Research on the Intelligent Recognition System of Printing Roller Surface Defects Based on Machine Vision

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Abstract. The printing machine’s sleeves installation operation is a typical peg-in-hole assembly problem. The printing machine’s sleeves are usually heavy, and the precision requirement of fit is high. Therefore it is hard to fit them together, and the assembly efficiency is low. What’s more the assembly tasks may make great damage to the worker who assembles it. To solve these problems, a Gough-Stewart parallel peg-in-hole assembly robot with high precision is designed. The robot has a stereoscopic laser measurement system to obtain position and speed information to realize closed-loop workspace control of the robot. The stereoscopic laser measurement system can also ease the impact in the assembly process. The robot has a passive flexibility wrist to solve the jamming question [1, 2].

In this paper, the kinematics model of the stereoscopic laser measurement system and the dynamic model of the Gough-Stewart parallel robot are built. A sliding mode controller is designed for the control of this robot, and the parameters of the controller are optimized [3, 4, 5].

1. Introduction
Most printing machine’s sleeves have high precision requirement in the printing industry. The printing machine’s weight is about 40 kilograms and requires assembly precision less than 5μm. At present the manual assembly efficiency is very low, and the assembly work harms the workers’ lumbar vertebra.

To solve these problems, a Gough-Stewart parallel peg-in-hole assembly robot with high precision is designed. The robot has a stereoscopic laser measurement system to obtain position and speed information to realize closed-loop workspace control of the robot. The stereoscopic laser measurement system can also ease the impact in the assembly process. The robot has a passive flexibility wrist to solve the jamming question [1, 2].

In this paper, the kinematics model of the stereoscopic laser measurement system and the dynamic model of the Gough-Stewart parallel robot are built. A sliding mode controller is designed for the control of this robot, and the parameters of the controller are optimized [3, 4, 5].
2. Design of passive flexibility printing machine’s sleeves assembly robot

Passive flexibility printing machine’s sleeves assembly robot with peg-hole relative position and orientation measuring tooling stereoscopic laser measurement system is shown as Figure 1.

The Gough-Stewart parallel robot has a fixture to fix the peg-hole relative position and orientation measuring tooling. The robot has a passive flexible wrist behind the fixture to solve the jamming question. The passive flexible wrist can compensate assembly errors. It could also reduce the robot’s control accuracy requirement.

The stereoscopic laser measurement system has 9 laser rangefinders. The front of the system is a peg-hole relative position and orientation measuring tooling whose size is smaller than the through-hole’s. The peg-hole relative position and orientation measuring tooling have two groups of laser measurement scanners, and each group has three laser measurement scanners uniformly distributed on the circular. The back of the system is a laser rangefinder anti-collision system, it has three laser rangefinders that can obtain the distance of the robot and the wallboard when the peg-hole relative position and orientation measuring tooling’s axis overlap with the axis of the through-hole. It can reduce the impact in the assembly process. When the distance is relative small, the robot will reduce its velocity. The robot’s stereoscopic laser measurement system is shown in Figure 2.
To use the system in the assemble process, we need the kinematics model of the peg-hole relative position and orientation measuring tooling.

3. Application strategy and kinematics model of stereoscopic laser measurement system
The front of the stereoscopic laser measurement system is a peg-hole relative position and orientation measuring tooling. As shown in Figure 3, we insert the peg-hole relative position and orientation measuring tooling into the through-hole. Then we can obtain the distance of the points where the laser measurement scanners are fixed on the wall of the through-hole. Then we can build the relationship between the present position/pose and the aim position/pose. We use the peg-hole relative position and orientation measuring tooling’s front center as the center of rotation, and rotate the tooling to the position and pose where its axis is parallel to the through-hole’s axis by the robot. Then we move the tooling to make its axis overlap with the axis of the through-hole’s. The control system will record the position and pose of the robot at this moment. Then the platform will get back to the origin. Then we replace the tooling by the sleeves. After that the control system can make the robot move to the place points which are remembered, and the assemble process are completed.

Figure 3. Schematic diagram of the stereoscopic laser measurement system

We build the coordinate systems as follows: the axis of the peg-hole relative position and orientation measuring tooling is the Z axis, the extension line from the point where the right above laser measurement scanners fixed to the Z axis is the X axis. By the right-hand rule the Y axis is determined. \( r \) is the radius of peg-hole relative position and orientation measuring tooling’s front center as the center of rotation, and \( l \) is the distance between the two groups scanners, \( l_1 \) is the distance between the center of mass of the platform and the tip of the tooling, \( l_2 \) is the distance between the top platform and the tooling’s bottom. \( c_i \) is the point where scanners fixed, \( e_i \) is the distance between the points where the scanners are fixed and the wall of through holes, \( d_i \) is the point on the wall of the through hole where the laser radiate.

