

Research on the Remote Control System of Robot Based on Augmented Reality

G. F. Liu^{†*} & T. Shishkina[‡]

[†]School of Earth Sciences and Resources, China University of Geosciences (Beijing), Beijing 100083, China

[‡]Department of Health, Government of Western Australia, Perth, Australia

ABSTRACT: The remote control system benefits from the application of virtual reality technology. Augmented reality technology is the extension of virtual reality technology. It adds the computer-generated virtual objects into the real world within in users' perception. This paper proposes a remote control system of robot based on augmented reality, elaborates its structure and key technologies, and proposes the improved algorithm of collision-free trajectory planning based on velocity vector field. This paper also makes experiments of efficient safe avoidance of static and dynamic obstacles. The results prove that the proposed system enhances the human-computer interaction effectively, and improves the accuracy of remote control.

KEYWORDS: Augmented reality; Virtual reality; Velocity vector; Robot simulation; Remote control.

INTRODUCTION

With the rapid development of computer and network technology, virtual simulation and remote control technologies have received increasing attention. Virtual simulation of robot is an important method in research of robot performance and characteristics, widely used in robot's trajectory planning, collision detection, performance testing, and so on. Remote control of robot allows the operator to stay away from dangerous operating environment, realizes integrated control of robot networks, and improves economic efficiency. The integration of virtual simulation technology into the remote control system of robot implements advanced human-machine interfaces, provides an intuitive and efficient virtual environment for complex tasks and tele-operation, saves debugging time and improves the system security [1-6]. Remote control technology of robot has made great contribution to human development in its several decades' development. The current technologies are still not enough to manufacture intelligent robot with complete independent ability [7]. Therefore, the remote robot is generally controlled by an operator through operation systems. The application of virtual reality in remote control of robot has achieved great success and improved the promptness and accuracy of operation and control effectively. According to the prediction demo, the virtual reality technology also solves the problem of communication delay [8]. But in remote control system of robot based on virtual reality, mishandling caused by modeling error and motion cumulative error still exists, and in unknown operating environment, there is no way for modeling [9].

Augmented reality technology is a new area of research on virtual reality technology. It is a technology to expand the human visual system through integrating the computer-generated virtual objects or scenes organically into the real scenario. With the adoption of augmented reality technology, three-dimensional model of the robot can be created, and its superimposition with the real scene of robot's work environment is displayed to the operator [8, 10]. The operator can see the real robot and virtual robot in one video area, and control their motion at the same time. By comparing the virtual work scenarios with real work scenarios, the operator can detect and correct modeling errors and motion cumulative error promptly. Furthermore, since the virtual and real work scenarios are superimposed in the same video, it is easier for the operator to concentrate, reduce fatigue, and improve work efficiency.

This paper introduces a remote control system of robot based on augmented reality. The system realizes camera calibration by identifying position mark in robot work scene video, and integrates the robot's 3D model into the video accurately for augment. The experimental results show that the use of augmented reality technology not only can improve the human-computer interaction effectively, but also can improve the accuracy and efficiency of the operating system.

SYSTEM STRUCTURE

Robot virtual simulation and remote control system SCARAadopts object-oriented C/S mode. The system is

composed of three layers: user layer, service layer, and the physical layer. Its logical structure is shown in Figure 1, and functions of each layer is illustrated as the below.

