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Implementation of Robot Binocular Vision Teaching

LIU Jie, PING Xue-Liang, YING Zai-En, JIANG Yi
School of Mechanical Engineering, Jiangnan University,
Jiangsu Province Key Laboratory of Advanced Food Manufacturing
Equipment and Technology, Wuxi Jiangsu214122, China

***Abstract* – According to binocular vision positioning and tracking technology, this paper proposed a robot 'binocular vision teaching' method and developed teaching control software according to open, modular design concept. Different from the traditional artificial teaching and pendant teaching methods of robots, the proposed method acquires arbitrary complex operation trajectories of teaching handle and then reproduced. The paper successfully controlled the robot to reproduce the trajectories of handwritten characters based on the binocular vision teaching. Experiments show that the design of control software enables real-time teaching and reproduction of any complex operation efficiently, making the method easy to use, widely broadening robotic application scope and having an extremely important value.**

***Keywords* – Binocular Vision Teaching, Control Software , Industrial Robots, Trajectories Reproduction.**

I. Introduction

With the rapid development of industrial automation level, robot has been more widely used in all walks of life. As a humanoid automation equipment, robot mainly takes the place of human to complete high-intensity, high-precision and harsh environment job tasks. Currently, robots rely mainly on teaching to achieve movement in accordance with the human scheduled requirements of the job [1] .The operators guide the robot end effect or manually or operate the robot through teaching pendant to complete a desired position and orientation and record the position and orientation of each teaching point, then carry out robot language programming, when the program is played back, the robot can move according to the motion trajectory required. Teaching playback method and offline programming method are most widely used in today's industrial production, which can basically meet the production requirements, but their existing drawbacks and limitations limit the operating environment, production efficiency and application scope of robots [2-3].

This paper presents a new method of reproducing robot trajectory called "Binocular Vision Teaching" which is based on the binocular vision positioning technology. The method can reproduce any complex trajectories fast with high efficiency and have low professional demanding to operator. It can also achieve teleoperation remote teaching and operators do not have to work in a dangerous environment. The paper has developed a robot teaching control software based on stereo vision 3D measurement technology on the basis of a modular design idea , seamlessly docked binocular vision with robotics technology and finally gives examples to achieve the robot "binocular vision teaching " control.

II. Robot Binocular Vision Teaching System

2.1 Basic principle of binocular vision teaching method

Robot binocular vision teaching method is a reproduction of complex robot trajectories. The main contents include two blocks: making use of binocular vision to obtain and record complex operation of the robot teaching handle; controlling the robot to achieve complex operation reproduction. There are several steps to achieve the method: track and record the arbitrary complex operation trajectory of robot teaching handle by applying binocular stereo vision 3D measurement technology, conduct coordinate transformation of the trajectory data, inverse kinematics, calculate the expected rotating angle values for all the six joints, input the values into controller and drive all the robot motors and reproduce the teaching handle's complex operation.

2.2 Binocular positioning principle

The core of binocular vision positioning technology is to detect moving targets automatically and achieve real-time three-dimensional distances tracking. According to the parallaxes formed from the two images which are obtained by the same feature point P in the left and right cameras, we can measure the depth information of the feature point and achieve three-dimension positioning [4]. The basic principle is shown in Figure 1.

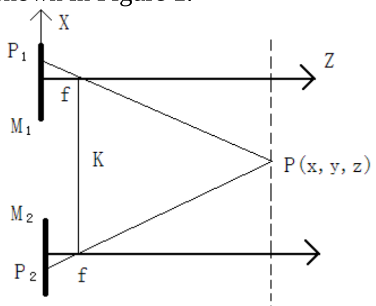

Fig.1. Schematic of binocular vision positioning

Fig.2. Physical map of binocular vision system

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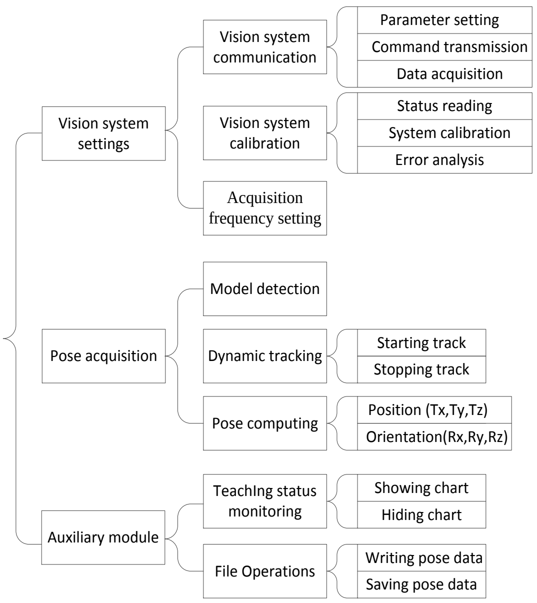
The left camera and the right camera are on the same horizontal plane. K is the distance of these two camera optical centers, f is the camera focal length, M1 and M2 are respectively the left and right image plane, an arbitrary point P in space whose coordinates on the left and right image planes are P1 (x1 , y1) and P2 (x2, y2), where y1 = y2, parallax b = x1-x2, the coordinate of P in the camera coordinate system can be obtained according to the geometric relationship, which is

