is constructed by SolidWorks, 3dsmax and Unity3D engine. The third part introduces the control module and communication module and the fourth part is the deployment of the system. This control system is able to be used to guide the optimization process of human-computer cooperation of industrial robots in a variety of application environments.

## 2. Modeling of the Cyber System

It is important to build a model for the real industrial robot in the virtual reality engine, which is capable of perform a realistic visual operation. This chapter will introduce the specific process of establishing the model of industrial robot and its working environment in the real-time control system of industrial robot based on virtual reality technology. The modeling process includes the structure modeling in SolidWorks, the model post-processing in 3dsMax and the construction of virtual reality interactive environment based on Unity3D engine.

In the structure modeling process, the basic dimension of the object robot is measured. The joint model realization is carried out according to the relevant feature information of the robot. The model of each joint axis of the robot are exported according to the IGS format, as shown in Figure 1.

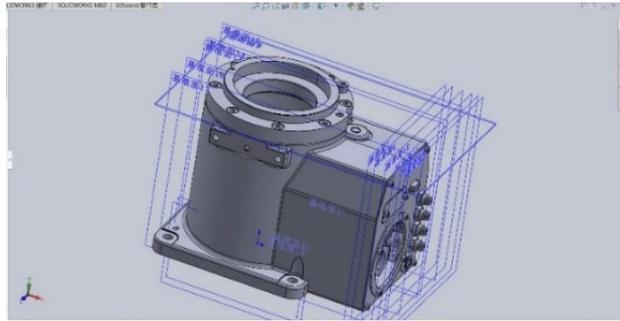


Figure 1. 3D model of the robot joint

The established model file is imported into 3dsmax for post-processing operation, which includes appearance rendering, axis position adjustment and format conversion. In the appearance rendering part, although the surface features of each joint axis model have been set in SolidWorks, the visualization effect is not realistic, so it is necessary to give each model a surface effect similar to the solid surface material in physical world. Moreover, considering the compatibility of the model with Unity3D engine, which will be used to develop the cyber system, the material effect is only limited to standard material and Muti/Sub-object. The rendering effect is shown in Figure 2.



Figure 2. 3D model before appearance rendering(left) and after appearance rendering(right)

In order to control the model of the robot in unity engine, it is necessary to adjust the axis center of each axis of the robot after importing the 3D model into 3dsmax to ensure that there is no movement error after assembly in the Unity3D platform. Before importing the model into Unity3D platform, the axis of the model needs to be fixed to

the interface of the rotation axis of the previous robot joint. In the process of adjusting the axis center of each axis, through editing the axis hierarchy in 3dsmax, the axis with deviated position is repositioned to the rotation center by capturing its coordination. The adjustment process is shown in Figure 3 and the processed joint axis model is imported into the Unity3D engine to complete the assembly as shown in Figure 4.

