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Geometric Size Optimization of the Series Manipulator of the Electric Vehicle Mobile Charging Robot

Shangjunnan LIU[a], Shuhai LIU[a,b,1] and Huaping XIAO[a,b]
[a] *College of Mechanical and Transportation Engineering, China University of Petroleum-Beijing, Beijing 102249, China*
[b] *Center of Advanced Oil and Gas Equipment, China University of Petroleum-Beijing, Beijing, 102249, China*

Abstract. Due to the compact parking of vehicles in parking lots, the working environment of electric vehicle charging robots is complex and narrow, which puts higher demands on the flexibility of robot manipulators. The workspace of manipulator reflects its working range, while the density of the workspace reflects the flexibility of all parts of the manipulator within its working range. According to the working range of the electric vehicle charging robot, adjusting the ratio of the number of manipulator joints and the length of the manipulator can improve its dexterity. This article uses MATLAB simulation to calculate the workspace density of manipulator with different joint numbers and length ratios, and draws workspace density cloud map, which can more intuitively judge the performance of the manipulator. The research provides guidance and inspiration for optimizing the geometric dimensions of the manipulator.

Keywords. Electric vehicle charging; mobile charging robot; serial manipulator; workspace density.

1. Introduction

Electric vehicle has many technical problems to be solved, such as battery life, long charging time [1]. Electric vehicle mobile charging robot can solve the above problems, which is mainly divided into four parts: (a) manipulator; (b) controller; (c) battery; (d) mobile base, as shown in figure 1a. Most of the robots adopt discrete manipulator, which has a lot of room for improvement in structure and control.

The types of manipulators are classified into discrete, serpentine, and continuous according to the number of joints and degrees of freedom, as shown in figure 1b [2]. Discrete manipulator and serpentine manipulator are widely used in manufacturing, aerospace, medical, etc. The discrete robot arm has simple structure, large load, high accuracy, and easy trajectory planning. However, the elbow joint of the discrete robot is often too large, which limits the design and motion space of the discrete robot. Its rigid chain structure also brings the disadvantage of poor obstacle avoidance ability [3]. Serpentine manipulator uses discrete joints, but combines very short rigid connections

[1] Corresponding Author, Shuhai LIU, College of Mechanical and Transportation Engineering, China University of Petroleum-Beijing, Beijing 102249, China; Email: liu_shu_hai@163.com.

and high-density joints, which structure gives it a lot of redundant degrees of freedom, leads to low load, low power efficiency, and low robustness [4-6].

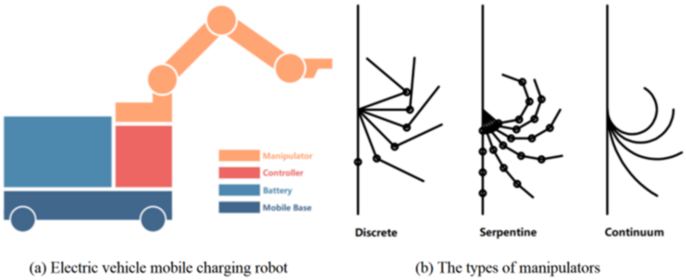


Figure 1. Electric vehicle mobile charging robot and manipulators.

The charging environment of electric vehicles is complex, including parking lots, streets, etc., which requires that the mechanical arm of the electric vehicle charging robot needs a certain load capacity and flexibility (obstacle avoidance capability) at the same time. According to the analysis of the structures of Discrete Manipulator and Serpentine Manipulator, it can be inferred that adjusting the proportion of each segment and the number of joints of the manipulator is one of the methods to solve the problem.

Scholars studied the workspace from three aspects [7]: (a) Algebraic and Geometric formula [8,9]; (b) Heuristic oriented [10]; (c) Mono-objective and multi-objective optimization [11].

In the process of literature research, we found that the analysis of the specific nature of workspace includes: the scope of workspace; workspace density; workspace translation; workspace Orientation; workspace velocity sensitivity.