$$x=\frac{K\cdot x_1}{b},\ y=\frac{K\cdot y_1}{b},\ z=\frac{K\cdot f}{b}$$

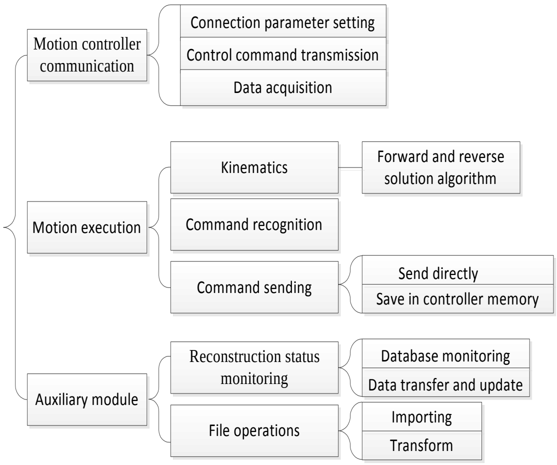
Binocular vision system is mainly responsible for collecting and recording position and orientation of the teaching trajectories, whose physical map is shown in Figure 2, which is equipped with two high-quality optical CCD and the special lighting. The system can automatically measure the target spots within the operating range and calculate the three-dimension coordinates in real time according to triangulation principle. The determined coordinates are sent to the control software for further processing.

III. The Software Design Of Binocular Vision Teaching Control

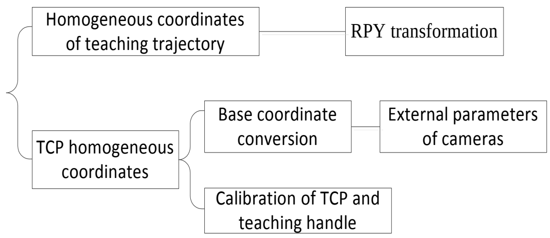
Teaching control software is a bridge for binocular vision and robot system, designed to complete robot teaching process, reduce expertise requirements to operators and achieve fool-operation. According to the proposed method, the developed software should have communication, position and orientation acquisition, data processing, motion control, status monitoring and other functions, where data processing is a bridge, converting the Cartesian position and orientation collected by binocular vision system to joint variable values needed by robot system. On the basis of these function requirements, overall framework of the developed software is shown in Figure 3.



(a) Binocular vision module



(b) Robot control module



(c) Data processing module

Fig.3. Overall framework of the software

3.1 The achievement of main software modules

For teaching control software, communication module is cornerstone of other modules. The core of binocular vision teaching method is to get the position and orientation data of robot end and input joint variables into controller, respectively achieving by position and orientation acquisition and data processing module. Condition monitoring is very useful auxiliary module, whose role is to feedback teaching and reproduction process to the host computer in real-time, helping the operator to observe the operation intuitive, easy to troubleshoot experimental failure [5].

3.1.1 Communication modules

ACR9000 motion controller offers serial, Ethernet, USB, PCI bus and other interfaces, we apply Ethernet protocol to achieve communication with the host computer. The controller is equipped with ComACRSrvr dynamic link library, providing IControl, Iterminal and other interfaces for users' secondary development. After establishing the communication ,you can call other interface functions. Part program of the connection is shown in Figure 4(a).

C-Track380 measurement system offers Ethernet interface, equipped with software VXelements, providing API for users' secondary development. In order to establish connection with PC, the IP addresses of measuring system and PC should be set at the same segment after judging whether the network cable connected well, part program of the connection is shown in Figure 4(b).

