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# Space Trajectory Planning of Electric Robot Based on Unscented Kalman Filter

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**Abstract**

Because the motion state of electric robot cannot be determined, the result of planning has the phenomenon of moving collision in many environments. Therefore, a space trajectory planning method of electric robot based on Unscented Kalman filter is proposed. Through the working environment of electric robot, the kinematics and dynamics of electric robot are analyzed from the aspects of position, attitude and pose. According to the analysis results, the space trajectory constraint of electric robot is set, and the real-time motion state of electric robot is detected by using Unscented Kalman filter technology. The space trajectory planning of electric robot is completed by smoothing the space trajectory Stroke. The experimental results show that the collision times of the robot are reduced in both fault free and multi fault environments, which improves the accuracy of space trajectory planning and shortens the moving time of the robot.



*Keywords:* Kalman filter; Electric robot; Space track; Mobile trajectory planning;

## 1. Introduction

Robot is a kind of machine which can automatically perform work, including all the machines that simulate human behavior or thoughts and other creatures. In modern industry, robot is a kind of man-made machine that can automatically run tasks, which is used to replace or assist human work. Generally, it is an electromechanical device controlled by computer programs or electronic circuits. Based on the application environment, Chinese roboticists divide robots into two categories: industrial robots and special robots. The so-called industrial robot is a multi-joint manipulator or multi degree of freedom robot facing the industrial field. In addition to industrial robots, special robots are all kinds of advanced robots that are used in non-manufacturing industries and serve human beings [1]. International roboticists divide robots into two categories based on application environment: industrial robots in manufacturing environment and service and humanoid robots in non-manufacturing environment, which is consistent with China's classification. Electric robot is a kind of industrial robot, which is mainly responsible for the inspection of power equipment in substations or other power systems. The working process of the robot is to perform specific motion to meet the specific work needs, and trajectory planning is an important part of the robot's work, which is based on the task needs and the robot's own motion ability. The path planning method can be divided into two aspects: for the mobile robot, the path planning which means to move is preferred, for example, what kind of path the mobile robot will follow when the robot has a map or does not have a map; for the industrial robot, it means two directions, the curve path of the end of the mechanical arm, or the position of the operating arm in the movement process; the curve outline of displacement, velocity and acceleration. For the same task, its motion track may not be unique, different tracks have different operation indexes, such as running time, running energy consumption, running stability [2]. Based on realizing the requirements of motion function, trajectory planning can optimize these indexes to obtain a motion scheme with shorter time, lower energy consumption and less impact.

Researchers at home and abroad have done a lot of research work on the path planning methods of robots. The related researchers abroad have proposed the random landmark method and the flexible polyhedron search algorithm, which are very effective in solving the path planning problems of multi DOF robots. Chinese scholars have also proposed a sub group optimization algorithm, which regards a single robot as a particle to achieve optimal search. This method is used for multi robot collaborative path planning [3]. However, the obstacle avoidance problem of robot movement is not considered in the existing robot space trajectory planning methods, so the robot will encounter collision phenomenon when it moves according to the planned path, and the number of collisions is more, which will not only affect the working efficiency and results of the electric robot, but also shorten the service life of the electric robot.

After a long time of research and analysis, it is found that the problem of high collision rate in the traditional space trajectory planning of electric robot is mainly due to the fact that the real-time motion state of the robot is not considered in the planning process, so the Unscented Kalman filter technology is applied to the space trajectory planning of the

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robot, and the optimal trajectory planning method is obtained. Kalman filter is an algorithm that uses the linear system state equation to estimate the system state optimally through the system input and output observation data. Since the observation data includes the influence of noise and interference in the system, the optimal estimation can also be regarded as the filtering process [4]. The unscented Kalman filter is different from the extended Kalman filter, as it is an approximation of the probability density distribution. Because the higher-order terms are not ignored, the accuracy is higher when solving the nonlinearity. The core idea of Unscented Kalman filter Transformation: approximate a probability distribution ratio to approximate any nonlinear function or nonlinear transformation. Through the reference of Unscented Kalman filter technology, the collision free path planning in three-dimensional space is completed to ensure that the robot can better complete the work of the power operation production line.

## 2. Space trajectory planning of electric robot based on Unscented Kalman filter

The purpose of spatial trajectory planning of electric robot is to realize the non-collision inspection of electric robot. Therefore, in this spatial trajectory planning, it is necessary to optimize the trajectory from two aspects, namely, the inspection movement of robot and the spatial movement change of robot arm and joint [5].

### *2.1. Establish working environment of electric robot*

The three-dimensional position parameters of the target are obtained by the trigonometry and parallax. On the premise of knowing the relative position relationship between the two cameras and the internal parameters of the camera, only the parallax of the features of the object needs to be known to obtain the spatial coordinates or dimensions of the object [6]. The environment image coordinate system is shown in Figure 1:

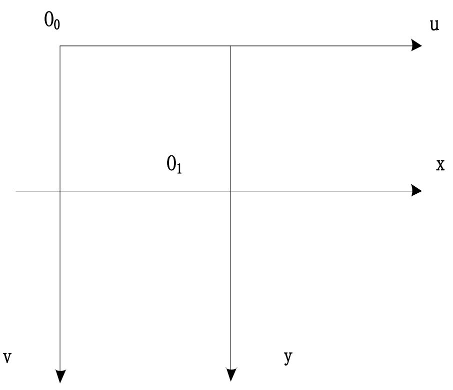


**Figure 1.** Environment image coordinate system

According to Fig. 1, $u-v-o$ rectangular coordinate system is defined in the obtained picture, and the coordinates of its pixel points refer to the rows and columns in the sequence, so $(u,v)$ is the coordinates of the image coordinate system in pixels.

