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Study of Web-based integration of pneumatic manipulator and its vision positioning*

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Abstract: Pneumatic driven system is widely used in industrial automation, mainly for relatively simple tasks with open-loop control. Because of the pneumatic system's compressibility and few stop positions, it was considered hard to control in a precise motion control system. With the help of newly developed pneumatic servo control technology, using servo-pneumatic positioning controller now is just as easy as using electro-servo system. This article discusses Web-based servo-pneumatic manipulator control and object recognition and positioning. The authors built a three-degrees-of-freedom (3 DOF) pneumatic manipulator with a servo-pneumatic closed-loop control system and machine vision system in their lab. Web-based tele-operation was a basic ability in this experimental system. After installing a CCD camera, video capture card, and related software developed by the authors, the robot could recognize the user specified object through the Web page and find its position. The remote user could command the robot to move to the position and to grab the object. The critical issues of Web-based control are to integrate hybrid open-architecture mechatronic system through the Web and develop a software language environment characterized by the script. The authors' experiment showed that pneumatic devices could serve as accurate position control and be controlled through the Web.

Key words: Servo-pneumatic control, Pneumatic manipulator, Vision positioning, Web-based tele-operation
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INTRODUCTION

Pneumatic devices are traditionally used as air clamp to position worktable tools, because they can transfer a wild range of power at the high response speed of the actuators; while electro-servo systems are used in the areas where servo control and accurate positioning control are the basic requirements such as in process automation and robotics. There are two limitations in the use of pneumatic technology in these areas. The first one is the compressibility of the atmosphere, leading to difficulty of accurate positioning. The other is the few stop positions of the cylinder. The traditional pneumatic device can stop stably only at the two ends of the cylinder. If an application requires that the cylinder stop at more than two positions, then the multi-position cylinder that must be used will increase the complexity of the whole mechanical and pneumatic system. The moving speed of the cylinder can be set by the throttle at configuration and cannot be regulated during operation. These limitations are big obstacles when we try to use pneumatic devices in flexible control applications such as robotic manipulators. There are engineers and technicians who try to use pneumatic devices in a servo-control system. But the results showed that it is hard to configure. If we cannot find solutions for automatic positioning of pneumatic system, basically we cannot call it servo-pneumatic system even though the system uses a lot of pneumatic devices and the control sequence is set by PLC (Zhou, 1999). Study of the servo-pneumatic system can be traced back to the 1980's. Researchers

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found that the most suitable control algorithm for pneumatic system was the state feedback control (Zhou and Lu, 1998). The problem is that the optimal parameters of state feedback control are hard to determine, especially for the end user. The final user has to deliver all system information including system load, running speed of the cylinder, the damping of the system, the characteristics of friction of the cylinder, etc. to the manufacturer. The manufacturer then sets up the optimal parameters of state feedback control in the factory. Once the condition of system operation is changed, the optimal parameters of the state feedback control have to be re-adjusted in factory again. It is time-consuming and very uneconomical, restricts the application of servo-pneumatic system. This situation was ended at the end of last century, when Festo Co. offered its innovative products, SPC-100 and later SPC-200 Axis Controller. SPC series are open-architecture servo-pneumatic positioning systems. With the help of WinPISA (Programmierung, Inbetriebnahme und den Service fur Pneumatische und elektrische Achsen unter Microsoft Windows, which stands for programming, commissioning and service for pneumatic and electric axes under Microsoft Windows), users can configure the optimal parameters of the state feedback control calculation automatically by inputting the basic size of the pneumatic devices and the information on the running situation. In this situation, final users do not need to master special knowledge of control techniques and aerodynamics. They only need to type in relevant information in WinPISA windows and get the results. This sequence reduces the requirements of human skills and simplifies the usage of servo-pneumatic positioning systems. The servo-pneumatic positioning systems have been into used since then (Zhou, 1999).

