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Research Article

Pulse Point Position Tracking-control and Simulation based on 4-DOF Pulse Diagnosis Robot

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ABSTRACT

Pulse diagnosis has been proved to be of great practical value in the past dynasties. The key of high-quality pulse diagnosis is how to dynamically adjust the vertical relationship between the pulse and the sensor dynamically. The design adopts a four degree of freedom manipulator combined with a matrix sensor to form a diagnostic robot, so as to achieve rapid adjustment and keep the diagnostic pulse sensor perpendicular to the pulse. As a result, kinematics analysis and simulations can be performed and the feasibility of the results can be showed as well.

1. INTRODUCTION

For more than 2000 years, pulse diagnosis has played a very important role in the practice of diagnosis and treatment [1]. The theory of pulse diagnosis has been applied through the physiology, pathology, diagnosis, treatment and other aspects of Chinese medicine. The quality of pulse diagnosis is related to the effect of "syndrome differentiation and treatment" in all clinical departments, which is of great significance to the guidance of Traditional Chinese Medicine (TCM) theory in medical practice. Since the 1960s, with the development of modern science and technology, many domestic and foreign researchers have been committed to promoting the modernization of TCM pulse diagnosis and expected to improve the situation of "difficult to identify" by using modern medical instruments [2].

2. COMPOSITION OF THE PULSE DIAGNOSIS ROBOT

The key of high-quality pulse diagnosis is how to dynamically adjust the vertical relationship between the pulse and the sensor (only the vertical relation between sensor and pulse can guarantee the accuracy of pulse diagnosis). The robot is made up of a Four Degree of Freedom (4-DOF) manipulator and a pulse diagnosis sensor matrix, as shown in Figures 1 and 2.

3. KINEMATICS OF THE 4-DOF MANIPULATOR

According to the standard D–H parameter table method, the coordinate system of the manipulators is shown in Figure 3. The coordinate system 1 is coinciding with the origin of the base coordinate system 0, and the origin of the coordinate system of the pulse sensor coincides with the origin of the wrist coordinate system. The D–H parameters are obtained as shown in Table 1.

The length of the connecting rod is a_i: the distance from the Z_{i-1} axis to the Z_i axis is moved along the X_i axis. The angle of the connecting rod is α_i: the angle of rotation of the Z_{i-1} axis to the Z_i axis around the X_i axis. Connecting rod offset d_i: along the Z_{i-1} axis, the distance between the X_{i-1} axis and the X_i axis is moved. Joint angle θ_i: around the Z_{i-1} axis, rotate the X_{i-1} axis to the angle of the X_i axis.

3.1. Forward Kinematics of the Manipulator

According to the standard D–H parameter method, the general equation of the link homogeneous transformation matrix is [Equation (1)]:

$$ {}^{i-1}_{\ i}T = \begin{bmatrix} c\theta_i & -c\alpha_i s\theta_i & s\alpha_i s\theta_i & a_i c\theta_i \\ s\theta_i & c\alpha_i c\theta_i & -s\alpha_i c\theta_i & a_i s\theta_i \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1} $$

where, c = cos, s = sin.

From Equation (1) and the established D–H parameter table, the homogeneous transformation matrix equation of each adjacent joint can be obtained [Equation (2)]:

$$ {}^{0}_{4}T = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\,{}^{3}_{4}T = \begin{bmatrix} c_1c_{234} & -c_1s_{234} & -s_1 & a_3\,c_1c_{23} + a_2\,c_1c_2 \\ s_1c_{234} & -s_1s_{234} & c_1 & a_3\,s_1c_{23} + a_2\,s_1c_2 \\ -s_{234} & -c_{234} & 0 & -a_3\,s_{23} - a_2\,s_2 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2} $$

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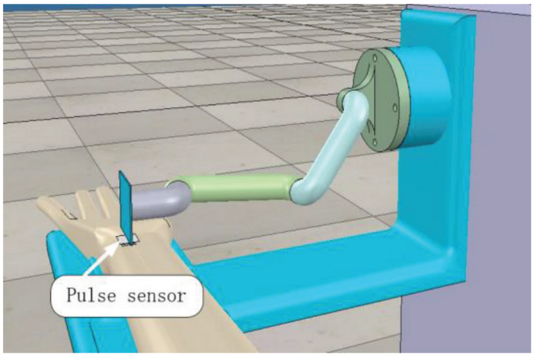

Figure 1 | The robot which is made up of a 4-DOF manipulator and a pulse diagnosis sensor matrix.