Since $(u,v)$ only represents the number of columns and rows in which the pixel is located, to describe the pixel position in the image, a coordinate system with physical equivalent meaning needs to be established. Therefore, a coordinate system parallel to the $(u,v)$ -axis is established, and the x-axis corresponds to the $u$ -axis, and the y-axis corresponds to the $v$ -axis [7]. Where $(u,v)$ is the coordinate in pixels and $(x,y)$ is the image coordinate in millimeters under the image coordinate system. Then the position of any pixel of the image has the following corresponding relationship in the two coordinate systems:

$$\begin{cases} u = \dfrac{x}{dx} + u_0 \\ v = \dfrac{y}{dy} + v_0 \end{cases} \tag{1}$$

where $(u_0, v_0)$ represents the position of the coincidence point between the optical axis of the camera and the image plane in the xy coordinate system. By transforming the above formula into the form of homogeneous coordinates and matrix, it can be concluded that:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \dfrac{1}{dx} & 0 & u_0 \\ 0 & \dfrac{1}{dy} & v_0 \\ z & 0 & 1 \end{bmatrix} \tag{2}$$

In the formula, $z$ represents the state vector of the matrix.

The inversion is as follows:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} dx & 0 & -u_0 dx \\ 0 & dy & -v_0 dy \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \tag{3}$$

When the camera is shooting an object, the real coordinates of the object and the image coordinates obtained by shooting have a unique projection relationship [8]. On the premise of knowing the geometric structure parameters of the camera, it can be obtained by the similar triangle principle:

$$\begin{cases} u = \dfrac{f}{-z_e} x_e \\ v = \dfrac{f}{-z_e} y_e \end{cases} \tag{4}$$

where $-z_e$ is the depth and $\dfrac{f}{-z_e}$ is the scale ratio. Perspective projection can only ensure the correspondence between image points one by one and projection lines, that is, the same point on the image corresponds to a series of points on the projection line. It is obvious that the depth information of spatial points is lost in this process, which just shows that the determination of 3D objects requires two or more cameras [9].

The position of 3D space point in camera coordinate system can be obtained by image coordinate calculation, namely:

$$\begin{cases} x_e = \dfrac{f}{f+w}u \\ y_e = \dfrac{f}{f+w}v \\ z_e = \dfrac{f^2}{f+w} \end{cases} \Rightarrow \begin{cases} x_e = \dfrac{-z_e}{f}u \\ y_e = \dfrac{-z_e}{f}v \\ z_e = z_e \end{cases} \quad (5)$$

where $z_e$ is the parameter related to the true distance between the subject and the camera. Thus, the mapping transformation from 3D environment image to 2D image is realized.

*2.2. Kinematic analysis of robot*

The robot is generally composed of actuator, driving device, detection device, control system and complex machinery, among which the actuator is the robot body, the motion pairs are often called joints, and the number of joints is usually the number of degrees of freedom of the robot. The relevant parts of the robot body are often called base, waist, arm, wrist, hand and walking part [10]. The driving device is the mechanism that drives the actuator to move. According to the command signal sent by the control system, the robot moves with the help of power components. It inputs electrical signal and outputs line and angle displacement. The detection device is a real-time detection of the robot's movement and working conditions. It feeds back to the control system according to the needs. After comparing with the set information, the actuator is adjusted to ensure that the robot's action meets the predetermined requirements [11]. The control system is centralized control, that is, all the control of the robot is completed by a microcomputer. Based on the establishment of the working environment of the electric robot, the kinematics analysis of the robot is realized from the position, posture and pose of the robot.

*2.2.1. Robot position*

The position description of a point P in the space is shown in Figure 2. Set the point P in the built rectangular reference coordinate system a.

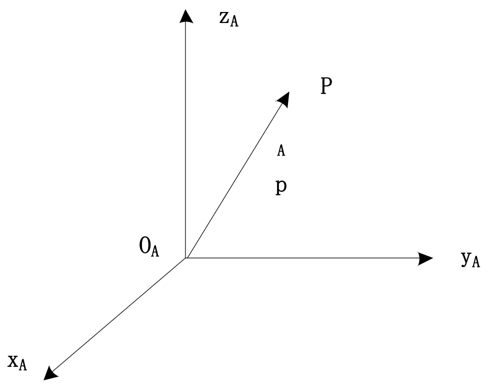


**Figure 2.** Location description

Its coordinates can be expressed as a matrix of 3 x 1:

$$^{A}P = \begin{bmatrix} p_x & p_y & p_z \end{bmatrix}^T \quad (6)$$

*2.2.2. Robot posture*

Determine the pose of the robot in the three-dimensional space, establish the rectangular coordinate system B, and place it on the object, where $^{A}R_B$ represents the rotation matrix, and the elements in the matrix represent the direction cosine of each unit vector in the coordinate system B and the unit vector corresponding to the reference coordinate system a:

$$^{A}R_B = \begin{bmatrix} ^{A}x_B & ^{A}y_B & ^{A}z_B \end{bmatrix} = \begin{bmatrix} r_{11} & r_{21} & r_{31} \\ r_{21} & r_{22} & r_{32} \\ r_{31} & r_{23} & r_{33} \end{bmatrix} \quad (7)$$

The result of formula (7) is the attitude of electric robot B in coordinate system a.