There were now many applications of SPC's Axis Controller in robotic manipulators (Wang, 1999). The lists include Tron-X pneumatic robot, designed and manufactured by Showtronix, an Australia company. This Robot can shake hands with human beings. Its head, waist, and hands can bend with great flexibility as in humans. There are 32 SPC-100 Axis Controllers used in this robot. Another example is the calligraphy manipulator designed and manufactured by Zhejiang University, China (Tao *et al*., 2001). It was a 3 DOF calligraphy manipulator that could follow human calligraphy, can also be used in gelatinizing and jointing, and is controlled by one SPC-200 Axis Controller. The calligraphy manipulator was upgraded by more improvements introduced by a research team of the Zhejiang Institute of Science & Technology (Hu *et al*., 2002). They added Web accessibility to this system. So that the user can log in an Internet connected browser, fill out the form supplied by the Web, and control the manipulator motion.

The authors applied the results of their pneumatic manipulator research and added machine vision into this system. With the machine vision, the robot can recognize the object specified by the browser user, and determine the position of the object. Then, the remote user can command the manipulator to move to a specific position and grab the object.

PNEUMATIC MANIPULATOR

The pneumatic manipulator was a 3 DOF manipulator (Fig.1). All components and sensors were manufactured by Festo Co., Germany. The major characteristics are: *X*, dia. of cylinder 32 mm, displacement 400 mm; *Y*, dia. of cylinder 20 mm, displacement 250 mm; *Z*, dia. of cylinder 20 mm, displacement 150 mm; Static positioning precision <0.05 mm; Dynamic positioning precision<0.5 mm.

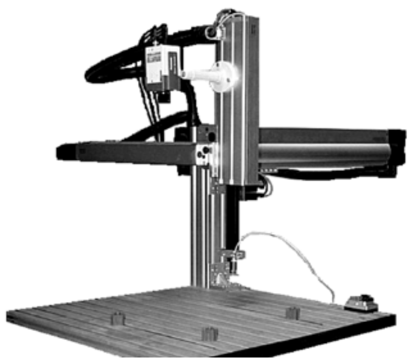


Fig.1 Three-degrees-of-freedom pneumatic manipulator

The structure of the electro-pneumatic proportional/servo control system of the pneumatic manipulator is shown in Fig.2.

The axis interface connects the SPC-200 controller with proportional directional control valve and

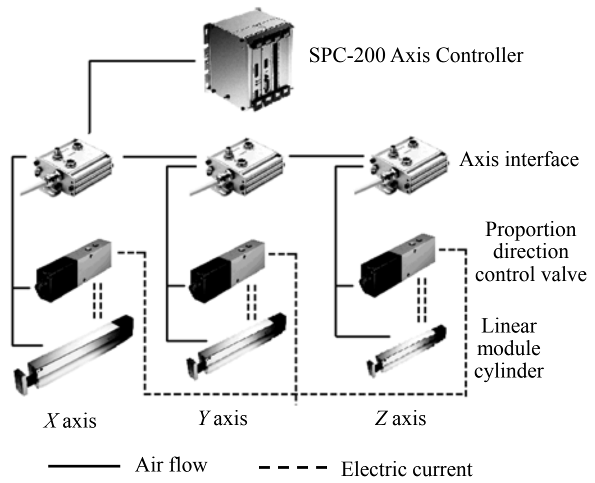


Fig.2 Structure of the SPC-200 electro-pneumatic proportional/servo control system

position sensor located in the cylinder. It is used as signal conditioning. The type of proportional directional control valve of *X*-axis, *Y*-axis and *Z*-axis is MPYE-5-1/8HF. The linear module cylinder for each axis is HMP series. In the pneumatic manipulator, all the connections within the three axes and framework are modular and standard. Thus, the pneumatic manipulator's assembly is very simple, convenient, fast, and firm.