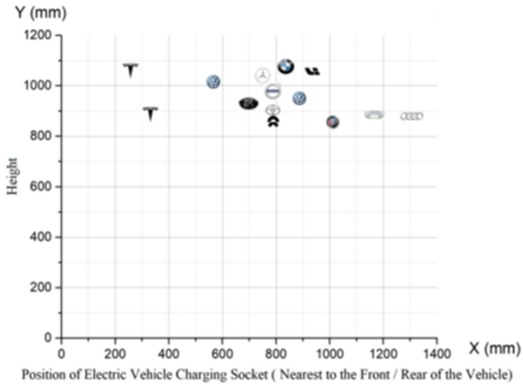
The charging robot of electric vehicle needs high flexibility to cope with complex environment in the working process. In this paper, the working environment of the charging robot of electric vehicle is divided into three types according to the parking mode of the vehicle. The number of joints of the mechanical arm affects its working reliability, load, flexibility and the difficulty of control algorithm at the same time. During the design of the mechanical arm structure, the number of joints should be reduced as much as possible to improve reliability and reduce the difficulty of control under the condition that the load and flexibility are met.

2. Modeling

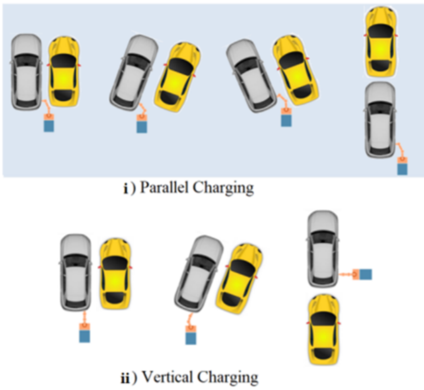
In this section, the structure of the mechanical arm of the electric vehicle charging robot is designed, the Jacobian matrix of the position and attitude of the 2-bar, 3-bar and 4-bar manipulator is established according to the D-H method, and the working environment of the electric vehicle charging robot is analyzed.

2.1. Working Condition

This paper investigated the charging sockets of some electric vehicle models, and found that the location area of the charging sockets of most models is horizontal (the nearest distance from the front and rear ends/mm) $X_{min} \in [0,936]$; Vertical (relative to the ground/mm) $Y_{min} \in [861,1037]$. The plan locations of charging sockets of various models of electric vehicles are shown in figure 2a.



(a) The plan locations of charging sockets of various models of electric vehicles



(b) Charging poses of electric vehicle mobile charging robot

Figure 2. Location of electric vehicle charging ports.

Based on the above research results, the working attitude of the electric vehicle charging robot can be divided into the following two types (the robot arm is relative to the charging socket plane): (a) parallel charging attitude; (b) Vertical charging attitude. The parallel charging attitude includes 4 different situations, and the vertical charging attitude includes 3 different situations, as shown in figure 2b.

2.2. Kinematic Model

According to the plane position area of the electric vehicle charging socket $X_{min} \in [0,936]$, $Y_{min} \in [861,1037]$, this paper sets the geometric parameters of the mechanical arm of the electric vehicle charging robot: the relative height of the origin position is 880mm, and the total length is 1000mm.This paper uses Matlab robot toolbox to establish a mathematical model of the mechanical arm. The conversion matrix from parameter coordinate system {n-1} to parameter coordinate system {n} is ${}^{n-1}_{\ \ n}T$, as shown in equation (1). Diagrammatic sketch of the D-H parameter coordinate system as shown in figure 3.

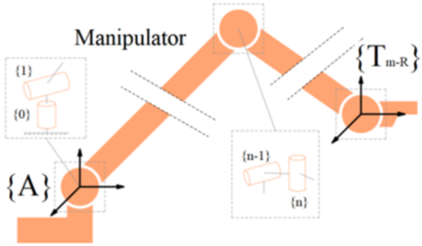


Figure 3. Diagrammatic sketch of the D-H parameter coordinate system.

$$
{}^{n-1}_{n}T = \begin{bmatrix} cos\theta_n & -sin\theta_n & 0 & a_{n-1} \\ sin\theta_n cos\alpha_{n-1} & cos\theta_n cos\alpha_{n-1} & -sin\alpha_{n-1} & -d_n sin\alpha_{n-1} \\ sin\theta_n sin\alpha_{n-1} & cos\theta_n sin\alpha_{n-1} & cos\alpha_{n-1} & d_n cos\alpha_{n-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}
$$

The parameter coordinate system {A} is the basic coordinate system.