*2.2.3. Posture of robot*

By synthesizing the position matrix in coordinate system, a described in equation 6 and the attitude transformation matrix described in equation 7, the position and attitude of a rigid body in the coordinate system can be described. The transformation formula is as follows:

$$\{B\} = \{ ^{A}_{B}R \quad ^{A}p_{Bo} \} \quad (8)$$

where $^{A}p_{Bo}$ represents the position matrix of the origin of coordinate system B in reference coordinate system [12].

*2.2.4. Forward kinematics of robot*

When the angular velocity of the two driving wheels is known, set the left and right angular velocities of the electric robot as $\dot{q}_r$ and $\dot{q}_l$ respectively, so as to find out the moving track of the electric mobile robot:

$$\begin{bmatrix} x_R \\ y_R \\ \theta \end{bmatrix} = \begin{bmatrix} r\cos(\theta+\alpha) \\ r\sin(\theta+\alpha) \\ \dfrac{r}{L} \end{bmatrix} \begin{bmatrix} q_r \\ q_l \end{bmatrix} \quad (9)$$

where, $\theta$ is the angle of rotation of the robot after time t, and $\alpha$ is the initial attitude of the robot.

*2.3. Robot dynamics analysis*

The electric robot system is a multivariable and nonlinear kinematic coupling system. In order to further study the dynamics related problems, it is necessary to establish the dynamics model of KUKA robot [13]. The definition of Lagrangian function L is the difference between the kinetic energy k and potential energy P of the system, namely:

$$L = K - P \quad (10)$$

where the difference between K and P is independent of the coordinate system position. The dynamic state equation of electric robot can be expressed by Lagrangian function L as follows:

$$F_i = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} \quad (11)$$

where, $q_i$ is the generalized coordinate selected by the robot, $\dot{q}_i$ is the generalized speed, $F_i$ is the force or moment applied on the ith coordinate, and n is the number of connecting rods. The kinetic energy of connecting rod i is:

$$K_i = \int_i dK_i = \frac{1}{2} tr\left[\sum_{j=1}^{i}\sum_{k=1}^{i} \frac{\partial T_i}{\partial q_i} I_i \frac{\partial T^T{}_i}{\partial q_j} \dot{q}_j \dot{q}_k\right] \quad (12)$$

where $I_i$ is the pseudo inertia matrix [14]. The total kinetic energy of the robot system can be expressed as:

$$K_i = K + K_a = \int_i dK_i = \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{i}\sum_{k=1}^{i}\left(\frac{\partial T_i}{\partial q_i} I_i \frac{\partial T^T{}_i}{\partial q_i}\right)\dot{q}_j \dot{q}_k + \frac{1}{2}\sum_{i=1}^{n} I_i \dot{q}_i^2 \quad (13)$$

According to the potential energy of particle DM at any position on the connecting rod, the dynamic equation of n-joint electric robot system is obtained as follows:

$$dP_i = -dmg^{T0}r = -g^T T_i^i rdm \quad (14)$$

*2.4. Set the space trajectory constraint of electric robot*

In order to study the working space of the manipulator, it is necessary to determine the range of rotation of each joint of the manipulator. For UR5 manipulator, although the range of the motor to allow the joint angle to rotate is - 360 ° - + 360 ° at each joint of the manipulator, due to the design of the mechanical structure of the manipulator itself, there are conflicts (overlaps, intersections, etc.) between the links of the manipulator at some joint angle positions, so not all joints of the manipulator can be - 360 ° - + 360 ° in any case Turn in range [15]. It is an essential step to determine the motion range of each joint of the manipulator or find out the constraints of the motion range of each joint angle.

The conflicts between the connecting rods of the manipulator are mainly intersection and overlap. The study of the possibility of such conflicts between the connecting rods is equivalent to the study of the collision avoidance between the connecting rods [16]. The connecting rod of the mechanical arm can be regarded as different line segments. In order to prevent the collision between the connecting rods of the mechanical arm, and as long as the distance between these lines in space is skillfully proved to be greater than the sum of the radius of the corresponding two connecting rods, its mathematical expression can be expressed as follows:

$$d\left(l_i, l_j\right) > r_i + r_j \quad (15)$$

where, $l_i$ represents the segment corresponding to the manipulator link I, $d\left(l_i, l_j\right)$ represents the shortest distance between segment $l_i$ and $l_j$, $r_i$ represents the radius of the manipulator link corresponding to segment $l_i$, and $r_j$ is the known parameter of the manipulator [17]. Let the coordinates of the two endpoints of segment $l_i$ be $\left(x_1, y_1, z_1\right)$ and $\left(x_2, y_2, z_2\right)$, and the coordinates of the two endpoints corresponding to segment $l_j$ be $\left(x_3, y_3, z_3\right)$ and $\left(x_4, y_4, z_4\right)$. Let Q be any point on the connecting rod $l_i$ of the mechanical arm of the electric robot, then the coordinate $\left(Q_x, Q_y, Q_z\right)$ of Q can be expressed as:

$$\begin{cases} Q_x = x_1 + s\left(x_2 - x_1\right) \\ Q_y = y_1 + s\left(y_2 - y_1\right) \\ Q_z = z_1 + s\left(z_2 - z_1\right) \end{cases} \quad (16)$$

where s is the parameter. If W is any point on the connecting rod $l_j$, the coordinate of W can be obtained, and the parameter in W coordinate is t [18]. If the values of the parameters s and t obtained from this system of equations do not satisfy the conditions in formula (17), then the shortest distances from points $\left(x_1, y_1, z_1\right)$ to, $\left(x_2, y_2, z_2\right)$ to $l_j$, $\left(x_3, y_3, z_3\right)$ to $l_i$, and $\left(x_4, y_4, z_4\right)$ to $l_i$ can be obtained respectively.

$$\begin{cases} 0 \le s \le 1 \\ 0 \le t \le 1 \end{cases} \quad (17)$$

Then compare the four distances, the smallest of which is the shortest distance $d\left(l_i, l_j\right)$ between $l_i$ and $l_j$. The length and radius parameters of the connecting rod of the mechanical arm of the electric robot are shown in Table 1.

**Table 1.** Length and radius of connecting rod of mechanical arm of electric robot

| connecting rod i | length/mm | radius/mm |
|---|---|---|
| 1 | 89.159 | 60 |
| 2 | 425 | 54 |
| 3 | 392.25 | 40 |
| 4 | 93 | 45 |
| 5 | 94.65 | 45 |
| 6 | 82.3 | 45 |

Similarly, the range of joint angular motion of electric robot can be calculated, as shown in Table 2.

**Table 2.** movement angle range of each joint of mechanical arm

| Joint angle i | Minimum range of motion | Maximum angle of motion |
|---|---|---|
| 1 | -360° | 360° |
| 2 | -360° | 360° |
| 3 | -145° | 145° |
| 4 | -180° | 0° |
| 5 | -360° | 360° |
| 6 | -360° | 360° |

In practical engineering application, in order to ensure that the tool end can rotate freely and as much as possible, that is to say, when the sixth joint rotates, the tools and instruments at the end will not touch the mechanical arm itself, it is necessary to further limit the rotation range of the fourth and fifth joints [19].

*2.5. Real time motion detection of electric robot based on Unscented Kalman filter*

In order to achieve the purpose of research, this paper uses MATLAB software to obtain the waveform of the electric robot, which lays the foundation for the follow-up research. Figure 3 shows the waveform of the Unscented Kalman filter installed on the electric robot.

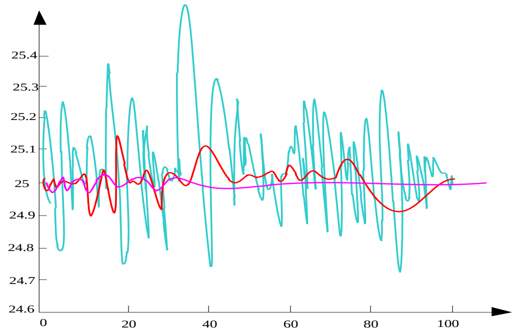


**Figure 3.** Waveform of Unscented Kalman filter

The initial state and variance are assumed to be:

$$\begin{cases} \hat{x}_0 = E(x_0) \\ P_0 = E\left[(x_0 - \hat{x}_0)(x_0 - \hat{x}_0)^T\right] \end{cases} \tag{18}$$

Then the initial state and variance of the whole dimension are respectively:

$$\begin{cases} \hat{x}_0^a = E(x_0^a) = \left[\hat{x}_0^T \quad 0 \quad 0\right]^T \\ P_0^a = E\left[(x_0^a - \hat{x}_0^a)(x_0^a - \hat{x}_0^a)^T\right] = \begin{bmatrix} P_0 & 0 & 0 \\ 0 & Q_0 & 0 \\ 0 & 0 & R_0 \end{bmatrix} \end{cases} \tag{19}$$

At k-1 moment, select $x_{k-1}^a$ from sigma point, to select the corresponding mean and variance weights. Through the nonlinear state equation, the mean and variance of the state prediction of electric robot can be obtained, and the state update and prediction of electric robot can be realized [20].

### *2.6. Space trajectory planning of electric robot*

In the working environment of electric robot, the space trajectory planning of electric robot is realized by generating path points from two aspects of joint and movement.

#### *2.6.1. Joint trajectory planning of electric robot*

In the process of electric robot motion, an interpolation function about the joint angle of the starting point and the ending point is used to describe the motion track, in which the joint angle of the starting point is known, and the joint angle of the ending point can be obtained through kinematic solution. There are many smoothing functions that can be used as joint interpolation functions. In order to realize the smooth movement of a single joint of the palletizing robot, the trajectory function must meet at least four constraints, namely the joint angle corresponding to the starting point and the ending point, the joint speed of the starting point and the ending point [21]. In the process of trajectory planning, the two adjacent path points are regarded as the starting point and the ending point respectively, then the interpolation function is determined, and finally the path points are smoothly connected [22-24].