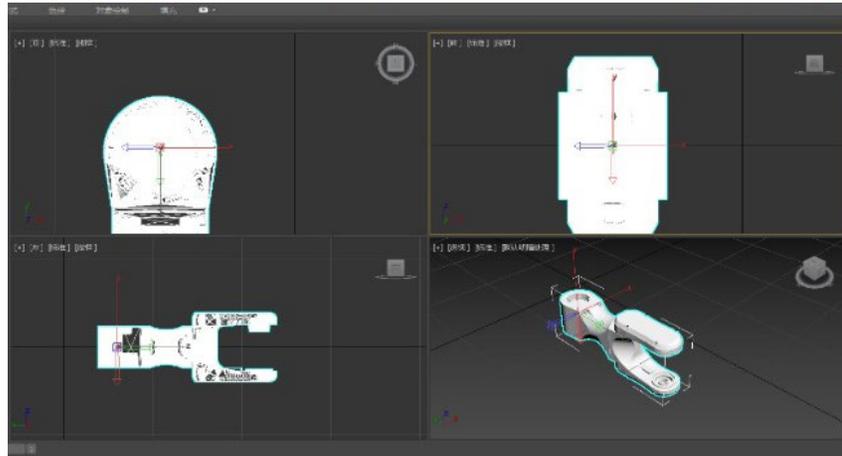


Figure 3. The axis adjustment process

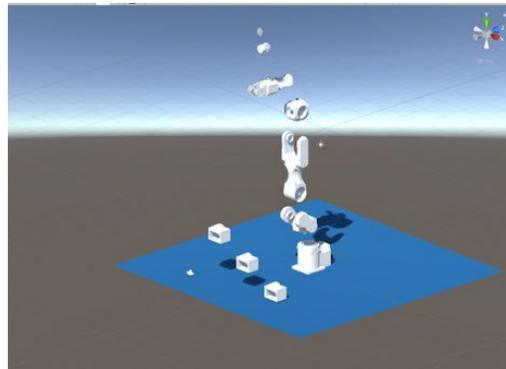


Figure 4. Model of the industrial robot in cyber system

At the same time, environmental resources are the basic elements of the industrial robot cyber system environment. According to the physical system of the industrial robot, the cyber system is improved through the multi resource module provided by Unity3D engine. In order to have a better visual effect of the operation environment of the physical robot system in the cyber system scene, the main camera and direction light are deployed, together with the model of the robot in the scene. Since the industrial robot cyber system requires a realistic physical effect to provide real experience of gravity, collision and friction, each axis of the robot is loaded with a rigid body to make it subject to gravity.

### 3. Operating Mechanism of the control system

After completing the model of the robot and its operation environment, it is necessary to carry out the operation and interaction design of the model to create an association between the model and the physical entity of the robot, so as to realize the real-time control. The framework of the control system is shown in Figure 5.

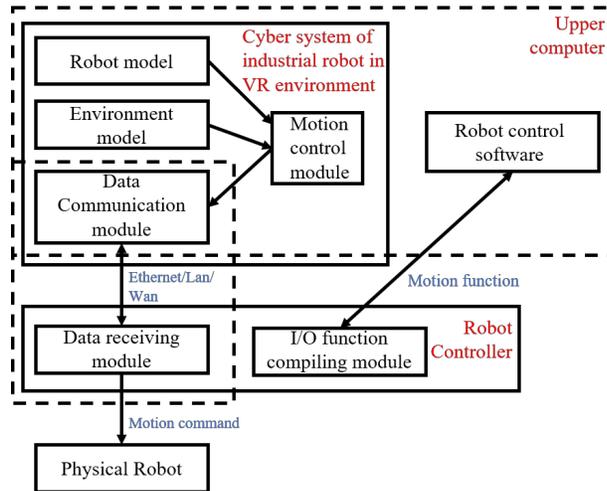


Figure 5. Framework of the control system

The cyber system of industrial robot in VR environment in Figure 5 is the system built by Unity3D engine in the previous chapter. The motion control module maps the working space of the industrial robot in physical space to the cyber system: the coordinate system is established with the center of the robot base contacting with the ground as the origin. During the operation of the model, users interact with the cyber system through VR handle. When the handle contacts the bounds, the gripper changes into a highlighted color, and triggered grabbing option. Press and hold any handle side key to drag the end gripper of the robot to move the robot to any position within the work space.

Based on this coordinate system interaction strategy, the mesh control points are set in the corresponding work space equidistant in cyber space and bounds for each control point are created (as shown in Figure 6). The bounds limit the control range of the control point, and the bound of the material box coincides with its outer contour. When the gripper moves into the space range of the bounds, the control code corresponding to the control point is triggered, and the robot in physical space will complete the motion from the current position to the control point. The trajectory of the robot is circular interpolation or linear. The specific motion command is compiled and integrated into the communication module of the system.

The communication module uses Unity3D engine to communicate with the robot controller. In cyber system, the script related to the communication module is mounted on the model of the gripper. The script is written in C# language, and the specific logic is shown in Figure 7. After the gripper has touched the bounds, the program identifies the number of the control point, generates the corresponding control code, and transmits it to the robot controller.