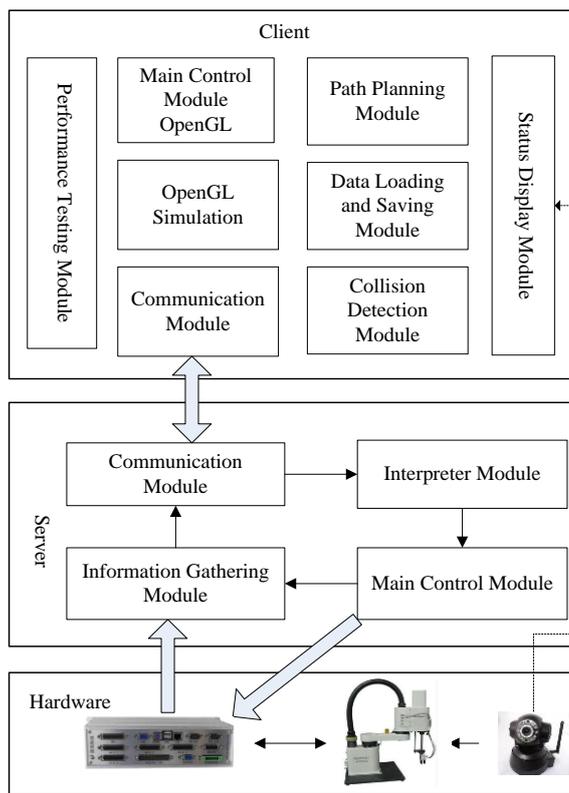


Figure 1. System logical structure.

- (1) User layer is the remote client. Downloading client installation package enables virtual robot motion simulation and remote monitoring in the human-computer interface.
- (2) Service layer is the remote server as well as the local controller. It receives the control information through communicating with client, and converts the information into a control command, which is sent to the robot controller, thus to realize remote control.
- (3) The physical layer is composed by the robot controller, SCARA robot, IP camera. The camera is directly connected to the client through IP, therefore, its occupied bandwidth is small and with better promptness.

The system structure of augmented reality-based robot remote control system is rather complex. The system consists of the server in robot work site and remote operating terminal connected by network communications. The server is composed of video collection module of working scenario and robot control module. The operating terminal includes human-computer interaction module, three-dimensional simulation, video integration, and remote control module. In this designed system, the video server obtains the robot's real work scenario by CCD video camera and sends it to the remote operating terminal via the network. In operation terminal, 3D simulation module builds a three-dimensional simulation model of the robot. Graphic image information of live video module and three-dimensional simulation module is sent simultaneously to the video integration module, which will analyzes the live video and calibrates the camera's internal and external parameters, calculates the three-dimensional robot registration information, and then superimposes the three-dimensional simulation model into the video and finally presents to the operator. In video integration module, it must be sure that the coordinates of virtual scene overlap with the actual coordinates in real live scene in the integrated video, in order to ensure the consistency of positions and gestures of real robot and virtual robot. By observation and comparison of their status in the integrated video, the operator adjusts the robot's position and gesture to reduce errors. The operator can control the virtual robot to finish virtual tasks through human-computer interface, and can send control command to the server through remote control module and control the real robot in server terminal to finish real tasks. The control commands of operating terminal can be low-level motion commands as well as high-level tasks commands. The control methods of remote control system can be master/slave mode as well as director/agent mode. The robot controller feedbacks the robot's status information and sends it back to the operating terminal through the network. Based on the status information, the operator can adjust the position and

movement of the virtual robot.

KEY TECHNOLOGIES IN SYSTEM IMPLEMENTATION

The Robot and Its Control

The real robot in this paper is Googol GEN-2012-type sculpture robot, and the motion control card model is GT-400-SG. The user sends control commands on the client, which will be passed on to the distal server through the network; the server can realize all functions of motion controller and control the sculpture robot finish appropriate actions by calling the functions in the Windows motion functions dynamic link library of the sculpture robot controller. On the other hand, the sculpture robot returns feedback signals in the opposite path back to the client, so that the operator can master the real-time conditions of the sculpture robot.

Video Collection of Real Scenario and Network Transmission

The video collection is done by LCH-P49A type 1/4 "CCD camera, with effective pixels of 752×582 , the focal length in the range of 4.0 ~ 9.0mm, the horizontal viewing angle range of $51.8^\circ \sim 23.8^\circ$, the vertical viewing angle in the range of $38.3^\circ \sim 17.8^\circ$. The video capture card uses 10 Moons SDK2000. The development knit of video image acquisition is the Direct Show module in Microsoft's Directx XSDK9.0.