The cores of the pneumatic manipulator's hardware are the servo-pneumatic positioning systems. SPC-200 Axis Controller was developed by Festo Co., Germany. They achieve closed-loop control through the axis interface and proportional directional control valve, and be used in servo-pneumatic positioning control. The characteristic features are optimized for two-axis coordination and can be expanded to three-axis coordination by adding one more independent axis motion. The standard I/O includes an RS-232 series port through which users can program SPC-200. They can also download NC program to SPC-200 or upload NC program to computer.

Simple operation, setting of control parameters and programming of SPC-200 can be performed via the control panel while enhanced programming can be done with WinPISA in Windows 9x. WinPISA supports NC programming complying with DIN 66025. User can also use serial commands to control SPC-200. Serial commands for SPC-200 consist of an index, a numerical command and optional parameters:

Index	Command	Parameter (opt.)	<CR>

The index addresses the axes (only single axis selectable):

…	3	2	1	0	Bit
	U	*Z*	*Y*	*X*	Axis

The command includes all operations of the SPC-200, such as: set communication, read out position, move to position, modify position, program control, etc.

If users want to read the actual positions of the *X*-axis, *Y*-axis and *Z*-axis of the manipulator, and let *X*-axis, *Y*-axis and *Z*-axis move to 200 mm, 100 mm and 50 mm respectively, the serial commands for SPC-200 to complete this process are as follows:

1*D*1 //*D*1 means read actual position
2*D*1
4*D*1
1*C*7+200 //*C*7 means move to position
2*C*7+100
4*C*7+50

MACHINE VISION POSITIONING

Machine vision system can greatly enhance the robot flexibility. The vision function added by the authors to the pneumatic manipulator can recognize the specified object and determine the object's position. In this machine vision system, the authors adopted the CCD camera Super Dynamic IIWV-CP460 manufactured by Panasonic Co., Japan and the video acquisition card PCI-1409 developed by National Instrument Co., USA. Machine vision server acquired the image of the pneumatic manipulator's platform through the CCD camera attached on the *Z*-axis of the robot (vertical cylinder in Fig.1), which then recognizes the specified object using the NI-IMAQ software package provided by NI Co. The procedures of image processing are as follows:

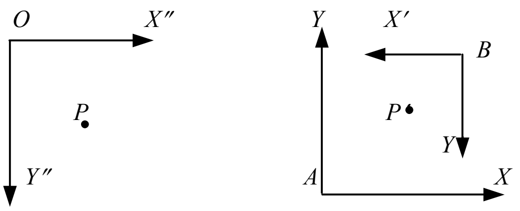
Step 1: Select an image of the specified object as the template image;

Step 2: Use the pattern matching algorithm *imaqlearnPattern*() to train the template image. If successful, the template image will include the information for matching;

Step 3: Use *imaqSetupGrab*() to acquire the continued video from the CCD camera, and use *imaqsnap*() to get a frame of the video;

Step 4: Set the tolerances and parameters to specify how the algorithm operates at run time using the options parameter of *imaqMatchPattern*(). The return value of *imaqMatchPattern*() includes all the matching information: amount of the matching object, the position coordinate of the center of the matching object, the rotation angle of the matching object and the estimated resemblance of the matching object.

In Step 4, if the specified object is recognized, the coordinate of the object's center will be acquired in the return value of the function *imaqMatchPattern*(). As the unit of the image is pixel, it should be transformed to millimeter used by the pneumatic manipulator. The distance between the CCD camera and the platform of the robot determines the ratio of pixel to millimeter. We marked points A and B in the platform. The real distance between points A and B is 100 mm. The distance of pixel unit between A and B in the image can be calculated easily in computer. Finally we get the ratio, which is 1/3.42 mm/pixel.



(a) (b)

Fig.3 Transform of coordinate systems
(a) Coordinate; (b) Coordinate system of the system of the screen pneumatic manipulator

As shown in Fig.3, XAY comprise the coordinates of the pneumatic manipulator, and $X''OY''$ comprise the coordinates of the image in computer screen. The coordinates of $X'BY'$ in the XAY is mapped to the computer screen via CCD camera, that is, $X'BY'$ corresponds to $X''OY''$. Considering the difference of the measurement unit, the relation between $X''OY''$ and $X'BY'$ is

$$ {}^{B}P=\xi\,{}^{O}P \tag{1}$$

where ξ is the ratio of pixel to millimeter, here ξ=1/3.42.