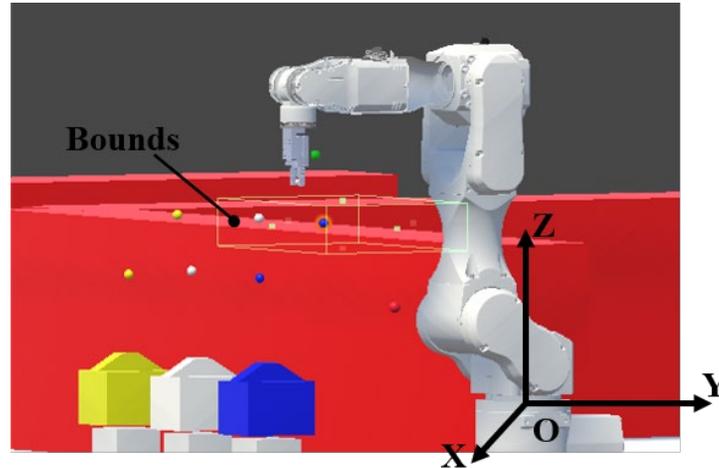


Figure 6. Bounds for control points and the coordinate of the robot model

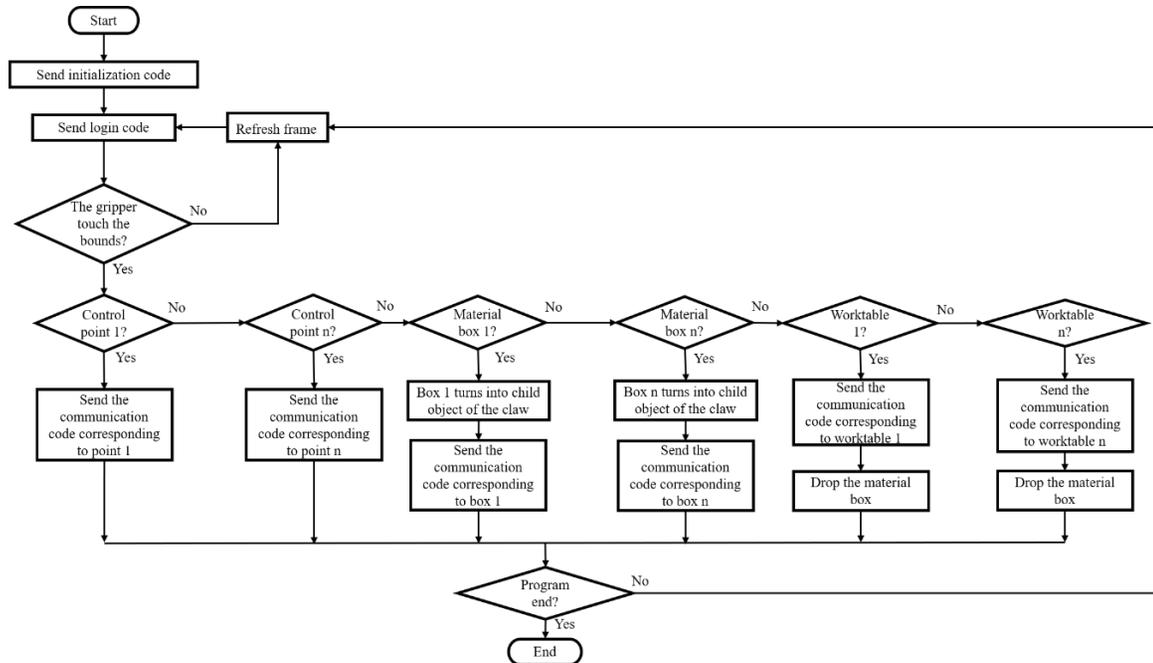


Figure 7. Flow chart of communication script

In the data receiving module, the control software for robot controller is used to plan the relevant control data of the control points, including the coordinates of the control points, the speed and acceleration of the joints, and the trajectory of the robot. The control data set is synchronized from the host computer to the robot controller through the I/O interface of the robot controller, then the robot control mode is switched to the remote-control mode. The data transmission mode can be Ethernet, LAN, Wan, etcetera. The robot controller supports RS232 serial communication or network communication with the host computer.

#### 4. Deployment of the system

The application platform based on this system is an industrial robot control system which combines virtual and reality. The platform consists of a set of software and hardware. The software includes RC+ 7.0 robot control software, Unity3D engine and Visual Studio 2013 development tools; The hardware includes EpsonC4 robot, robot controller and HTC-VIVE-Pro Professional VR package which includes VR helmet, positioner and handle.

