The Development of a Customized 4-axis SCARA Robot

Chin-Yu WANG*, Shin-Hong SYU, Kuo-chung WANG and Wei-Chih LIU
No. 840, Chengcing Rd., Niaosong Dist., Kaohsiung City, Taiwan (R.O.C.)
*Corresponding author

Keywords: SCARA robot, Customized, Industry robot.

Abstract. In this research, the Taiwan-made equipment, devices, key components, such as precision transmission system, servo motor and drive system, multi-axis controller, are employed to develop customized 4-axis SCARA robot arm. For meeting the geometric working space, load and operating conditions requirements of robot arm, the geometric design, motion simulation and analysis, standardized parts and component size inspection are accomplished. More, the multi-body dynamic software RecurDyn is used to simulate and analyze the stress, acceleration and motor torque. By adjusting the operation parameters, the customized motion schedule is completed and validated by contrasting the theoretic results. At last, the prototype machine assembled by the Taiwan-made components is tested and adjusted to meet the customized specification, thus sharing the customized industrial robot design experience with the academic and industry.

Introduction

Due to the revolution of Industry 4.0, the global developed and developing countries all promote the smart machine and industrial robot as the industrial policy. Undoubtedly, this unstoppable trend will play the pioneering role in the competitiveness and dominate the economic power of a nation. In the past few decades, Taiwan has possessed good foundation and industry cluster in the electronics, information, communication, and machine tool manufacturing. Hence, Industry 4.0 will allow Taiwan to stay a globally competitive economy. In the passes few years, the industrial robot industry of Taiwan is confined by the technical bottleneck of precision transmission system, servo motor and drive system, standardized controller and, thus, cannot take hold of the total key secrets in the robotic system. Hence, in recent years, the Taiwan government and the associated industry league have vastly engaged in robotic technology by massively producing industrial robot arms and manufacturing customized multi-axis robot arm to meet gigantic demand using production line automation, thus rapidly promoting the technology and product quality of industrial robot. Plus, the immense demand of industrial robot from China and Japan offers Taiwan’s robot industry the advantages at the right time, the right place, and the right connection.

Regarding the associated researches on SCARA, the COBRA i600 robot of the Adept company employed host computer and servo driver to integrate over three robots to realize the coordination of communication and operation among robots by using a controller of Adept, thus curtailng the cost [1]. Considering the effective load, the new-generation SCARA robot can move larger load, the G20 series SCARA robot of EPSON, for example, can bear the maximum effective load of 20kg [2]. To manage more effective load, the robots need more powerful drive system including decelerator with much severer reduction ratio. A modern robot is required to possess speed of 5m/s and acceleration up to 10 G to accomplish high efficiency performance. However, the high speed operation possibly leads to resonance between the mechanical system and the servo control system at a fixed frequency. To conquer this problem, Erkorkmaz and Altintas [3] developed a quantic curve interpolation technique to improve the relationship between parameters and practical arc length. This kind of curves can be used to eliminate the feed rate change owing to the improper parameter setting and, thus, achieve smooth feed rate. More, Wang [4] employed B-spline interpolation method to the trajectory of industrial robot. Zhang and Greenway [5] developed the real-time NURBS curve interpolation
method and achieved NURBS interpolation 6-axis robot lotus control. In the parametric equations of
NURBS curve, the parameters of curve in each axis is independently driven, thus being easily defined
in the robot or machine tool control. The commonly used parameter definition methods are Taylor
series expansion [6], numerical solution method [7] and iterative approach method, respectively.
These high-precision interpolation methods can reduce the trajectory error of complicated trace [8].

Based on the above-mentioned discussion along with the introduction of the 3D CAD design
software SolidWorks and the multi-body dynamics CAE software RecurDyn, the motion curve
interpolation method analysis, motor torque and drive parameter adjustment of the robotic system can
be accomplished.

**Robot Arm: Design, Analysis and Standardization**

**Function Requirement**

Fig. 1 shows the anchor points of the 9 circle centers in a 30cm by 30cm square area with the required
positioning accuracy being within 0.1mm. The motion track cycle time and cycle index requirements
are illustrated in Fig. 2. Fig. 3 shows eight 1 cm³ ingots which must be picked and placed within 30
seconds. Table 1 lists the robot’s specification.

![Figure 1: Positioning accuracy.](image1)
![Figure 2: Cycle time limit.](image2)
![Figure 3: Pick/place function.](image3)

**Table 1. The parameter specification of the customized SCARA robot.**

| Rated load | Positioning accuracy | Working area | Cycle time       | 8 pick/place |
|------------|----------------------|--------------|------------------|--------------|
| 2(kg)      | 0.1(mm)              | 400*400(mm)  | 45 cycles/min    | 30 sec.      |

**Geometry and Mathematic Modelling**

Fig. 4 shows the coordinate system and the mathematical modelling of the proposed SCARA robot
arm, in which the 3rd and 4th freedom perform the coaxial motion. The contact pair types and motion
parameters of arm joints are listed in Table 2.

