Measurement and Control System for Underactuated Manipulator Based on LabVIEW

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Abstract

The paper describes the method which is used to develop measurement and control system for manipulator based on LabVIEW since motion control of servo motors and data acquirement of joints are operating in different programming environment, respectively. The motion control system makes up of two parts: the upper computer for human-computer interface and the lower computer for explanation of program command and analysis and transmission of data. UMAC (Universal Motion and Automation Controller), the lower computer, is programmed to control velocity of servo motors by calling dynamic link library in upper computer. Simultaneously, the real-time data, which includes velocity and position of servo motors and those of joints, can be acquired from UMAC and DAQ and compared with the theory data to achieve the error that can offer some reference for improvement of measuring and controllable precision and mechanism accuracy of manipulator. The experimental result indicates that it is effective and feasible to achieve pickup operation of the five joint manipulator and decrease development threshold of motion control system.

Keywords: Path planning, Motion control system, LabVIEW, PMAC

1. INTRODUCTION

Robotics is a frontier subject with high comprehensiveness. Designers must have not only the basic theory of the subject but also the relevant technology since the development of robot system is involved in wide range of technical fields, such as measurement technique, the application of computer technology, etc. It has become a practical problems that need urgently to be solved that how to reduce the technical difficulty of the robot system development and shorten the development cycle and focus on theoretical and experimental research.

Professor Chen presents a measurement and drive control system based on ARM and FPGA according to its operational requirements (Chen et al., 2011). ARM realizes the control algorithm of the system and data storage, while FPGA acquires the seven channels encoder data. The scheme with ARM+FPGA can reduce the complexity of the external wiring and compact the structure of the system. LEGO Mindstorms NXT also uses ARM scheme with abundant interferences of sensor and communication (SEMICorp, 2006). (Li et al., 2006) addresses a measurement and control system for pipeline girth-welding robot based on virtual instrument. The system uses DAQ (Data Acquisition) to acquire signal and motion unit of NI to drive mechanism movement of welding robot. One of advantages is excellent integration of software structure. Some robot systems are established by PMAC which is a stable and reliable control approach with disadvantages of human-computer interaction and insufficient condition monitoring system, for example (Zhong and Jiang, 2014; Zi et al., 2012).
The underactuated manipulator has become one of concerned focus in the field of robotics and has received much attention from worldwide scholars (Nakamura et al., 2001). It has been widely used in system location (Grosch and Thomas, 2013), robotic grapping (Gregorio, 2014), transportation (Yamaguchi, 2012) and so on. The scope of this paper is the establishment of measurement and control system for the underactuated manipulator with three joints proposed in (Li et al., 2014).

2. PATH PLANNING SCHEME OF UNDERACTUATED MANIPULATOR

The three joints underactuated manipulator is shown in Figure 1 which consists of three revolute joints with two servo motors. Path planning is essentially an open control scheme that steers manipulator move from initial configuration to desired configuration with the action of a typical control law. Therefore, the measurement and control system must generate two control input: the velocity \( v_1, v_2 \) of two motors and acquire three output signal: angular displacement \( \theta_1, \theta_2, \theta_3 \) of the three joints, as shown in Figure 2. Joint 1 (active joint) is connected directly with servo motor 2; joint 2 and joint 3 (passive joints) are driven by motor 1. The number of drive units less than the number of joints for the underactuated manipulator.

![Figure 1. Three joints underactuated manipulator with two motors](image)

![Figure 2. Manipulator of input and output parameters](image)

The measurement and control system consists of the motion control module, sensing and data acquisition module and the instructions and data analysis processing module, as shown in Figure 3. The instructions and data analysis processing module is responsible for the preparation and issues of instructions, experimental process control, data display and storage. Motion controller, servo drives and servo motors constitute the motion control module which has three basic functions: first, compiling and execution of instructions; second, driving the servo motor movement according to the setting path; third, motor movement \( \theta_i \) sampling. The sensing and data acquisition module with angular displacement sensor and DAQ acquires the angular displacement \( (\theta_2, \theta_3) \) of joint 2 and joint 3 of the underactuated manipulator and send it to the instructions and data analysis processing module.
2.1 Hardware structure

Measurement and control system needs to be accomplished as follows: within the specified time, driving the manipulator move from the initial configuration to the target configuration, while collecting the data of joint angular displacement and indicating the result on the computer screen. The experiment will verify the validity of the control strategy and effectiveness of the system.