From Fig.3b, the transform matrix between $X'BY'$ and XAY can be described as follows:

$$ {}^{A}_{B}\boldsymbol{T} = \text{Rotate}(z,-90°)\cdot\text{Rotate}(x,180°)\cdot\text{Trans}(B_x, B_y, B_z)$$

$$ = \begin{bmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & B_x \\ 0 & 1 & 0 & B_y \\ 0 & 0 & 1 & B_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$ = \begin{bmatrix} 0 & -1 & 0 & B_x \\ -1 & 0 & 0 & B_y \\ 0 & 0 & -1 & B_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

where (B_x, B_y) is the origin's coordinate of $X'BY'$ in XAY, i.e. the origin's coordinate of $X''OY''$ in XAY. They are determined by the position of the CCD camera, and equal to 278 mm, 83 mm and 100 mm respectively in this system.

Therefore, the transform relation between XAY and $X''OY''$ is

$$ {}^{A}_{O}\boldsymbol{T} = \xi \begin{bmatrix} 0 & -1 & 0 & 278 \\ -1 & 0 & 0 & 83 \\ 0 & 0 & -1 & 100 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

WEB-BASED TELE-OPERATION

Web-based vision positioning

All operations of machine vision positioning mentioned in Section 3 are performed in image server. However, in order to complete the Web-based interactive operation, the browser user should have the ability to specify the target object and acquire the object's position. Therefore, the following strategies were adopted: (1) Refresh the image of the Web page periodically to ensure the browser has the latest image acquired by the CCD camera; (2) Browser user edits the image downloaded from the Web page with local image edit tools, and select the areas of the target object to save as a template image file; (3) Upload the template image file to server. Once the server receives a new template image file, it can carry out the other steps of the image process, and return results to the browser.

Web-Based pneumatic manipulator tele-operation

In the Web-based tele-operation, there will be some special requirements for the hardware and software. Basically, the hardware used in Web-based tele-operation should be open-architecture. That is, the hardware should have well-defined behavior and well-defined relationships, the definitions for which are known to all (Cheng *et al*., 1998). By definition, an open-architecture provides open access to system data. Inside the software development environment, the script characteristic is the basic requirement. It is impossible to program an application program and then compile, link and run it in the Web-based application. In the case of SPC-200 Axis Controller, its hardware satisfies the requirement of open-architecture. It has a standard RS-232 series port. The user can reach internal command register and control data. But the programming environment WinPISA is not suitable for the Web-based application directly. It is a Windows-based application environment and does not include script characteristic. The user cannot callback WinPISA's command in the Web directly. If the user wants to make it possible to use the script in Web directly, the program and running environment of SPC-200 have to be reconstructed.

The authors of this paper modified the pneumatic manipulator. After developing related dynamically loaded libraries and functions, the pneumatic manipulator can now be controlled through Web. The user can log into the pneumatic manipulator Web page, fill out the coordinate data and parameters that describe the path of the motion, and then click the "run" button. The Web-browser will transfer the data filled out by the user to the Web-server using CGI (Common Gateway Interface) programming. After getting the coordinate data and parameters, the server starts-up a script program, which is then sent by serial command and parameters to the SPC-200 through the RS-232 port. Fig.4 is the operation flow diagram.