The network transmission scheme of video stream uses RTP feedback scheme. RTP protocol is divided into two closely related components: Real-time Transport Protocol (RTP) and RTP Control Protocol (RTCP). RTP is used for transmitting data having real-time characteristics, and RTP is used for monitoring quality of service (QoS). In this scheme, the network bandwidth controls the quality of video. When the bandwidth is abundant, the quality of video is high, and when the bandwidth is not enough, appropriate reduction of number of frames in the video and image size or adjustment of compression ratio in compression algorithm to meet the requirement of promptness in video transmission.

Virtual Modeling

Solidworks can process three-dimensional solid modeling of robot truly and quickly. OpenGL is strong in rendering and application portability. The combination of these two results a three-dimensional lifelike robot virtual simulation platform^[9]. The three-dimensional graphics rendering process of the robot is shown in Figure 2.

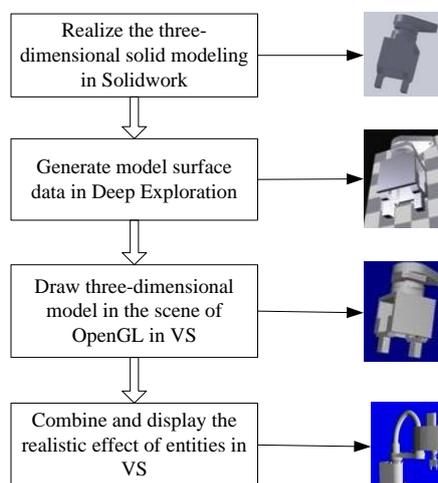


Figure 2. Robot Three-dimensional modeling process.

The uppermost node in the scene graph is the root of work scenario of virtual sculpture robot, which represents a collection of all nodes in the entire scene graph. The left-most node in the second layer is the background node, which displays the real scene video through real-time updates and draw of live images captured in Direct Show module. The nodes in Open Inventor are arranged in tree topology. Each node is rendered in turn according to the depth-first order in scene graph drawing. Therefore, putting the background node which displays the real scenario video in front of other nodes can ensure the real scenario video to be rendered before the three-dimensional simulation model, thus to make the model block part of the video, and to realize the basic integration of real video (realistic work scenes) and the virtual objects (virtual robot). After the background node is the optical node and viewpoint node. At the right end of the second layer is the ontology node of the sculpture robot. The first subnode of the sculpture robot is rendering

form node for setup of drawing form of simulation model. The wireframe model is applied in drawing the simulation model in order to avoid the virtual robot blocking the real robot when superimposed on the live images, which will affect the operator's comparison of the two motion status. Since the sculpture robot is composed by various components with linkage, the packet node constructs the virtual system of hierarchy. Because all parts of the sculpture robot is born by its base, therefore, the base node is at the top of all other components. The Y-axis motion arm carries the Z-axis motion arm, so the Y-axis motion arm is located in the upper of the Z-axis motion arm. The first subnode of each component is a transform node, describing the pose of this component compared with the upper one. When the parameter of transform node of a certain component is changed, the pose of itself and the component it bears changes. Therefore, through kinematics analysis of each component of the sculpture robot, and changing the parameters of transform node with time, the movement of the components of virtual sculpture robot can be realized, thus to complete the virtual working process.

Robot Collision-free Trajectory Planning

In the context of obstructions, robots obtain the collision-free trajectory from the initial point to the target point according to certain algorithms. This paper adopts swept sphere volumes^[11] to simplify the robot and obstruction, calculates the shortest distance between the two, obtains the collision-free trajectory through velocity vector filed algorithm based on artificial potential field, and optimizes the velocity using exponential velocity field^{[12]-[14]}.

As shown in Figure 3, the speed-driven velocity vector field of robot collision-free trajectory is achieved by controlling the speed of the robot movement, which includes attraction velocity vector field, exclusion velocity vector field and rotational velocity vector field. The functions and definitions of each vector field is shown as below.