\[
\begin{align*}
e_1 &= (-\frac{1}{2}r, \frac{\sqrt{3}}{2}r, 0), \quad e_2 = (-\frac{1}{2}r, -\frac{\sqrt{3}}{2}r, 0), \quad e_3 = (r,0,0), \quad e_4 = (-\frac{1}{2}r, \frac{\sqrt{3}}{2}r, l), \quad e_5 = (-\frac{1}{2}r, -\frac{\sqrt{3}}{2}r, l), \\
\end{align*}
\]

\( c_i \) is the point where scanners fixed.

\[d_i = (0,0,l)\]

Vector \( n \) is the toolings’s direction vector: \( n = (0,0,l) \).

\[
\begin{align*}
d_1 &= (-\frac{1}{2}r - \frac{1}{2}e_1 + \frac{\sqrt{3}}{2}e_1, 0), \quad d_2 = (-\frac{1}{2}r - \frac{1}{2}e_2 - \frac{\sqrt{3}}{2}e_2, 0), \quad d_3 = (0,0,l) \\
\end{align*}
\]

\[
\begin{align*}
d_4 &= (-\frac{1}{2}r - \frac{1}{2}e_3 + \frac{\sqrt{3}}{2}e_3, l), \quad d_5 = (-\frac{1}{2}r - \frac{1}{2}e_4 - \frac{\sqrt{3}}{2}e_4, l), \quad d_6 = (0,0,l) \\
\end{align*}
\]

Vector \( m = (m_x, m_y, m_z) \) is the direction vector of sleeve’s axis, then:

\[
m_x = \frac{1}{6} (2e_6 - 2e_3 + e_1 - e_4 + e_2 - e_5)
\]
\[ m_y = \frac{\sqrt{3}}{6} (e_4 - e_1 + e_2 - e_3), \]
\[ m_z = l \]

Straight line from point \( O \), the length of the line is as same as \( l \). The endpoint of this line is \( C = (x_c, y_c, z_c) \).

\[ |C|^2 = x_c^2 + y_c^2 + z_c^2 = l^2 \quad (1) \]

These two lines are parallel, then:

\[
\begin{align*}
x_c &= \frac{y_c}{m_y} = \frac{z_c}{m_z} = \lambda \\
\beta \gamma - \alpha \delta + s \alpha \beta \gamma &= \frac{\lambda m_z}{l} \\
\beta \gamma + \alpha \delta + s \alpha \beta \gamma &= \frac{\lambda m_y}{l} \\
-s \beta + \alpha \delta + c \alpha \beta &= \lambda
\end{align*}
\]

The origin of the platform \( \dot{O}_b \)'s coordinates in the peg-hole relative position and orientation measuring tooling’s coordinate system is:

\[ \dot{O}_b = (-l_1 + r, 0, l_2) \]

Then we can obtain the relationship of the top plate of the platform shown as follow:

\[
\begin{align*}
x &= (1 - c \beta \gamma)(l_2 + r) + (s \alpha \gamma + c \alpha \beta \gamma - 1)l_1 + x_m - m_x, \\
y &= (1 - c \beta \gamma)(l_2 + r) + (s \alpha \gamma + c \alpha \beta \gamma - 1)l_1 + y_m - m_y, \\
z &= (1 + s \beta)(l_2 + r) + (c \alpha \beta - 1)l_1 + z_m - m_z
\end{align*}
\]

Then we can obtain the transformation of coordinates caused by \( \dot{q}_c \).

\[
\begin{align*}
\dot{c}_T &= \begin{bmatrix}
\dot{c}_R \dot{A} R & \dot{c} R \dot{A} p_{org} + \dot{c} P_{org} \\
0 & 0 & 0 & 1
\end{bmatrix}
\end{align*}
\]

\( \dot{c}_T, \dot{A} T \) are the transformation caused by \( \dot{q}_b , \dot{q}_s \).

Then the closed-loop workspace control of the passive flexible printing machine’s sleeves assembly robot is realized. The robot can make the sleeves axis overlap with the axis of the through-hole. Then the robot moves the sleeve to the rectilinear motion along the axis of the through-hole. The passive flexible wrist can compensate assembly errors. The laser rangefinder anti-collision system ease the impact in this process[6,7].

4. **Sliding mode controller of passive flexible printing machine’s sleeves assembly robot**

The standard form of the dynamic model is shown as follows[8,9,10]:

\[
M(q)\ddot{q} + C(q, \dot{q})\dot{q} + G(q) = J_p \ddot{\tau}
\]

\( M(q) \) —Inertial matrix, which can be obtained by the expression of kinetic energy \( K(q, \dot{q}) \).
\( G(q) \) — Gravity term, which can be obtained by the partial derivative of the potential energy
\( G(p) = \frac{\partial P(q)}{\partial q} \).

\( C(q, \dot{q}) \dot{q} \) — Centripetal force and Coriolis force.

