A Method of Electric Vehicle Wireless Charging Coil Alignment based on Binocular Vision and Neural Network

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Abstract**—For the inefficient wireless charging between the electric vehicle transmitting coil and receiving coil cannot be accurately aligned, this paper puts forward a specific solving method for aligning of electric vehicle transmitting coil and receiving coil based on binocular vision and neural network. Firstly, the method collects image of the parking space through the binocular vision system and then preprocess the image, with that locates the image processed in the horizontal and vertical directions. Establishing the extracted centroid coordinates of the LED at the center of the launching device and its coordinates in the world coordinate system (camera coordinate system) as the data sets of the input and output, respectively, training the neural network model of camera to calibrate, and realize the conversion of image pixel coordinates to world coordinates. Comparing the alignment data with given data to obtain the alignment parameters. Finally, the parameters are converted to the number of turns of the motor, and then controlling the movement of the receiving device in horizontal and vertical direction, to achieve alignment. This paper mainly focus on the acquisition of parameters in this method. The experimental results show that the method can obtain parameters of alignment well, and it also can be achieved in the condition of weak light.**

Index Terms**—Electric vehicle wireless charging; Coil alignment; Binocular Vision; Neural Network**

I. INTRODUCTION

At present, the alignment of the transmitting receiving coils is the key to the efficiency of wireless charging of electric vehicle. Therefore, the precise alignment method is the focus of future research and hot spots.

Now, wireless charging of electric vehicle to realize alignment for drivers is mainly through the parking assist system. This system improves the alignment rate, but it requires a special visual alignment system, and it is also very cumbersome when the driver begins the behavior of alignment. Two electric vehicle wireless charging system are presented [6] [7]. The systems improve wireless charging performance by moving transmitting or receiving device respectively. The same drawback is that there are limitations for electric vehicles with different chassis heights. At the same time, the image acquisition and positioning method needs to have a fixed reference point. For applications such as electric vehicles and the like where the size and parking position are not fixed, this method has great limitations in implementation.

In this paper, an innovative alignment system for electric vehicle wireless charging based on binocular vision and neural network is proposed. In this system, this binocular vision is used to collect image of the parking space. Besides, this system can achieves the alignment by moving receiving device in the horizontal and vertical directions. Camera calibration is an essential part of the coordinate conversion process. The traditional calibration method is to simulate the imaging process initialization parameters of the camera using the ideal aperture imaging model, and then correct the parameters by nonlinear least squares method to complete the distortion correction. Since the calibration of the camera and the neural network are both establishing a mapping relationship, the new data is processed by the existing data to establish a parametric model. In the calibration, the imaging model of the camera is a nonlinear model, when a nonlinear model is adopted. To calibrate the camera, non-linear optimization calculations are needed, but the introduction of too many nonlinear parameters often not only improves the accuracy, but also causes the instability of the solution, while the neural network has a strong nonlinear approximation capability. Therefore, applying neural networks to camera calibration is achievable.

This paper mainly focus on the acquisition of alignment parameters in this method and the parameters can be obtained by image processing and camera calibration. Simulation and experiments are carried out to obtain the parameters and verify the feasibility of the method.

II. THE IMAGE COLLECTION

In the system, the transmitting coils are pre-embedded under the ground and receiving coils are located in the control device with lateral, longitudinal and vertical lifting. The binocular vision system is located in the center of the receiving device. Because the distance between the binocular vision system and the ground transmitting device is fixed and the camera focal length is constant, the size of the image collected is fixed. The left and right cameras of the binocular vision system collect the image of the parking space at the same time. The LED in the center of the transmitting device is located at a certain position on the image and installed at the center of the ground transmitting device, which is to extract the center coordinates of transmitting device easily and ensure the center point is not lost when images are collected in the day or night.

III. THE IMAGE PREPROCESSING

Since the LED lamp installed in the center of the launching device has a higher resolution than the transmitting plate, in the acquired image, the LED can be used as a feature point, and a certain threshold is directly set to binarize the acquired image. The characteristics of the LED can be highlighted. At this time, the extraction of the center of the LED becomes simpler. After the center coordinate of the LED is obtained, the center of the transmitting board can be in the space by the conversion of the image coordinate system and the world coordinate system. for positioning.

Due to external factors such as uneven illumination and the influence of the binocular vision system, some noise will be generated in the captured images. The presence of these noises will cause multiple center point coordinates to appear in the centroid extraction process, which will affect the later processing. Therefore, In this paper, Gaussian filtering is used to denoise the image, so that the image is clear and the visual effect is good. It is easier to extract the features of the object as the feature model of image recognition. Thereby, the center point coordinates of the LED are more easily calculated, and the positioning is simpler and more precise.

IV. CAMERA CALIBRATION BASED ON NEURAL NETWORK

A. Neural network technology

Neural networks are increasingly used by people because of their powerful nonlinear approximation capabilities. It can be used to deal with some complex mathematical model fitting problems, and has good adaptive, self-learning and generalization capabilities. In this paper, a BP neural network with simple model and good generalization performance is adopted. BP neural network is a multi-layer feedforward neural network trained according to the error back propagation algorithm, which mainly includes input layer, hidden layer and output layers, each layer connected by weights and deviations. In theory, a three-layer BP neural network with a hidden layer can approximate any continuous function with arbitrary precision when the number of hidden layer neurons can be arbitrarily set [5], so this paper uses a three-layer BP neural network. As shown in Figure 1, we assume that the input feature vector of the network is$[x_1, x_1 \dots x_n]$, and the output feature vector of the network is$[\acute{y}_1, \acute{y}_1 \dots \acute{y}_j]$. The weight between the input layer and the hidden layer is w_{ih}, and the offset is b_h, and the weight between the hidden layer and the output layer is w_{hj},and the offset is b_j.