The hardware structure of measurement and control system for manipulator is established by upper computer and lower computer. As shown in Figure 4, PC is the upper computer which realizes human-machine interaction, programs motion control and data acquisition, data analysis and processing. Lower computer is responsible for instruction interpretation and execution and the physical signal perception and acquisition.

The Measurement and control system for Underactuated Manipulator is shown in Figure 5. The two servo motors employ Yaskawa AC servo motor (model: SGMAH-02AAA41) with 13 bit incremental encoder and the servo drivers with pulse and direction work mode. Motion controller uses UMAC presented by Delta-Tau Crop. Moreover, the selection of the UMAC axis interface board should adapt to work mode of the servo drivers. Acc24E2S axis interface board in UMAC can meet the n and achieve to separately control four axes. For this experimental platform, it can attain precise velocity control of two servo motors that forming position feedback and velocity feedback between UMAC and servo motor. In other words, it provides the basis for velocity control of the servo motor that the measurement
and control system can be effectively close position loop and velocity loop. The angular displacement of joint 1 connected with servo motor is acquired by UMAC. The DAQ samples the angle data of joint 2 and joint 3 equipped with angular displacement sensor (model: TDR-BZ-A). The upper computer communicates with UMAC and DAQ through USB bus and PCI bus, respectively. The results of static calibratio for sensors are shown in table 1 and table 2 within the scope of 0 to 75 degrees.

Figure 5. The Measurement and control system of underactuated manipulator

Table 1 Static calibratio for sensor 1

<table>
<thead>
<tr>
<th>Degree</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
<th>18</th>
<th>21</th>
<th>24</th>
</tr>
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<tbody>
<tr>
<td>Degree</td>
<td>27</td>
<td>30</td>
<td>33</td>
<td>36</td>
<td>39</td>
<td>42</td>
<td>45</td>
<td>48</td>
<td>51</td>
</tr>
<tr>
<td>Degree</td>
<td>54</td>
<td>57</td>
<td>60</td>
<td>63</td>
<td>66</td>
<td>69</td>
<td>72</td>
<td>75</td>
<td></td>
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</tbody>
</table>

Table 2 Static calibratio for sensor 2

<table>
<thead>
<tr>
<th>Degree</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
<th>18</th>
<th>21</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>2.104</td>
<td>2.366</td>
<td>2.625</td>
<td>2.885</td>
<td>3.144</td>
<td>3.397</td>
<td>3.653</td>
<td>3.908</td>
<td>4.159</td>
</tr>
<tr>
<td>Degree</td>
<td>27</td>
<td>30</td>
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<td>36</td>
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</table>

Linear fitting equations of static calibration of angular displacement sensor, having the form below:

\[ y = 0.082x + 2.1 \]  \hspace{1cm} (1)

\[ y = 0.082x + 2.2 \]  \hspace{1cm} (2)

where x is angular displacement of joint 2 and 3, and y is output voltage of sensor. The minimum output voltage of sensor is 8.2mV according to Eq.1 and Eq.2 since resolution of
0.1 °, and data acquisition card NI DAQ6221 with resolution of 16 bit and -10V~10V range, then the minimum resolvable voltage is given by:

\[
\frac{10 - (-10)}{2^{16}} \approx 0.31mV < 8.2mV
\]  

Therefore, data acquisition card meets the conditions of experiment.

2.2 Software structure

The measurement and control system is based on LabVIEW which provides abundant function library and graphical programming environment. However, motion control procedure for the servo motor need program in Pewin32. There are two questions need to be solved, one is how to program at different programming environment, another is how to acquire data of joints angular displacement while the servo motors rotate in accordance with instructions.

Delta-Tau Crop proposed two different programming way to satisfy different demand. The first method called motion program uses G code in Pewin32 and downloads instructions to the EPROM of UMAC and run on it; the second is called the host computer program, the specific method uses Windows programming language by calling PCOMM32.DLL dynamic link library and achieves the motion controller programming. The difference with the first method is the execution of the program in the upper computer.

These two programming methods have advantages and disadvantages. The motion program has simple procedure and high efficiency, but can’t easily develop their own application interface and monitor the condition of the system. The host computer program overcomes the defects of the former method, and can achieve the outstanding UI and extend the function of the system. However, there are two serious problems which are low efficiency of execution and hard to use the more than 400 functions (Delta,Tau Corp. 2003) of PCOMM32.DLL in LabVIEW.