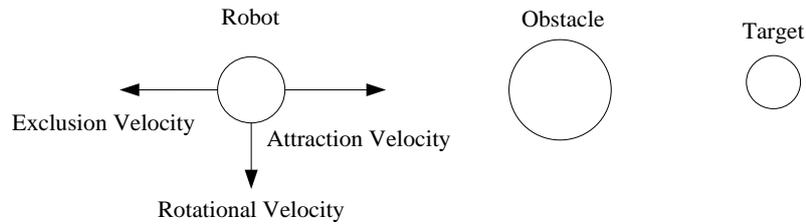


Figure 3. Robot's velocity vector field.

- (1) Attraction velocity vector field ensures the robot stick to the target point, and is usually set associated with the minimum distance between the robot and an obstacle. In general robot collision avoidance task, the attraction velocity is set to a constant speed v_s , the direction of the attraction velocity is

$$\vec{V}_{att} = \frac{{}^R_G \vec{P}}{\left| {}^R_G \vec{P} \right|}$$

Among which, ${}^R_G \vec{P}$ is always the vector of the present position \vec{P}_R directing to the target point \vec{P}_G .

- (2) The exclusion velocity ensures that the robot won't collide with obstacles. The traditional r exclusion velocity is in

$$\begin{cases} d_0 < r_{obs} & \Delta x_{rep} = -\text{sign}\left(\cos\left(\theta_{rep}\right)\right) \cdot \infty \\ & \Delta y_{rep} = -\text{sign}\left(\sin\left(\theta_{rep}\right)\right) \cdot \infty \\ r_{obs} \leq d_0 \leq R & \Delta x_{rep} = -\beta \cdot \left[e^{\left[\left(R-d_0\right)/10-1\right]} + e^{\left[\alpha\left(R-d_0\right)' / 10-1\right]} \right] \cdot \cos\left(\theta_{rep}\right) \\ & \Delta y_{rep} = -\beta \cdot \left[e^{\left[\left(R-d_0\right)/10-1\right]} + e^{\left[\alpha\left(R-d_0\right)' / 10-1\right]} \right] \cdot \sin\left(\theta_{rep}\right) \\ d_0 > R & \Delta x_{rep} = \Delta y_{rep} = 0 \end{cases}$$

correlation with the distance between the robot and obstacles. But the motion velocity of the robot is unstable. This paper designs the exclusion velocity vector field based on exponential law. The exclusive law is defined as below.

Among which, $R=r_{rob}+S+r_{obs}$, α and β are exclusion factors, $S=S_{in}+S_{out}$ stands for the exclusion range of obstacles, e is Napierian base, d_0 is the shortest distance between robot and obstacles, and θ_{rep} is its direction angle.

By application of exclusion velocity vector field based on exponential law, the robot can avoid abrupt change in velocity when it enters into the exclusion field, and can avoid the obstacles with high exclusion velocity when approaching to the obstacles. In this definition, the rate of change of distance $(R-d_0)'$ is taken into consideration, which makes the velocity vector can be applied in avoidance of moving obstacles.

(3) When the robot, the obstacle, and the target point are in a straight line, the attraction velocity and the exclusion velocity might counteract, which will result the robot stagnating at some intermediate point. To avoid this local minimum problem and increase robot's speed of obstacle avoidance, this paper proposes the rotational velocity vector field, whose definition is shown as below.

$$\begin{cases} d_0 < r_{obs} & \Delta x_{rep} = -\text{sign}(\cos(\theta_{rep})) \cdot \infty \\ & \Delta y_{rep} = -\text{sign}(\sin(\theta_{rep})) \cdot \infty \\ r_{obs} \leq d_0 \leq R & \Delta x_{rep} = -\beta \cdot \left[e^{(R-d_0)/10-1} + e^{[\alpha \cdot (R-d_0)/10-1]} \right] \cdot \cos(\theta_r) \\ & \Delta y_{rep} = -\beta \cdot \left[e^{(R-d_0)/10-1} + e^{[\alpha \cdot (R-d_0)/10-1]} \right] \cdot \sin(\theta_r) \\ d_0 > R & \Delta x_{rep} = \Delta y_{rep} = 0 \end{cases}$$

Among which, $\theta_T = \theta_{rep} \pm 90^\circ$.

The robot moves under the coordinated effect of vector fields of attraction velocity, exclusion velocity and rotational velocity, and avoids obstacles safely and stably.