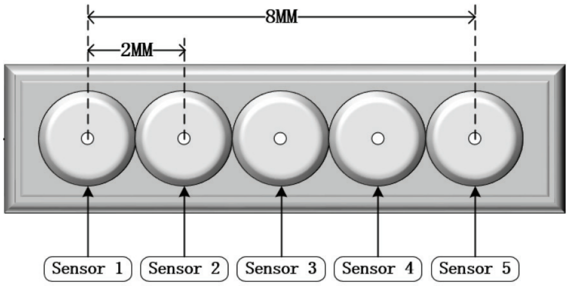

Figure 2 | The pulse diagnosis matrix sensor is composed of five pressure sensors in a row. The matrix sensors are fitted on the end of the manipulators.

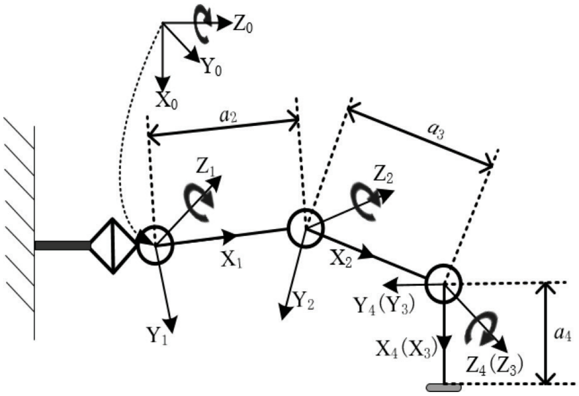

Figure 3 | Manipulators structure and its coordinate systems of joints.

Table 1 | Parameters of D–H

i	α_i	a_i	d_i	θ_i
1	$-\pi/2$	0	0	θ_1
2	0	a_2	0	θ_2
3	0	a_3	0	θ_3
4	0	0	0	θ_4

where, $c_{234} = \cos(\theta_2 + \theta_3 + \theta_4)$, and the others can be replaced in the same way.

3.2. Inverse Kinematics of the Manipulator

The common methods of inverse kinematics solving mainly include algebraic method and geometric method [3]. Compared with the algebraic method, the geometric method has advantages of simple calculation and avoids the discussion of range of values by using the constraint relationship between the joints [4]. In this paper, the inverse kinematics of the 4-DOF pulse diagnosis robot is solved by geometric method [5].

Before solving the kinematics with the geometric method, the first rule is that θ_1 has rotated to a position parallel to the target position. According to the establishment rule of D–H, the schematic diagram of the plane based on the geometric method can be obtained as shown in Figure 4.

Assuming that the position coordinates (x_p, y_p) of the end point P and the azimuth angle γ of the point P are known. According to the geometric relation, Equations (3) and (4) can be drawn that:

$$x_{o3} = x_p - a_4 \cos\gamma \tag{3}$$

$$y_{o3} = y_p - a_4 \sin\gamma \tag{4}$$

By using the cosine theorem in $\Delta o_1 o_2 o_3$, Equations (5), (6) and (7) can be drawn that:

$$\theta_3 = \frac{\arccos\left(x_{o3}^2 + y_{o3}^2 - a_2^2 - a_3^2\right)}{2a_2 a_3} \tag{5}$$

$$\theta_2 = \arctan\left(\frac{y_{o3}}{x_{o3}}\right) \pm \frac{x_{o3}^2 + y_{o3}^2 + a_2^2 + a_3^2}{2a_2\sqrt{x_{o3}^2 + y_{o3}^2}} \tag{6}$$

$$\theta_4 = \gamma - \theta_2 - \theta_3 \tag{7}$$

4. MODELING AND SIMULATION

4.1. Modeling in V-REP

The robot model is established in Virtual Robot Experimentation Platform (V-REP) as shown in Figure 1. Setting the parameters of the robot model: $a_2 = 0.08$ m, $a_3 = 0.1$ m, $a_1 = -90°$. The initial posture of the robot can be calculated by assigning the angle of each joint to 0° as shown in Equation (8):

$${}^{0}_{4}T_{\text{initial position}} = \begin{bmatrix} 1 & 0 & 0 & 0.18 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8}$$

This data we got is identical to the data obtained in the V-REP simulation.

