Development of a Customized High-Speed Delta Robot

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Abstract. The Robot industry is playing one of the key roles of global market and economic development of Taiwan. In recent years, the Taiwan official is inspired and has encouraged the development of the emerging industry. This study focuses on developing the industrial 3-axis Delta parallel robot system due to its advantages of high-precision, high-speed, high repeatability, long life span, and stable mechanism. For shortening the product development time, different geometric design software, Solidworks and RecurDyn, are employed to accomplish the key components design, simulation, and analysis. The practical implementation uses the Taiwan-made key components including servo motor, actuator, transmission elements, and various controllers. It is hopefully expected that Taiwan can keep up with the torrent of the global 4th industry revolution and develop the cutting-edge robot system which will create drastic profits for Taiwan.

Introduction

Under the influence of the tendency of aged population and low birth rate, the rising wages, and the general shortage of human labor, more and more electronics factories spend big invest on production automation to curtail the man-power demand. Plus, starting from 2003 China has been played the most important country for more than ten years that imported industrial robots from Taiwan. Following the emerging of China and her vast usage of industrial robots, Taiwan possesses the pan-new business opportunities. The extensive research and integration of robotic system is very urgently. Especially, after the maturation of electronics industry and precision machinery industry, the robotics industry will be the very one to help sustaining economic growth of Taiwan.

Compared with Japan and Germany, there still exits certain technology gap in the core components of the industrial robotic industry of Taiwan. The over-dependency of importing core components has greatly reduced the competitiveness of our robotic products. In addition to the main embodiment, the transmission gear box, servo system and controller are also the essential elements needing improvement.

Although the 3-axis parallel Delta robots are produced by many overseas company, merely customized products can satisfy the requirements, such as working time, motion inertia of holding weight, execution speed, system sensitivity, and motion trajectory programming. Thus, despite that the manufacturers have developed various Delta robots, they are hard to meet the vast user-end demands.

In the development of the high-speed Delta parallel robot, the main manufacturers include ABB, Bosch, FANUC, Festo and so on. Recently, HIWINMIKRO and Advantech has actively plunged into the robotic industry. The commercial Delta robot products include ABB IRB360/3 using DELTA robot original design [1]; ADEPT S650H being the extension of DELTA mechanism with 3-axis extended to 4-axis and performing the same task as the original DELTA parallel robot while both loading capability and speed are promoted [2]; FANUC M3iA/3S having 3-axis master arm and slave arm design like the DELTA original fixture while adding the 4th axis drive motor to the master arm thus enhancing the system freedom and meeting different users’ demands; MOTOMAN MPP3 owning the same 3-axis transmission rod as the DELTA original one [3] while the 4th axis installed on the motion platform. The above discussions reveal the importance of the development of customization of robotic products. Richard E. [4] provided two optimization methods, the first optimization object is to maximize the work space of the DELTA robot and the second object is to
maximize the number of full-range conditions, which will be used according to different requirements.

Regarding the control system of the 3-axis Delta robot, Zhang[5] etc. have developed Delta robots for KNT company by using computer, motion control card and C++ software and accomplished a 3-dimension robotic control platform. More, Zhao[6] etc. have made use of the controller parameter adjustment to decrease the motion trajectory error. In their research, the servo control parameters, PD control strategy and the least square method are used to analyze the effectiveness the motion trajectory error under different inertia load.

Based on the above-mentioned theory and the features of the commercialized product, this paper fulfills design, analysis, simulation, assembly, and test of a delta robot according to the customized requirements. With all the hardware coming from the Taiwan-made products, the prototype Delta robot is completed.

**Customized Delta Robot**

**Specification Requirements of the Robot**

Figure 1 shows the customized robot requirement that the position accuracy of 0.15mm upper limit. Figure 2 shows the Adept cycle requirement that specified the motion trajectory and cycle-index. Figure 3 illustrates the requirement of limiting the pick and place duration less than 1 minute. Accordingly, Table 1 lists the main performance index of the customized Delta robot.

![Figure 1](image1.png)  ![Figure 2](image2.png)  ![Figure 3](image3.png)

**Figure 1. Positioning accuracy.  Figure 2. Adept cycle function.  Figure 3. Pick and place function.**

<table>
<thead>
<tr>
<th>Rated load</th>
<th>Position accuracy</th>
<th>Working range</th>
<th>Maximum speed</th>
<th>Maximum acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2(kg)</td>
<td>0.1(mm)</td>
<td>500X500(mm)</td>
<td>10(m/s)</td>
<td>10G</td>
</tr>
</tbody>
</table>

**Geometric and Mathematic Modeling**

![Figure 4](image4.png)  ![Figure 5](image5.png)  ![Figure 6](image6.png)