The paper presents a new way which integrates the advantages of two methods. The Figure 6 shows the software structure of the system. Motion program download the EPROM, then the upper computer loads the PCOMM32.DLL to point to the motion program in EPROM and run it. Simultaneously, the system accomplishes the data acquisition and the control of the program execution flow. The strong point of the program way takes the simple way to program in the lower computer and controls the velocity of servo motor by calling the motion program. The upper computer program based on LabVIEW can conveniently accomplish data acquisition and program flow control. The lower computer program, using the way of motion program based on Pewin32, reduces the dependence of functions in PCOMM32.DLL. The advantages of the software structure employ the way of the host computer program, decrease the difficulties of programming.

The measurement and control with two layered software has the characteristics of flexible customization, the convenience of software update, the high efficiency of program execution and friendly UI. In lower computer, the motion program instead of the host computer program simplifies the difficulties of programming and facilitates troubleshooting by compiler of PEWIN32.
3. PATH PLANNING EXPERIMENT

The Figure 7 shows the method of path planning for underactuated manipulator by use of chained form conversion. The configuration variables $\theta_1, \theta_2, \theta_3$ and $\phi$, which is the displacement of the motor 1, are mapped into chained form variables $z_1, z_2, z_3$ and $z_4$ which presents the feasible laws. The inverse conversion can make a mapping from chained form field to configuration space to obtain the analytic solution of motion trajectory.

A major advantage of open loop control is that provides solutions for practical applications. There are many existing open loop controllers for the chained form, such as sinusoidal inputs, time polynomials and piecewise constant inputs, etc. These control methods are common in that inputs are given by solving algebraic equations using the input parameterization, any of the control laws can be applied to control the three joints underactuated manipulator. Time polynomial inputs are applied since inputs are easily obtained by solving simple algebraic equations. Furthermore, chained form of feedback control has two major drawbacks: one is that stabilizing chained system to the nonzero configuration is extremely difficult in practice, another is that obstacle or singularity avoidance problem cannot be solved some form of feedback control.

To verify the usefulness of the evaluation scheme, experiment has been carried out for three joints underactuated manipulator. Setting initial configuration and desired configuration are $\theta(0) = [5^\circ, 5^\circ, 5^\circ]^T$ and $\theta(T) = [30^\circ, 30^\circ, 30^\circ]^T$, respectively. The kinematics model with chained form can be expressed (detailed mathematical derivation sees (Li et al., 2014)): 
where configuration variables $\{\varphi_2, \theta_1, \theta_2, \theta_3\}^T$, and $[z_1, z_2, z_3, z_4]^T$ is chained form variables. The time-polynomial inputs of chained form control law is established in Eq.(5),

$$
\begin{align*}
    v_1(t) &= c_1 \\
    v_2(t) &= c_2 + c_3 t + c_4 t^2
\end{align*}
$$

(5)

where $[c_1, c_2, c_3, c_4]^T$ are undetermined coefficients of velocity inputs. And the chained form with 4 states can be expressed in Eq.(6):

$$
\begin{align*}
    \dot{z}_1 &= v_1(t) \\
    \dot{z}_2 &= v_2(t) \\
    z_3 &= \dot{z}_2 \cdot z_1 \\
    z_4 &= \dot{z}_3 \cdot z_1
\end{align*}
$$

(6)

Setting initial configuration and desired configuration are $\theta(0) = [5^\circ, 5^\circ, 5^\circ]^T$ and $\theta(T) = [30^\circ, 30^\circ, 30^\circ]^T$, respectively. Simulation results can be calculated by Eq.(4)-(6), the simulation result as shown in Figure 8 shows that the every joint can reach desired position.

**Figure 8.** Joint angles displacement (Simulation)

The Figure 9 illustrates the experimental result. In addition, there is existence of $5^\circ$ maximum error on the curve $\theta_3$. The backlash at the gear, transmission parts with low resolution and the lack of drive torque under guaranteeing rolling without slipping condition would have caused these errors. Moreover, the error of $\theta_3$ is obviously larger than the
others because of cumulative error of transmission system.

![Angular Displacement](image)

**Figure 9.** Joint angles displacement (Experimental result)

4. CONCLUSION

The paper proposes the measurement and control system of underactuated manipulator optimizes the software structure and reduces the technical requirement of computer programming capability. The experiment illustrates the three joints angles can reach the desired configuration with input velocity of two motors. Experimental result proves the validity of path planning scheme of three joints underactuated manipulator.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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