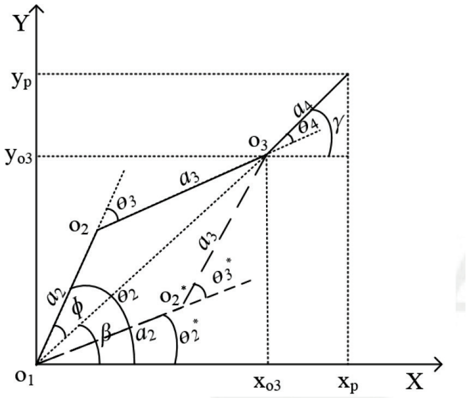

Figure 4 | Geometric relationship of three joints in *XY*-plane.

The pulse diagnosis matrix sensor adopted in this simulation is composed of five pressure sensors in a row, which is shown in Figure 5a. Each point of the sensors can sense the corresponding pulse. In the simulation, the pulse sensor is exposed to the pulse at different positions to obtain the simulation data. By analyzing the data, the relative pose of sensors with respect to the pulse can be drawn, which will be used to adjust the posture of the joints.

Pulse model is also established with similar dynamic properties to the human pulse, as shown in Figure 5b. The width of the pulse model is set as 3.6 × 3.6 mm^2 according to average adult's size.

4.2. Pulse Detect Simulation

In the V-REP simulation, the pulse beat curve at different positions is measured with changing the relative position of the pulse matrix sensor relative to the pulse model. When the first sensor of the pulse matrix sensor is aligned with the pulse model, the pulse curve obtained is shown in Figure 6. It is quite obvious from the figure that the value of sensor 1 is the largest, and the center of the pulse matrix sensor is not perpendicular to the pulse model.

When the third sensor of the pulse matrix sensor is aligned with the pulse model, the pulse curve is shown in Figure 7. It is clear that the intensity of sensors 2–4 are same to each other. When the curve similar to Figure 8 is obtained, the pulse matrix sensor can be considered as perpendicular to the pulse, and the third sensor is aligned with the pulse.

4.3. Pulse pose tracking control simulation

Figure 8 shows that the posture curves of the pulse sensors. The values changes related to the relative position between sensors and the pulse, until the matrix sensor is perpendicular to the pulse, and sensor 3 is aligned with the pulse. Figure 9 shows that the joints were adjusted to move from sensor 5 to sensor 3, and finally sensor 3 is perpendicular to the pulse as expected.

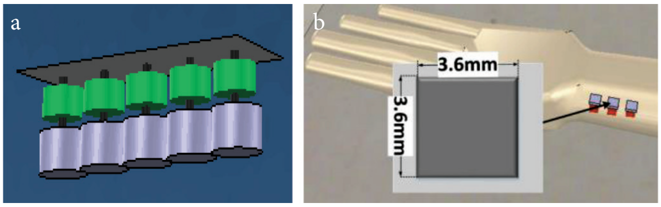

Figure 5 | Pulse sensor and pulse model in V-REP. (a) Pulse sensor model. (b) Pulse model.

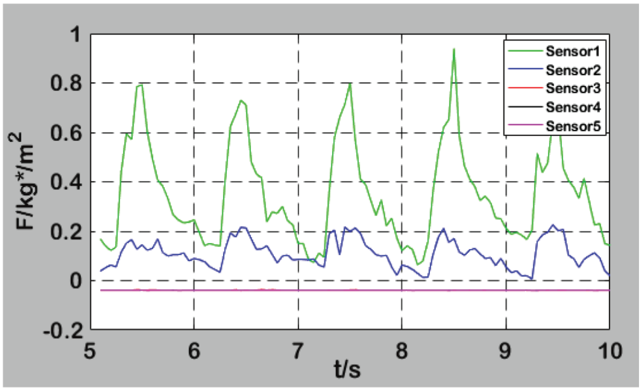

Figure 6 | The first sensor is aligned with the pulse.