Another key point of robot remote control based augmented reality technology is the accurate pose of tracking camera and the precise positioning of virtual objects in real scenario video^[10]. When integrated with the real scenario, the pose of virtual robot must be consistent with the realistic robot, namely the coordinate system of the virtual scene must coincide with that of real scene in video integration, in order to ensure that the system can correctly reflect geometric modeling error and motion cumulative error of the model.

CONCLUSION

This paper explores the programming method using MSComm32 control applied in the program Delphi7.0 under Windows 2000. The designed robot virtual simulation and remote control system can complete motion simulation and remote tasks excellently. Practice has proved that by combining Delphi7.0 and MSComm32, an application software of UAV ground detection system can be developed. And only through the well handle of its real-time serial communication section, a UAV ground detection subsystem with user-friendly interface and easy function expansion can be developed in a short time. The collision-free trajectory planning based on algorithm of velocity vector field can avoid the static and dynamic obstacles accurately. By introducing degree vector of exponential law, the system obtains a more stable operating speed. Through system testing and analysis, it shows that this system is high in accuracy and stability, can be a tool of discrete programming and remote control in the industrial sector, and serve as a robot teaching experimental platform in the field of education.

REFERENCES

- [1] S. Park and J. Cho, "ROI-based Visualization of Spatial Information for a Remote-controlled Robot", *IEEE Ubiquitous Robots and Ambient Intelligence*, vol. 24, no. 5, pp. 234-235, 2013.
- [2] J. S. Zhang and N. F. Xiao, "Real-time Simulation and Realization of Robot Remote Control System", *Computer*

- Engineering and Applications*, vol. 45, no. 14, pp. 245-248, 2009.
- [3] W. Chen, "Research on Virtual Simulation and Control of Robot", *Computer Engineering and Design*, vol. 31, no. 20, pp. 4455-4496, 2010.
- [4] G. Y. Gao, C. Xu, and D. X. Zhou, "Implementation of Remote Control of Virtual Hand", *Computer Engineering and Applications*, vol. 47, no. 23, pp. 79-83, 2011.
- [5] Y. F. Sun and A. H. Luo, "Development Research on China's Industrial Robot", *Science Technology and Engineering*, vol. 12, no. 12, pp. 2914-2915, 2012.
- [6] F. Guo, *Design of Robot Simulation System*, Nanchang: Nanchang University, 2013.
- [7] G. A. Rao and T. H. Chen, "Design of Real-time Detection System", *Electrical Measurement & Instrumentation*, no. 12, pp. 47-50, 2003.
- [8] M. S. Qian and K. Xiong, "Design of Test System for Air Data of UAV", *Journal of Guilin University of Electronic Technology*, no. 2, pp. 97-99, 2006.
- [9] H. S. Chen, J. Xu, and D. R. Chen, J. Li, "Transmit and Receive the Data of a MAV's Mesarue and Control System", *Computer Engineering and Applications*, no. 24, pp. 151-152, 2001.
- [10] Y. Q. Fan, *Manufacturing Technologies of Modern Aircraft*, Beijing: Beihang University Press, 2001.
- [11] Y. L. Gu, J. Li, and Z. M. Zhao, "Fast Distance Computation Based on Swept Sphere Volumes", *Journal of Engineering Graphics*, vol. 6, no. 6, pp. 1003-1008, 2007.
- [12] Y. C. Ma and Z. Gang, "Real-time Local Path Planning for Mobile Robot", *Robot Motion and Control*, no. 5, pp. 215-220, 2013.
- [13] S. S. Qiao, Y. Wu, and J. D. Zhang, "A Path Planning Method Based on Genetic Algorithms and Artificial Potential Field", *Modern Science and Technology*, vol. 35, no. 12, pp. 75-78, 2012.
- [14] A. K. Pamosoaji and K. S. Hong, "A Path-Planning Algorithm Using Vector Potential Function in Triangular Regions", *Systems, Man and Cybernetics*, vol. 43, no. 4, pp. 832-842, 2013.