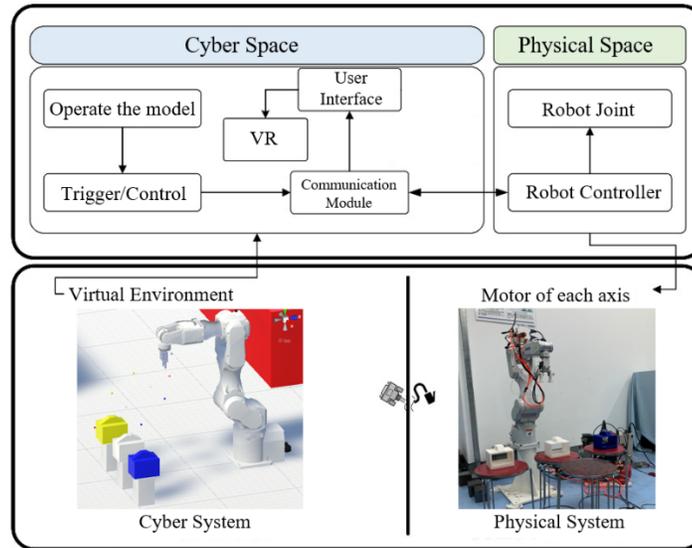


Figure 8. Correspondence and connection between cyber system and physical system

The robot controller is connected with the host computer through the PC local control port, and the relevant control data is edited in the robot control software and synchronized to the robot controller. After synchronization, the interface between the controller and the host computer is switched to RS232 serial communication, and the control mode is switched to remote control in the robot control software.

After editing the control data, connect the VR suit to the host computer and start the Unity3D engine. The VR helmet is driven by SteamVR and the main camera in virtual scene is associated with the VR helmet. After selecting the appropriate space to set up the positioner, the virtual model is functional under the condition that the helmet, positioner and handle are online.

After the cyber system has been started, the user put on the VR helmet within the projection range of the positioner to operate the virtual robot and realize the real-time control of the physical robot by dragging the gripper of the robot with VR handle.

#### 5. Conclusion

This paper introduces a real-time control system for industrial robot based on virtual reality technology, including the modeling process, operation principle and practical application process of the system. SolidWorks, 3dsmax and Unity3D engine are employed in the modelling process of the cyber system. The control strategy of the system is featured by the mapping of the coordinate system and setting of the control points with bounds.

Different control points will trigger different motion set, which are sent to the robot controller via the communication module.

This system is deployed to EpsonC4 robot. With HTC-VIVE-Pro Professional VR package connected with the Unity3D engine, the system is able to realize the real-time control of industrial robot in an intuitive and convenient interactive way. At the present time when the application scope of industrial robot is gradually expanding, this system has an important guiding significance for traditional teaching and human-robot collaboration.

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## **Biography**

**Jihong Yan** is a professor (since 2005) in Industrial Engineering at Harbin Institute of Technology (HIT), she is also the deputy dean of School of Mechatronics Engineering and head of intelligent manufacturing scientific research team at HIT. She received her PhD from Harbin Institute of Technology. Then she joined Tsinghua University, the University of Wisconsin, and Pennsylvania State University as a postdoctoral researcher. Dr. Yan is the director of National High-end Equipment Manufacturing Virtual and Simulation Experiment Teaching Center, head of Research Oriented Teaching Innovation Team for High-end Equipment Manufacturing of the Ministry of Industry and Information Technology of China, vice chairman of Production System Special Committee of Chinese Mechanical Engineering Society, and chairman of Industrial Engineering Professional Committee of the Mechanical Engineering Society of Heilongjiang Province. Her main area of research is industrial big data, sustainable manufacturing, intelligent logistics and advanced maintenance of machinery. As a PI, Dr. Yan has worked on and accomplished 15 projects in intelligent manufacturing and sustainability related areas, funded by the NSF of China (NSFC), NSFNSFC joint-project funding, National key R&D plan project funding, National High-tech project funding, National “863” project funding, EU EPSRC project funding, High-tech funding from industries, and so on. She has authored and co-authored over 100 research papers and published 3 books, two papers were ranked ESI high cited articles. Currently there are 17 professors and engineers with her research team, the team dedicates to theoretical research and system implementation in the fields of intelligent operation optimization theory and methods of manufacturing systems, manufacturing IoT technologies and devices, and equipment health monitoring, etc.