#### *2.6.2. Path planning of electric robot avoiding obstacles*

Figure 4 is a schematic diagram of the path planning of the wheeled mobile robot with or without obstacles between two states, where $r_{o1}$ and $r_{o2}$ are the outer envelope radius of the obstacles, and $r_{os1}$ and $r_{os2}$ are the outer envelope radius after the safety dimension is increased.

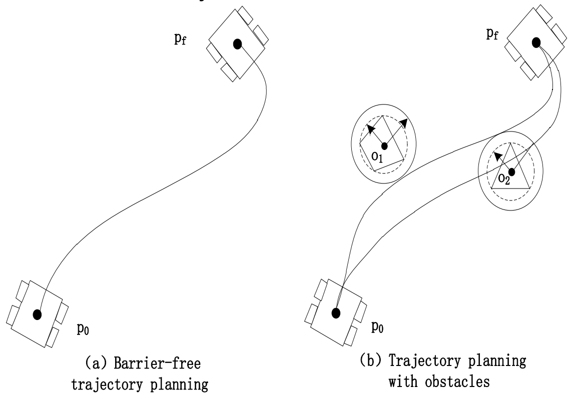


**Figure 4.** Path planning of electric robot with or without obstacles between two states

The solid line in Figure 4 (a) is the planning track between state $p_0$ and State $p_f$ when there is no obstacle, but when there are obstacles $O_1$ and $O_2$, the original planning track (dotted line in Figure 4 (b)) can no longer meet the requirements and needs to be re planned to meet the requirements. The re planned track curve after considering the size of obstacles and safe obstacle avoidance is realized in Figure 4 (b) [25].

#### *2.6.3. Planning track smoothing*

Planning trajectory curve is a kind of controllable free curve, which has geometric invariance, convexity and symmetry. The direction of the curve is only related to the vertex and sequence of the feature polygon, not to the selection of the current coordinate system [26]. Using this kind of curve to smooth the path of electric robot, the path sequence of the algorithm can be taken as the feature vertex directly without additional interpolation. At the same time, the smooth path enables the omnidirectional robot to avoid the time loss at the turning point of the path, and ensures the consistency of the robot's motion [27]. The smoothing results of the spatial planning trajectory of electric robot are shown in Figure 5.

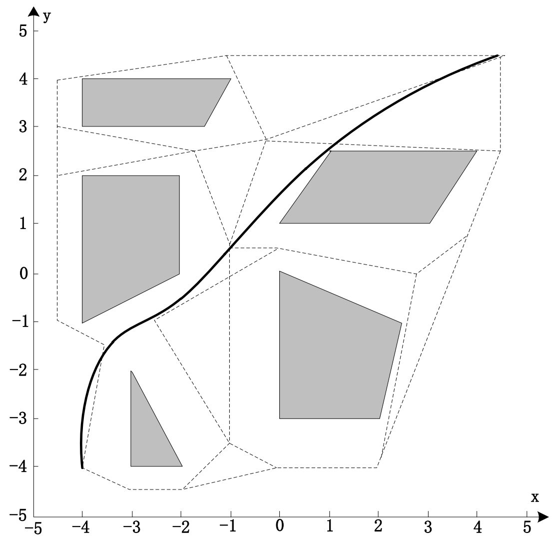


**Figure 5.** Smoothing results of spatial planning trajectory of electric robot

## 3. Experimental results and analysis

In order to prove the application performance of the designed space trajectory planning method of electric robot based on Unscented Kalman filter in actual electric power work, the space trajectory planning method of electric robot based on random landmark method, the space trajectory planning method of electric robot based on flexible polyhedron search algorithm and the space trajectory planning method of electric robot based on subgroup optimization algorithm are set up. As an experimental comparison method, under the same working environment, the corresponding planning results are obtained respectively, and the quantitative comparison results are obtained by counting the relevant parameters of the robot in the work.

### *3.1. Experimental platform*

The control system software of electric robot takes Visual Stiudio 2018 integrated development environment as the experimental platform, combines Microsoft's Windows XP based operating system, uses C + + language to program, selects SCARA electric robot as the research object, and uses the above four methods to plan its space trajectory. The SCARA electric robot is shown in Figure 6.

**Figure 6.** SCARA electric robot

The GUI of MATLAB is used to write the simulation interface of electric robot to display the pose matrix and Euler angle of the robot end actuator. The simulation platform of electric robot is shown in Figure 7.