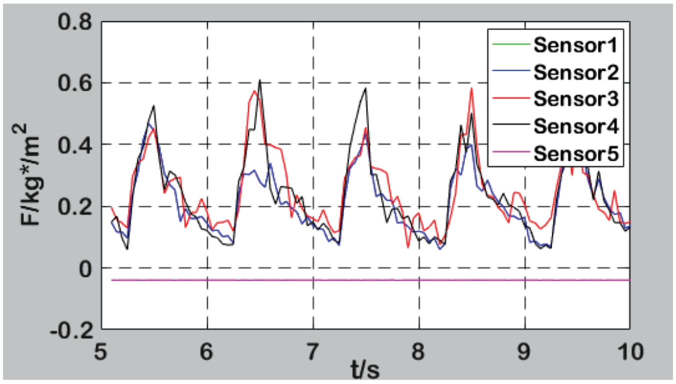

Figure 7 | Beating curves of sensors when the third sensor is aligned with the pulse.

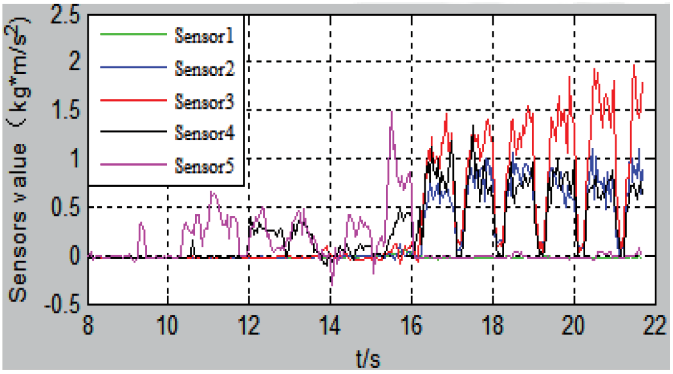

Figure 8 | Curve change of each sensor point during pulse pose tracking control.

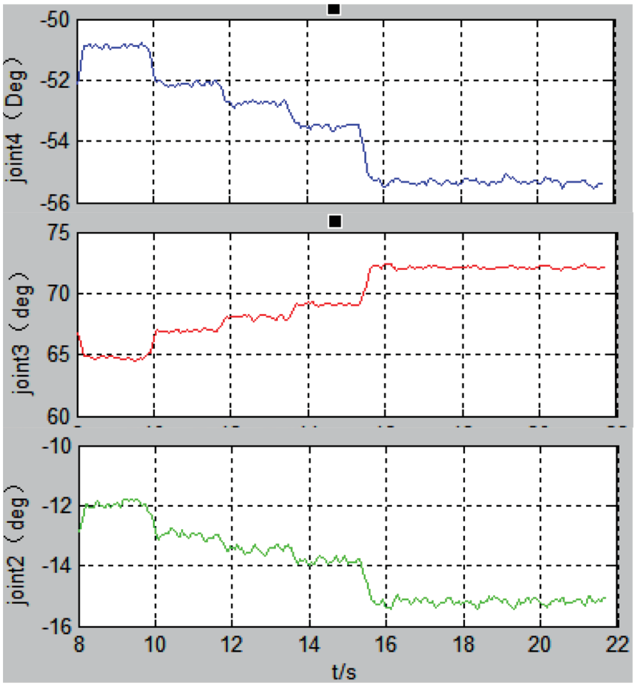

Figure 9 | Curve change of θ_2, θ_3, and θ_4 during pulse pose following control.

5. CONCLUSION

In this paper, a diagnostic robot with a 4-DOF manipulator and a pulse diagnosis matrix sensor was introduced. The kinematic was analyzed and the model was simulated on V-REP. The simulation results show that the proposed robot can find the position of pulse and adjust the joints to the posture as expected according to the feedback information from the pulse diagnosis matrix sensor.

CONFLICTS OF INTEREST

The authors declare they have no conflicts of interest.

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