The Jacobian matrix of posture of different joints (2-R; 3-R; 4-R) are T_{2R}, T_{3R} and T_{4R}, as shown in equations (2)-(4).

$$
T_{2R} = {}^0_1T\,{}^1_2T\,{}^2_3T\,{}^3_4T \tag{2}
$$

$$
T_{3R} = {}^0_1T\,{}^1_2T\,{}^2_3T\,{}^3_4T\,{}^4_5T \tag{3}
$$

$$
T_{4R} = {}^0_1T\,{}^1_2T\,{}^2_3T\,{}^3_4T\,{}^4_5T\,{}^5_6T\,{}^6_7T \tag{4}
$$

3. Method and Result

3.1. Method

In this paper, the workspace of the electric charging robot is studied, and the workspace density is used as the performance index of the manipulator. This section describes its research theory and method, and designs a program to complete the calculation of the workspace density of the manipulator and the workspace density of the section.

3.1.1. Method of Workspace Density

Workspace is a set of points that can be reached by the end of the manipulator. Its contour range expresses the range of motion of the manipulator, which points in the interior can be reached is described using dexterity measures [12]. The workspace density is the number of reachable points in the designated area of the workspace. The probability density formed after normalization. The higher the workspace density in the designated area, the higher the accuracy and flexibility of the manipulator in the area. Inverse kinesthetics of discretely actuated hyper redundant manipulators using workspace identities and workspace density and inverse kinesthetics for planar serial revolutionary manipulators provide definitions and calculation methods of two workspaces respectively, as shown in Equation (5) [13] and (6) [14]:

$$\rho(box) = \frac{\text{\# of reachable points in box}}{\text{(unite volume) / (area)}} \tag{5}$$

$$\rho(box) = \frac{\text{\# of reachable points in box}}{\text{(total \# of points)} \cdot \text{(volume of the box)}} \tag{6}$$

In the opinion of the author, both methods can express the density of workspace, but the literature only shows the advantages in calculating the density of workspace of two-dimensional planar manipulators. There are still technical problems in mathematics and programming for calculating the density of workspace of three-dimensional manipulators, Therefore, this paper chooses the method in the literature (Inverse kinematics of discretely actuated hyper redundant manipulators using workspace identities) to control the rotation angle of the joint of the mechanical arm to find the workspace and the point set of the designated area.

3.1.2. Computing Framework

The calculation of the workspace and workspace density of the electric vehicle charging robot manipulator is completed by using MATLAB software. The robot toolbox program is also used for the calculation of the workspace.

The workspace program according to Monte Carlo method is described as follow:

- **STEP 1** Divide the sample space averagely, get the corresponding range of joint angles of the manipulator, and discrete the joint angles;
- **STEP 2** Use the robot toolbox to calculate the forward kinematics according to the joint angles of the manipulator, and obtain the coordinates of the end point of the manipulator;
- **STEP 3** Record the coordinates of the end points of all mechanical arms, and slice the workspace in the x, y, and z coordinate directions according to the thickness t;
- **STEP 4** Project the points in the sheet onto the corresponding plane to represent the set of section points in the workspace, and mesh the section;
- **STEP 5** Calculate the workspace density in each section grid and store it in the corresponding matrix;
- **STEP 6** Use the grid coordinates of each section and the workspace density of this coordinate to draw the workspace density cloud map of this section.

By drawing the density nephogram of the working space of different sections of the manipulator, the working ability (accuracy and flexibility) of the manipulator at different positions in its working space is more intuitively expressed. At the same time, the density sum of the workspace in the designated area can be calculated to judge the advantages and disadvantages of different manipulator structures in different areas.

3.2. Results

This section shows and analyzes the calculation results of workspace density of the manipulator with different link numbers in figure 4 and figure 5, and the calculation results of workspace density of the 4R manipulator with different link proportions in figure 6 and figure 7.