**Figure 4. Units and components.  Figure 5. Geometric parameters.  Figure 6. Defined Parameters.**

The composition of Delta robot system is defined and depicted in Figure 4. Figure 5 shows the
coordinate system of the master arm and the slaver arm of one single-axis where 0 — XYZ denotes the stationary platform coordinate system and O' — X'Y'Z' represents the moving platform coordinate system; the radius of circumscribed circle of the stationary platform is R and the radius of circumscribed circle the moving platform is r; the length of the master arm is L1 and that of the slave arm is L2. The angles between three master arms and the stationary platform are $\alpha_1$, $\alpha_2$ and $\alpha_3$ respectively as shown in Fig. 6 with the origin being the joint of the master arm. Through the mathematical conduction, the inverse solution yields

$$\begin{align*}
L_2^2 &= (P_x + r \cos \alpha_1 - R \cos \alpha_1 - L_1 \cos \alpha_1 \cos \theta_1)^2 \\
&\quad + (P_y + r \sin \alpha_1 - R \sin \alpha_1 - L_1 \sin \alpha_1 \cos \theta_1 + (P_z + L_1 \sin \theta_1)^2
\end{align*}$$

$$\begin{align*}
L_2^2 &= (P_x + r \cos \alpha_2 - R \cos \alpha_2 - L_1 \cos \alpha_2 \cos \theta_2)^2 \\
&\quad + (P_y + r \sin \alpha_2 - R \sin \alpha_2 - L_1 \sin \alpha_2 \cos \theta_2)^2 + (P_z + L_1 \sin \theta_2)^2
\end{align*}$$

$$\begin{align*}
L_2^2 &= (P_x + r \cos \alpha_3 - R \cos \alpha_3 - L_1 \cos \alpha_3 \cos \theta_3)^2 \\
&\quad + (P_y + r \sin \alpha_3 - R \sin \alpha_3 - L_1 \sin \alpha_3 \cos \theta_3)^2 + (P_z + L_1 \sin \theta_3)^2
\end{align*}$$

Where $P_x$, $P_y$, $P_z$ are the position vectors of the moving platform center relative to the stationary platform. If the center coordinate of the moving platform is known, based on the nonlinear equations in (1), the motor rotation angles can be achieved. Similarly, the correct solutions of position can be determined as well, i.e., the three known motor rotation angles can determine the positions of the end holders of the moving platform.

**Motion Simulation and Dynamic Analysis**

With the introduction of the results into the multi body dynamics software RecurDyn, the maximum load motion simulation, the performance index analysis of mechanism, the dynamic analysis and motor torque analysis of the master arm and the slave arm are executed. Figure 7 demonstrates the attribute setup according to the relative motion among components. Figure 8 shows the simulated performance results by means of adjusting PID-controller parameters. Of course, applying CAD/CAE for analysis can greatly shorten the research and development cycle.

The Performance Index Verification of the Developed Mechanism Dexterity

The dexterity of robot is one of the performance index that features the ability of a robot to move from its original position to the indicated direction. If a robotic system can use less joint velocity to direct the end holder moving to the indicated direction in a faster speed, it implies that the robot possesses better dexterity in that direction. Inversely, the robot has worse dexterity.

**Motion Trajectory Programming**

In general, a high-speed robot arm can move its end holder in acceleration 10G (98m/s$^2$). With a motion under load, the associated effect of inertia and velocity will augment. For avoiding the impact, the continuum of velocity and acceleration during the travelling process are very important, i.e., the first and second derivatives of trajectory segment must be equal. Also, the jerk must be
constrained by limiting the quantities of triple derivative at the connection points of the trajectory function. Through the parameter adjustment in the software function of this robot, the dynamic performance of the product can be improved.

**Development of the Prototype Machine**

According to the above-mentioned design criteria, the associated components are obtained from Taiwan manufacturers. Based on the designed geometric sizes of moving platform, stationary platform, master arm and slave arm, the robotic system is assembled and processed in a standardized way. Figure 9 shows the transmission mechanism and the driver unit. Figure 10 exhibits the prototype machine and the controller. Table 2 lists the manufacturers of the core components and equipment specification.

<table>
<thead>
<tr>
<th>item</th>
<th>Manufacturer</th>
<th>Model</th>
</tr>
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<tbody>
<tr>
<td>Servo motor and driver</td>
<td>HIWINMIKRON</td>
<td>AC Servo 200W absolute D2-0423-E-B4</td>
</tr>
<tr>
<td>Teach-in controller</td>
<td>Advantech</td>
<td>LNC R6000</td>
</tr>
<tr>
<td>Planet gear box</td>
<td>LIMING</td>
<td>SD64-1-50M5</td>
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**Summary**

This study integrated CAD, motion simulation, multi-body dynamic software and Taiwan-made hardware equipment of industrial robot to accomplish a 3-axis Delta robotic system. The efforts include:

1. Applying Solidworks to carry out the design work and employing RecurDyn to attain motion simulation and dynamic analysis.

2. Using Taiwan-made hardware equipment to integrate motor actuation, precision transmission and controller to accomplish a customized Delta robotic system ready for helping future study and development of more advanced robots.

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References