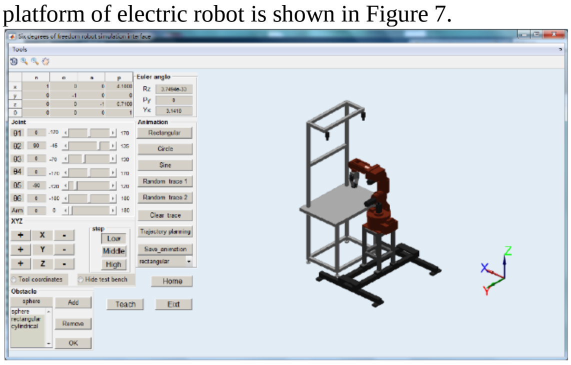

**Figure 7.** Simulation platform of electric robot

### *3.2. Parameter configuration*

Through the simulation platform of electric robot, when the kinematic characteristics of the target electric robot are determined, the parameters that are useful for the kinematic transformation of electric robot are selected for configuration, which do not include the length and rotation of all connecting rods. The specific configuration parameters of the experimental objects are shown in Table 3.

**Table 3.** Parameter configuration of electric robot

| Parameter exponent | Parameter value | Parameter representation |
|---|---|---|
| TRAFO6_KINCLASS | 1 | Type of kinematics used |
| TRAFO6_NUM_AXES | 5 | The joint axis / DOF of the target robot is 5 |
| TRAFO6_MAIN_AXES | 2 | Type of basic joint sequence you need to use joint order |
| TRAFO6_AXIS_SEQ | 6 | Whether the fourth joint and the first hand joint are parallel or reverse parallel to the basic joint of the last rotation type |
| TRAFO6_A4PAR | 1 | Type of kinematics used |
| TRAFO6_AXES_TYPE | [3,1,3,3,3] | The type of each joint of the robot, is it a moving joint or a rotating joint |
| TRAFO6_AXES_DIR | [2,1,3,4,5] | Whether the positive direction of each joint of the target robot rotates and moves in accordance with the mathematically predefined positive direction in the module |
| TRAFO6_MAMES | [1,1,1,1,1] | Angular deviation of mechanical zero point and mathematical zero point on each joint |
| TRAFO6_MAIN_LENGTH_AB | [0.0,0.0,0.0,0.0,0.0] | Connecting rod length in basic joint |
| TRAFO6_TIRORO_POS | [0.0,500.0] | The frame shift of the front T_IRO_RO of electric robot |
| TRAFO6_TIRORO_RPY | [0.0,0.0,500.0] | The frame rotation of the frontT_IRO_RO of electric robot |
| TRAFO6_TX3P3_POS | [0.0,0.0,90.0] | T_X3_P3 frame deviation in the middle of electric robot |
| TRAFO6_TX3P3_RPY | [300.0,0.0,200.0] | Rotation of T_X3_P3 frame in the middle of electric robot |
| … | … | … |

The controller with the same specification is installed on the configured electric robot. The purpose of installing the controller is to ensure that the electric robot can move according to the planned trajectory in the actual operation. Figure 8 shows the staff debugging the controller.

**Figure 8.** Schematic diagram of controller debugging

In this comparative experiment, the spatial trajectory and joint trajectory of electric robot are tested respectively, and the collision times, path length and movement time of different planning results are compared in different environments

where, P is the position matrix of the robot, and the three elements in the matrix are the coordinate components of P point in three directions.

*3.3. Mobile planning function test*

*3.3.1. Accessible environment*

Barrier free environment means that there are no other interference factors in the experimental environment except for electric robots and electric equipment. The space trajectory of electric robot is divided into six parts. The space trajectory planning method of electric robot based on random road sign method, the space trajectory planning method of electric robot based on flexible polyhedron search algorithm, the space trajectory planning method of electric robot based on sub group optimization algorithm and the space trajectory planning method of electric robot based on Unscented Kalman filter are used to make statistics The operation indexes of multiple robots are shown in Table 4 and Table 5.

From the data in Table 4 and Table 5, it can be seen that under the environment of no obstacle interference, the space trajectory planning method of electric robot based on the sub group optimization algorithm will have two collisions. The total space trajectory of the planned electric robot is 4.775 m, and the moving time of the robot is 39 s. There will be three collisions in the space trajectory planning method of electric robot based on the random landmark method. The total space trajectory of the planned electric robot is 5.054 m, and the moving time of the robot is 44.4 s. Based on the flexible polyhedron search algorithm, there will be four collisions in the space trajectory planning method of electric robot. The total space trajectory of the planned electric robot is 5.557 m, and the moving time of the robot is 50.4 s. However, no collision is found in the experiment by using the trajectory planning method designed in this paper. Compared with the space trajectory planning method of electric robot based on the sub group optimization algorithm, the planned trajectory is 0.407 m shorter and the moving time of the robot is saved by 1.8 s.

**Table 4.** Comparison between Subgroup Optimization Algorithm and Unscented Kalman Filter

| Stage | Global planning time (s) | Spatial trajectory planning method of power robot based on sub-group optimization algorithm | | | Space trajectory planning of electric robot based on Unscented Kalman filter | | |
|---|---|---|---|---|---|---|---|
| | | Trajectory (m) | Time consuming (s) | Collision times (time) | Trajectory (m) | Time consuming (s) | Collision times (time) |
| 1 | 1.239 | 0.711 | 6.3 | 1 | 0.700 | 6.1 | 0 |
| 2 | 0.535 | 0.909 | 7.8 | 0 | 0.906 | 7.3 | 0 |
| 3 | 0.212 | 0.828 | 6.9 | 0 | 0.823 | 6.5 | 0 |
| 4 | 0.123 | 0.973 | 8.1 | 1 | 0.796 | 7.9 | 0 |
| 5 | 0.114 | 0.739 | 4.8 | 0 | 0.568 | 4.6 | 0 |
| 6 | 0.265 | 0.615 | 5.1 | 0 | 0.575 | 4.8 | 0 |
| 合计 | 2.488 | 4.775 | 39 | 2 | 4.368 | 37.2 | 0 |