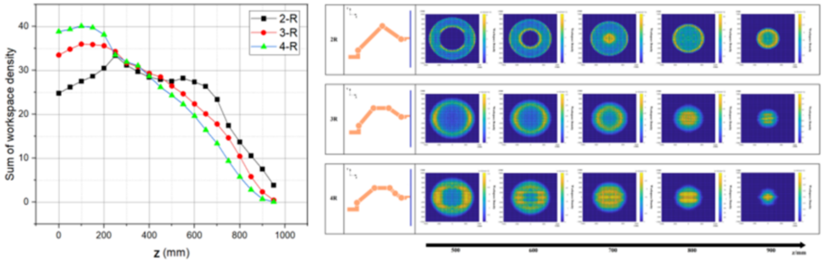


Figure 4. Working space density nephograms of X-Y section of manipulator.

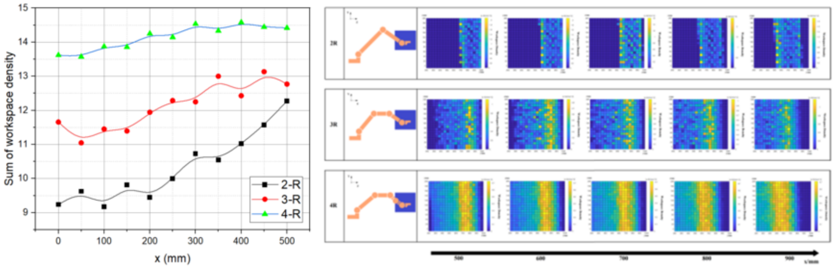


Figure 5. Working space density nephograms of Y-Z section of manipulator.

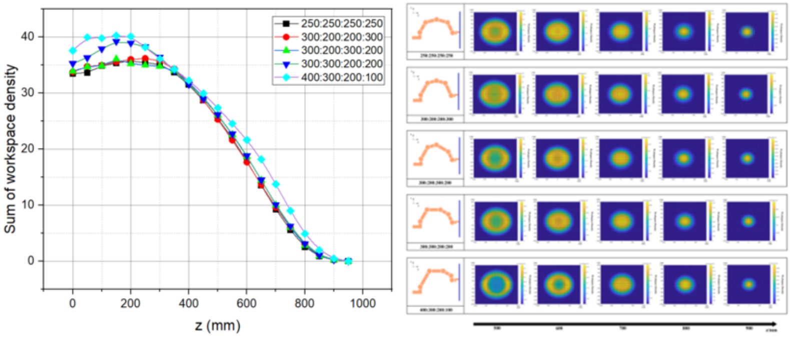


Figure 6. Working space density nephograms of X-Y section of manipulator.

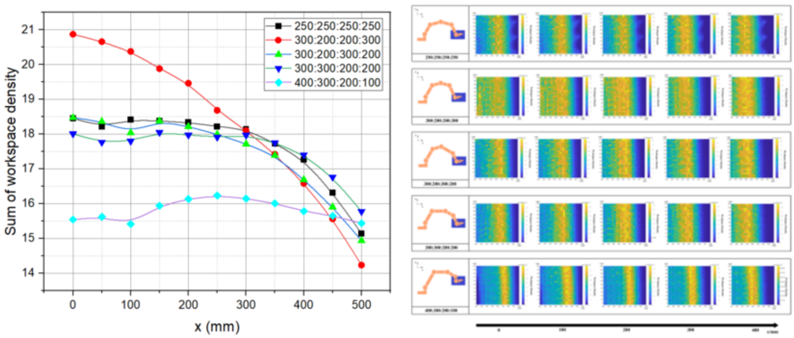


Figure 7. Working space density nephograms of Y-Z section of manipulator.

From results, it can be concluded that when the manipulator of the electric vehicle charging robot is parallel to the target plane, when the base is less than 300 mm from the target plane in the X-axis direction, the length ratio of the manipulator should be 300:200:200:300; when the base is less than 300 mm from the target plane in the X-axis direction, the length ratio of the manipulator should be 300:300:200:200.

4. Conclusion

Through the research on the working environment of the electric vehicle charging robot, this paper uses Matlab to study the working space density of the manipulator of the electric vehicle charging robot (search and calculate the workspace density, build the cloud maps) and selects the optimal number of manipulators (4-R) and the proportion of their length as the evaluation criteria. The research direction of the electric vehicle charging robot based on the optimized size manipulator will be the vehicle charging and obstacle avoidance of the manipulator in the future.

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