The critical issue of this executive mode is the absence of an interpreted script language environment. This environment should also have Web-based programming ability (Cheng, 1995). The CGI program transferred data to a script program running in the background while the data was filled out on the Web. The script program then coded the data received and called a communication function to transfer the serial command for SPC-200. All of this work should be done in a unique language environment. In our experiment, we chose Ch language as experimental pro-

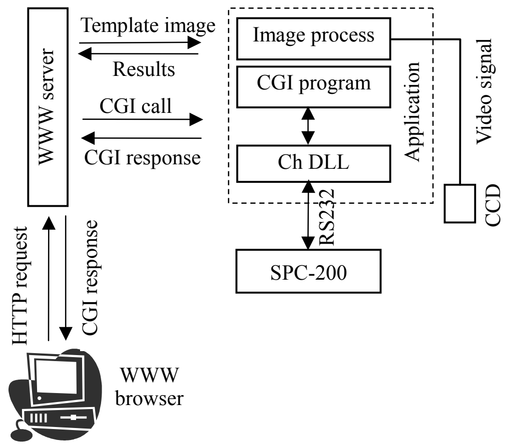


Fig.4 Operation flow diagram

gramming and executing environment. Ch is an extension and enhancement of the most popular Unix/Windows/C computing environment (SoftIntegration Inc.). As a superset of C interpreter, Ch retains C's low-level features for interface to hardware. Because Ch is implemented as a shell, a large collection of existing utilities and C programs can be readily used for integration of mechatronic systems. Functions, commands, and scripts are the basic building blocks for integration of mechatronic systems. Built-in networking features such as Berkeley sockets and restricted/safe Ch shell provide both flexibility and security for remote operation of mechatronic systems. Ch is designed to be especially suitable for Web-based client/server computing. Ch programs can be used for common gateway interface in the Web-server and as dynamic applets executed through the Web-browser (Cheng, 1996).

A CGI program can be written in any language that allows it to be executed on a host computer where a Web server is located. The most commonly used languages for CGI at present are C and Perl. CGI programs written in C or C++ normally have to be compiled and linked together. These compiled programs are difficult to modify and maintain. Therefore, many people prefer to write CGI programs in Perl, which is interpretive and resembles C language. Ch can also be used for common gateway interface directly without compilation. More important, it can keep a large body of existing C program. In Ch environment, it contains several classes for CGI programming. These classes provide convenient mechanisms for common gateway interface.

The authors had built a dynamic linked library called libspc.dl inside Ch language. This library contained the common communication functions that support information change between SPC-200 and computer. All functions can be called directly on Ch shell as internal functions (Cheng and Hu, 2000).

EXPERIMENTAL RESULT AND CONCULUSION

The authors built the experimental Web page shown in Fig.5 and Fig.6 for pneumatic manipulator tele-operation. This page is linked to ZIST Intranet. In this experiment, the user logs into the web page, edits the image of the target object, and uploads it to the server. All object's position on the platform of the manipulator will appear on the Web page. Thus, the user can fill out the trajectory coordinate data and the target object's position. *X*, *Y* and *Z* are the coordinates of the points in the trajectory. *V* is the velocity, and *S* is the state of the end-effector of the manipulator, 1 denotes switch on, 0 denotes switch off. Click "Submit" button, the pneumatic manipulator will grab the specified object and move along the defined path.

Fig.5 Select the target object and upload it as template image

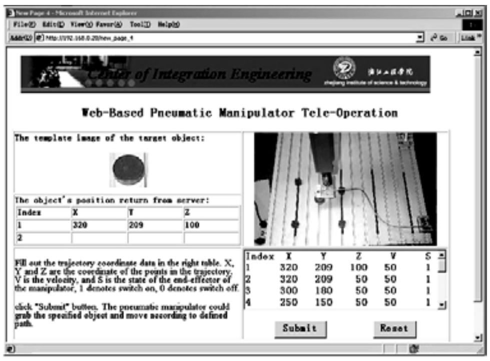


Fig.6 Define the movement of the manipulator

From the research and experiment mentioned before, we can conclude that: (1) User can recognize and position object for the remote manipulator through the Web; (2) Pneumatic devices can be used as accurate position control by using servo-pneumatic positioning systems; (3) It is possible to control SPC-200 through Web.

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