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......
m-Cntl–>SetBstrIP( "192.168.10.20" );
m-Stat–>SetBstrIP( "192.168.10.20" );m-Cntl–>Connect(3,0) ; m-Stat–>Connect(3,0);
if ( ! m-Cntl–>GetIsOffline( ) && ! m-Stat–>GetIsOffline( ) )
{ m-isOffline=" Successful connection! "+m-Stat–>GetBstrVersion（）; }
else
{ m-isOffline=" Not connected! "; }
......
```

(a)

```
......
VXelementsApi.ApiManager.Connect( );
if( ! VXelementsApi.ApiManager.IsConnected &&
! VXelementsApi.ApiManager.IsInstalled )
{ MessageBox.Show("Unable to connect devices",
"Check hardware interface and network address" }
else
{ MessageBox.Show("Successful connection" }
......
```

(b)

Fig.4. Program of the connection

3.1.2 Position and orientation acquisition module

Before tracking the teaching trajectory, you should detect each target spot on the teaching handle, and set the appropriate acquisition frequency which need trial and error .In a single acquisition cycle, two CCD cameras simultaneously shoot images for one target spot, and obtain the spot's coordinates(Px, Py, Pz, Rx, Ry, Rz) by feature extraction, stereo matching, trigonometric parallax principle, then we should construct coordinate system with the captured target spots, solve homogeneous coordinate matrix of the coordinate system according to the equation (1) RPY transformation [6], and record the current data, then repeat the steps of each acquisition period, until complete the teaching process.

$$RPY(\phi,\theta,\psi)=\begin{pmatrix} c\phi & -s\phi & 0 \\ s\phi & c\phi & 0 \\ 0 & 0 & 1 \end{pmatrix}\begin{pmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\theta \end{pmatrix}\begin{pmatrix} 1 & 0 & 0 \\ 0 & c\psi & -s\psi \\ 0 & s\psi & c\psi \end{pmatrix}=\begin{pmatrix} c\phi c\theta & c\phi s\theta s\psi - s\phi c\psi & c\phi s\theta c\psi + s\phi s\psi \\ s\phi c\theta & s\phi s\theta s\psi + c\phi c\psi & s\phi s\theta c\psi - c\phi s\psi \\ -s\theta & c\theta s\psi & c\theta c\psi \end{pmatrix} \quad (1)$$

3.1.3 Data processing module

The trajectory reconstruction desires angle values of each robot joint, which is obtained by inverse kinematics. In order to implement the process, solve the position and orientation of teaching handle relative to the robot's base coordinate system according to equation （2） Coordinate Transformation, and finally get the angle values of each joint according to inverse kinematics of robot.

$$^{Base}P_a = {}^{Base}T_{Tool} \bullet {}^{Tool}T_{Camera} \bullet {}^{Camera}T_a \quad (2)$$

3.1.4 Status monitoring module

Status monitoring module includes teaching status monitoring and reproduction condition monitoring: the former will present the real-time teaching status obtained by binocular vision system to users, and observe whether the target spots out of cameras' view. The teaching trajectory has two ways of interface display, curve form display and homogeneous coordinate matrix data form display [7].

IV. Binocular Vision Teaching Control Experiment

In this paper, we use a C-Track380 binocular vision measurement system and a 6R serial type robot self-developed in our lab to build the robot binocular vision teaching system. Binocular vision teaching control software is developed with C# programming language in Windows operating system, designing Human Machine Interface of software and completing the writing of underlying code. In this paper, a robot's motion instance was completed to demonstrate the feasibility and superiority of the binocular vision teaching control method. We wrote a Chinese character "大" with the teaching handle, and made the robot to reproduce the character, which is shown in Figure 5.

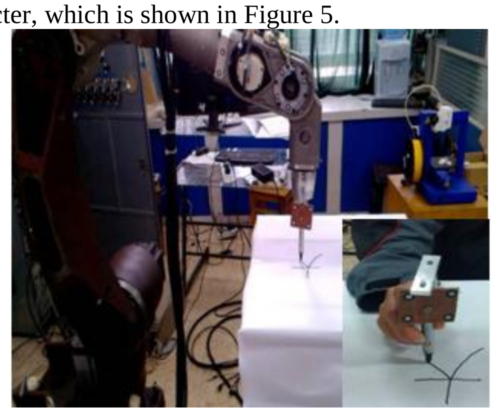

Fig.5. Binocular vision teaching control instance of robot

V. Conclusion

The quality of teaching method largely determines flexibility and intelligence of the robot function, this paper proposed a teaching method of reproducing any complex trajectory based on vision tracking technology, then developed the binocular vision teaching control software based on an open, modular design concept, and finally conducted experiments under the 6R serial type robot platform, which is independent researched and developed by our laboratory. Experimental results show that the proposed binocular vision teaching method is feasible and has great advantages compared to traditional manual or pendant teaching methods; the developed software is able to achieve binocular vision teaching control efficiently and reliably and extend the application scope of robot ,such as remote teaching operation, robot teaching in complex, dangerous environment, surgery remote control and so on, while the software is open source, easy to operate, easy to re-development and migration, with a very important research and application value.

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