**Table 5.** Comparison Results Based on Random Path Method and Flexible Polyhedron Search Algorithm

| Stage | Global planning time (s) | Spatial trajectory planning method of power robot based on stochastic routing method | | | Spatial trajectory planning method of power robot based on flexible polyhedron search algorithm | | |
|---|---|---|---|---|---|---|---|
| | | Trajectory (m) | Time consuming (s) | Collision times (time) | Trajectory (m) | Time consuming (s) | Collision times (time) |
| 1 | 1.239 | 0.823 | 7.1 | 1 | 0.912 | 8.1 | 0 |
| 2 | 0.535 | 0.811 | 7.4 | 0 | 0.902 | 8.2 | 1 |
| 3 | 0.212 | 0.832 | 7.2 | 0 | 0.952 | 8.5 | 1 |
| 4 | 0.123 | 0.845 | 7.5 | 1 | 0.916 | 8.4 | 0 |
| 5 | 0.114 | 0.866 | 7.4 | 0 | 0.940 | 8.6 | 1 |
| 6 | 0.265 | 0.877 | 7.8 | 1 | 0.935 | 8.6 | 1 |
| Total | 2.488 | 5.054 | 44.4 | 3 | 5.557 | 50.4 | 4 |

*3.3.2. Multi obstacle environment*

Based on the barrier free environment, multiple obstacles are added to the experimental environment. The obstacles introduced in this experiment are divided into moving obstacles and fixed obstacles. The trajectory planning results obtained by using four spatial trajectory planning are shown in Figure 9.

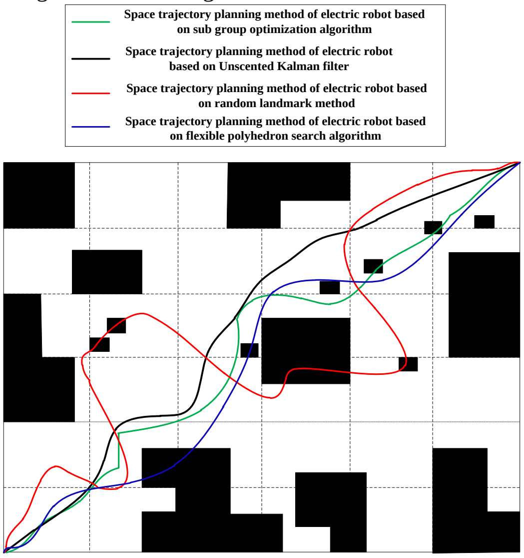


**Figure 9.** Comparison results of spatial trajectory planning in multi obstacle environment

It can be seen intuitively from the figure that in the first stage of trajectory planning, the trajectory results obtained by the design planning method in this paper do not coincide with the obstacles and their motion tracks, while the planning results of the spatial trajectory planning method of electric robot based on the sub group optimization algorithm overlap with the obstacles in two places, and the spatial trajectory planning method of electric robot based on the random landmark method. And the planning results of the space trajectory planning method of electric robot based on the flexible polyhedron search algorithm coincide with the obstacles many times. According to the statistics, there are 32 obstacles in the whole experiment. The number of collisions of the trajectory planning method based on the sub group optimization algorithm is 11, and the corresponding collision rate is 34.3%. However, the number of collisions of the trajectory planning method designed in this paper is 6, that is, the collision rate is 18.7%. In contrast, in the multi obstacle environment, the space trajectory planning of the robot is designed. The collision rate of the planning results is reduced by 15.6%.

*3.4. Joint planning function test*

The test of joint planning function is to plan the data reading track of electric robot when it performs patrol inspection task, carry out specific test for the track of multiple joints in electric robot, count the number of collisions between each joint and other electric equipment when it performs patrol inspection task, and the final statistical results are shown in Table 6.

**Table 6.** Comparison results of joint planning function test

| Space trajectory planning method | | Collision times | | | |
|---|---|---|---|---|---|
| | | Joint 1 | Joint 2 | Joint 3 | Joint 4 |
| Spatial trajectory planning method of power robot based on sub-group optimization algorithm | 1 | 2 | 3 | 1 | 3 |
| | 2 | 3 | 3 | 1 | 1 |
| | 3 | 1 | 2 | 4 | 3 |
| | 4 | 2 | 2 | 3 | 4 |
| | 5 | 3 | 3 | 2 | 3 |
| | 6 | 4 | 4 | 2 | 2 |
| Space trajectory planning of electric robot based on Unscented Kalman filter | 1 | 0 | 0 | 1 | 2 |
| | 2 | 1 | 1 | 0 | 0 |
| | 3 | 0 | 1 | 3 | 2 |
| | 4 | 3 | 1 | 2 | 2 |
| | 5 | 0 | 0 | 0 | 3 |
| | 6 | 2 | 2 | 1 | 1 |
| Spatial trajectory planning method of power robot based on stochastic routing method | 1 | 2 | 1 | 2 | 3 |
| | 2 | 2 | 2 | 1 | 1 |
| | 3 | 1 | 2 | 4 | 3 |
| | 4 | 2 | 2 | 3 | 3 |
| | 5 | 1 | 1 | 1 | 4 |
| | 6 | 1 | 3 | 2 | 2 |
| Spatial trajectory planning method of power robot based on flexible polyhedron search algorithm | 1 | 1 | 2 | 2 | 3 |
| | 2 | 3 | 2 | 1 | 1 |
| | 3 | 2 | 2 | 4 | 3 |
| | 4 | 2 | 2 | 3 | 3 |
| | 5 | 1 | 2 | 2 | 4 |
| | 6 | 3 | 3 | 3 | 3 |