The dynamic model can be translated to this form [11,12,13]
\[
\begin{align*}
\ddot{q} &= A(q) + C(q)J^T \tau = A(q) + B(q)u \\
\tau &= (\tau_1, \tau_2, \tau_3, \tau_4, \tau_5, \tau_6) \quad q = (x, y, z, \alpha, \beta, \gamma) \\
&\quad \quad \tau = (u_1, u_2, u_3, u_4, u_5, u_6)
\end{align*}
\] (7)

Then the dynamic model can be translated to the following form:
\[
\begin{align*}
\ddot{x} &= A_1(q) + B_1(q)u \\
\ddot{y} &= A_2(q) + B_2(q)u \\
\ddot{z} &= A_3(q) + B_3(q)u \\
\ddot{\alpha} &= A_4(q) + B_4(q)u \\
\ddot{\beta} &= A_5(q) + B_5(q)u \\
\ddot{\gamma} &= A_6(q) + B_6(q)u
\end{align*}
\] (8)

The controller is designed for the 6 coordinates control in the Cartesian space. The controller controls the 6-dof platform’s pose and position. When the platform reaches the aim pose and position, the velocity of the 6 degrees of freedom is 0, the angles arrive at \( \alpha = \alpha_e, \beta = \beta_e, \gamma = \gamma_e \), and the displacements reach \( x = x_e, y = \gamma_e, z = \gamma_e \). Six sliding surfaces are designed for the six state variables. These six sliding surfaces constitute a vector sliding surface as follows
\[
S = C(q - q_e) + D\dot{q}
\] (9)

The Lyapunov function is constructed as
\[
V = S^T S / 2 = (S_1^2 + S_2^2 + S_3^2 + S_4^2 + S_5^2 + S_6^2) / 2
\] (10)

The exponential reaching law is adopted such that
\[
\dot{S} = -\varepsilon \text{sgn}(S)
\] (11)

This means
\[
\dot{S}_n = -\varepsilon \text{sgn}(S_n), n = 1, 2, \ldots 6
\] (12)

\( \varepsilon > 0, k > 0 \)
\[
\dot{S} = C\dot{q} + D\ddot{q} = -\varepsilon \text{sgn}(S)
\]

Plugging \( \dot{q} = A(q) + B(q)u \) into the above equation, we can obtain that
\[
C\dot{q} + D(A(q) + B(q)u) = -\varepsilon \text{sgn}(S)
\] (13)
Solving the above equation, we can obtain
\[ u = B^{-1}(q)(D^{-1}(-\varepsilon \text{sgn}(S) - C\dot{q}) - A(q)) \]  
(14)

The optimal values of the sliding model controller’s parameters $\alpha, \beta, c$ are obtained by the genetic algorithm using real number coding[14,15].

The fitness function is chosen as $F = 1/J$

\[ J = W_1(\theta - \dot{\theta}) + W_2\dot{\hat{\theta}} + W_3\ddot{\hat{\theta}} \]  
(15)

$W_1, W_2, W_3$ are weighs, according to the control aims we set them as: $W_1 = \frac{1}{3}, W_2 = \frac{1}{3}, W_3 = \frac{1}{3}$. The mutation rate is 0.05, and the crossover rate is 0.5, and the generation number is 20. The simulation result is shown as Figure 4.

![Figure 4. Simulation result of parameter optimization](image)

The optimized values are obtained as $\alpha = 3.1410, \beta = 1.0009, c = 0.5704$.

5. Simulation

The control algorithm is simulated by Matlab, we set the aim as $\alpha = 0.1, \beta = 0.1, \gamma = 0.1, x = 0.1, y = 0.1, z = 0.1$. The results are shown in Figure 5-10.

![Figure 5. the curve of the relationship between the rotation parameter $\alpha$ (Vertical axis) and time(horiziontal axis)](image)

![Figure 6. the curve of the relationship between the rotation parameter $\beta$ (Vertical axis) and time (horiziontal axis)](image)
This simulation results show that the system state variables, i.e., the position and the pose of the top plate of the parallel robot can reach their desired target in a short time, and these results prove the validity of the dynamic model and the stability of the sliding mode control system.

6. Conclusion
In this paper, a passive flexible printing machine’s sleeves assembly robot is designed. The model of the passive flexible printing machine’s sleeves assembly robot’s stereoscopic laser measurement system which is used in the Gough-Stewart parallel robot is established. Then the closed-loop workspace control of the Gough-Stewart parallel robot can be realized. The robot has a passive flexible wrist behind the fixture to solve the jamming question. The passive flexible wrist can compensate the assembly errors as well as reduce the robot’s control accuracy requirement. The robot has a laser rangefinder anti-collision system which eases the impact in the assembly process. A sliding mode controller is designed for the control of this robot. The parameters of the controller are then optimized. The results of Matlab simulations prove the validity of the dynamic model and the stability of the sliding mode control system. This work is very important for high precision assembly parallel robot used in the printing industry and has wide application prospect in precise assembly and precise operation fields[16,17].
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