![Figure 4: Coordinate system and mathematical modelling.](image4)

**Table 2. Motion type and motion parameter of joints.**

| Motion type | Joint 1 | Joint 2 | Joint 3 | Joint 4 |
|-------------|---------|---------|---------|---------|
| Motion parameter | 0₁ | 0₂ | 0₃ | 0₄ |

**Kinematical Analysis of Robot Arm**

As shown in Fig. 4, the fixed coordinate of the robot arm is O₀- X₀Y₀Z₀. For different arm, a moving
coordinate system is established with respectively defined joint motion parameters and arm geometric
lengths (long arm length l₁, short arm length l₂). Through matrix transformation, the position of the
end holder of robot arm T₀⁴ can be achieved.
Inverse Kinematical Analysis of Robot Arm

As long as the end position of the robot arm is assigned, Eq. (1) yields the motion parameters of all joints. Accordingly, the rotation angles can be determined by the following equations.

\[
A_i^1(\theta_i)T_0^4 = H_i^4, \quad \text{where} \quad H_i^4 = A_2(\theta_2)A_3(d_3)A_i(\theta_i) \quad \text{yields} \quad \theta_i
\]

\[
A_2^1(\theta_2)A_i^1(\theta_i)T_0^4 = H_2^4, \quad \text{where} \quad H_2^4 = A_3(d_3)A_i(\theta_i) \quad \text{yields} \quad \theta_2
\]

\[
A_3^1(d_3)A_i^1(\theta_i)A_i^1(\theta_i)T_0^4 = H_3^4, \quad \text{where} \quad H_3^4 = A_i(\theta_i) \quad \text{yields} \quad \theta_3
\]

Whereas, regardless solving the linear equation (1) or tackling the nonlinear equations in (2), the unique solution is necessarily obtained. Further checking of continuity property is important to examine its feasibility.

Geometrical Modelling and Component Standardized

According the requirements of loading condition, speed, acceleration, power rating and geometrical size of motor, standardized transmission component and so forth, the geometric mechanism design is illustrated in Fig. 5.

Motion and Dynamic Analysis

The motion requirements of a multi-axis industrial robot includes: high enough speed to satisfy massive production, high precision to maintain good rate, high loading capability to meet manufacturing load demand. Therefore, the preceding motion simulation, including acceleration change, deformation quantity, motor torque change, post-load motion simulation, is indispensable for the prototype machine under various operating conditions. In this research, the multi-body dynamics CAE software RecurDyn is used to complete the detailed analysis of the above-mentioned motion requirements. Fig. 6 shows the dynamic stress analysis of the prototype machine in motion. Fig. 7 displays the motor torque curves of the 1st and 2nd axis.
Hardware System Construction and Assembly

The usage of Taiwan-made key components and equipment is listed in Table 3.

Table 3. Taiwan-made key components and equipment.

| Key component (manufacturer) | Spec. and model | graphic |
|-----------------------------|----------------|---------|
| 1. Motor drive (Delta Electronics) | 1\textsuperscript{st} axis motor 400W, 2\textsuperscript{nd} axis motor 200W, 3\textsuperscript{rd} axis motor 200W, 4\textsuperscript{th} axis motor 100W | Fig. 8 |
| 2. Planetary reducer (LI Ming) | 1\textsuperscript{st} axis cycloid pinwheel, 2\textsuperscript{nd} axis & 3\textsuperscript{rd} axis planetary reducer | Fig. 9 |
| 3. Ball spline screw (TBIMOTION) | 3\textsuperscript{rd}, 4\textsuperscript{th} axis transmission shaft, coaxial transmission | Fig. 10 |
| 4. Controller (Delta Electronics) | model: ASD-MS-0721-F | Fig. 11 |

Prototype Machine Layout Diagram

Fig. 12 shows the 4-axis motor and transmission system. Fig. 13 shows the controller and transmission system. The developed prototype machine is shown in Fig. 14.
Conclusions

In this paper, a customized 4-axis SCARA robot is constructed according to the standard operating procedure. Through the software simulation and analysis, the prototype robot is designed, developed and realized on the conditions of component standardization. The key components inclusive of servo motor driver, transmission devices and controller are all made in Taiwan. In the end, a 4-axis SCARA robot is developed. This paper can be summarized as follows:

1. According to the customized functions and geometrical size requirement, a 4-axis SCARA robot is accomplished by the preceding computer-aided design, analysis, and simulation, thus shorting the development time.
2. The shared axle design of the 3rd and 4th ball spline axes help allocating the multi-axis design and reducing the motion inertia.
3. The use of Taiwan-made servo motor, transmission device, driver, and controller has accomplished the aim of all-made-in-Taiwan in the production of SCARA robot.

Acknowledgement

The authors would like to show their gratitude to PMC Taichung, Delta electronics corp., TBIMOTION, Advantech and LIMING companies for their kindly offering the associated apparatuses and technical assistance. With their help, this research can thus be fulfilled smoothly.

References

[1] User Handbook of SCARA Robot for COBRA system of American Adept Company.
[2] User Handbook of SCARA Robot for G20 Series of Japan EPSON Company.
[3] K. Erkorkmaz and Y. Altintas, High speed CNC system design. Part I: jerk limited trajectory generation and quartic spline interpolation, International Journal of Machine Tools and Manufacture. 41 (2001) 1323-1345.
[4] Y.M. Wang and W.H. Xu, The Optimization of B-spline Trajectory in the Continuous Path Control of Robot, Mechanical Design. 10 (2000) 33-36.
[5] Q.G. Zhang and R.B. Greenway, Development and implementation of a NURBS curve motion interpolator, Robotics and Computer-Integrated Manufacturing. 14 (1998) 27-36.
[6] T. Yong and R. Narayanswami, A parametric interpolator with confined chord errors, acceleration and deceleration for NC machining, Computer-Aided Design. 35 (2003) 1249-1259.
[7] A. Shima, T. Sasaki, T. Ohtsuki and Y. Wakinotani, 64-bit RUSC based series 15 NURBS interpolation. FANUC Technical Review. (1996)

[8] X. Liu, F. Ahmad, K. Yamazaki and M. Mori, Adaptive interpolation scheme for NURBS curve with the integration of machining dynamics, International Journal of Machine Tools and Manufacture. 45 (2005) 433-444.