By synthesizing the four joints of the electric robot, it can be found that the total number of joint collisions of the spatial trajectory planning method of the electric robot based on the sub group optimization algorithm is 61 times, the total number of joint collisions of the spatial trajectory planning method of the electric robot based on the random landmark method and the spatial trajectory planning method of the electric robot based on the flexible polyhedron search algorithm are 49 times and 57 times respectively In this paper, the total number of joint collisions is 28, which is 33 times lower than the total number of joint collisions based on the sub group optimization algorithm.

*3.5. Trajectory planning error*

In order to further verify the effectiveness of this method, the spatial trajectory planning method of electric robot based on random road sign method, the spatial trajectory planning method of electric robot based on flexible polyhedron search algorithm, the spatial trajectory planning method of electric robot based on subgroup optimization algorithm and the spatial trajectory planning method of electric robot based on Unscented Kalman filter are studied The results of human space trajectory planning are compared with the actual planning results, and the comparison results are shown in Figure 10.

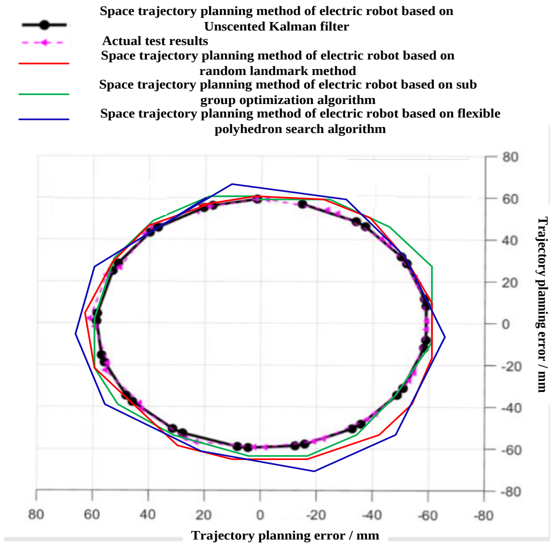


**Figure 10.** Comparison of trajectory planning errors

According to Figure 10, the spatial trajectory planning results of electric robot based on Unscented Kalman filter are basically consistent with the actual planning results, while the spatial trajectory planning methods of electric robot based on random road sign method, the spatial trajectory planning methods of electric robot based on flexible polyhedron search algorithm and the power robot based on subgroup optimization algorithm. The space trajectory planning results of electric robot based on robot space trajectory planning method are quite different from the actual planning results, which shows that this method can accurately plan the space trajectory of electric robot.

To sum up, applying the unscented Kalman filter technology to the space trajectory planning method of electric robot, the collision times of electric robot moving are reduced no matter in the barrier free or multi barrier environment, which realizes the design purpose of the space trajectory planning optimization method of electric robot.

## 4. Conclusion

China's electric robot market is the fastest growing and most dynamic electric robot market in the world, which brings great opportunities to the generation and development of electric robots in China. However, with the deepening of economic globalization, it is foreseeable that foreign large-scale robot companies will vigorously enter into the robot market. Due to the accumulation of technology and experience, Chinese robot companies still have a huge gap with foreign robot companies. Therefore, it is an urgent task to develop various functional modules of industrial robots with independent intellectual property rights as soon as possible. In view of the collision of traditional spatial trajectory planning methods for electric robots, which results in a long time and inaccurate trajectory planning, the optimal design of spatial trajectory planning method for electric robots is realized by using unscented Kalman filter. Firstly, the working environment of the electric robot is built. In this environment, the kinematics of the robot is analyzed, and the dynamics of the robot is analyzed. According to the analysis results of the kinematics and dynamics of the electric robot, the space trajectory constraint of the electric robot is set. Using unscented Kalman filter technology, the real-time motion state of the electric robot is detected, and then the spatial trajectory planning results of the electric robot are obtained by smoothing the spatial trajectory. Compared with the traditional space trajectory planning method, it is found that the collision times of the robot are reduced in the fault-free and multi fault environment.

Through the research of this paper, it can be concluded that using the trajectory planning method designed in this paper, no collision is found in the experiment. Compared with the space trajectory planning method based on sub group optimization algorithm, the planning trajectory is shorter by 0.407m and the robot motion time is saved by 1.8s. The number of collisions is 6, that is, the collision rate is 18.7%.

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