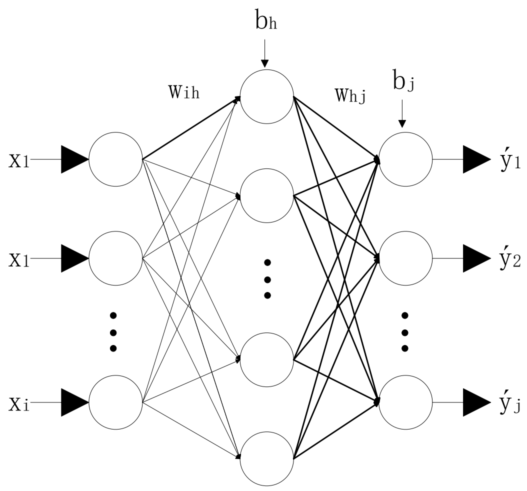

Figure 1 BP neural network structure

According to the connection relationship of the neural network, it can be known that:

$$z_j = \sum_{i=1} x_i w_{ih} + b_h \quad (1)$$

$$o_h = f_1(z_j) \quad (2)$$

$$o_j = \sum_{i=1} o_h w_{hj} + b_j \quad (3)$$

$$\acute{y}_j = f_2(o_j) \quad (4)$$

Among them, o_h and o_j are the input of the second and third layers of the network. The f_1 and f_2 are nonlinear activation functions, mainly to nonlinearize neurons to achieve nonlinear approximation.

The error function uses a squared error function, and the error of the total sample is:

$$\mathrm{E} = \frac{1}{2}\sum_{j=1}^{N}(y_j - \acute{y}_j)^2 \quad (5)$$

Using the gradient descent method to achieve the minimum error E, according to the full differential formula:

$$\frac{\partial \mathrm{E}}{\partial w_{hj}} = \frac{\partial \mathrm{E}}{\partial \acute{y}_j} \cdot \frac{\partial \acute{y}_j}{\partial o_j} \cdot \frac{\partial o_j}{\partial w_{hj}} = (\acute{y}_j - y_j) \cdot f_2'(o_j) \cdot o_h \quad (6)$$

$$\frac{\partial \mathrm{E}}{\partial w_{ih}} = \frac{\partial \mathrm{E}}{\partial \acute{y}_j} \cdot \frac{\partial \acute{y}_j}{\partial o_j} \cdot \frac{\partial o_j}{\partial o_h} \cdot \frac{\partial o_h}{\partial z_j} \cdot \frac{\partial z_j}{\partial w_{ih}} = (\acute{y}_j - y_j) \cdot f_2'(o_j) \cdot w_{hj} \cdot f_1'(z_j) \cdot x_i \quad (7)$$

The update rule of the weight is as follows(8)(9):

$$w_{hj} := w_{hj} - \alpha \cdot \frac{\partial \mathrm{E}}{\partial w_{hj}} \quad (8)$$

$$w_{ih} := w_{ih} - \alpha \cdot \frac{\partial \mathrm{E}}{\partial w_{ih}} \quad (9)$$

B. Camera calibration neural network modeling

Camera calibration is an essential part of the electric vehicle transmitting coil and receiving coil alignment method based on binocular vision and neural network, which can be understood as the position information of the LEDs in the center of the transmitting plate in the image pixel coordinate system. We convert it to the world coordinate system through the camera calibration. The $(x_0 o_0 y_0)$ plane of the camera coordinate system is parallel to the $(O x_w y_w z_w)$ plane of the world coordinate system, and the distance between the two planes is Z, which is obtained by extracting the centroid of the LED. The coordinates of the feature points in the image pixel coordinate system are converted into the coordinates of the camera coordinate system by the external parameters R and T, and then the coordinates in the camera coordinate system are converted into image coordinates by the pinhole model, and the image coordinates can be directly converted into pixel coordinates. Finally, the pixel coordinates are compensated by the distortion model. The first two steps are linear transformations, and the last step is nonlinear. The choice of the structural design and activation function of the neural network is based on the above ideas. As shown, the network's input is the location(u, v) of the target in the image. The output is the coordinates $(x_w y_w z_w)$ of the target in the world coordinate system.

The input value is designed as $[u, v]$ and output value is designed as $[x'_w, y'_w, z'_w]$, and actual value is$[x_w, y_w, z_w]$. The overall error is designed as:

$$E = \frac{1}{2}\sum_{j=1}^{N}\left(y_j - \acute{y}_j\right)^2 =$$

$$\frac{1}{2}\sum_{j=1}^{N}\left[\left(x_j - x_j'\right) + \left(y_j - y_j'\right) + \left(z_j - z_j'\right)\right] \quad (10)$$

V. LAUNCHER CENTER AND VERTICAL POSITIONING

As shown in figure 2, the world coordinate system coincides with the first camera coordinate system. There is only one translation B in the X axis direction with the second camera coordinate system.

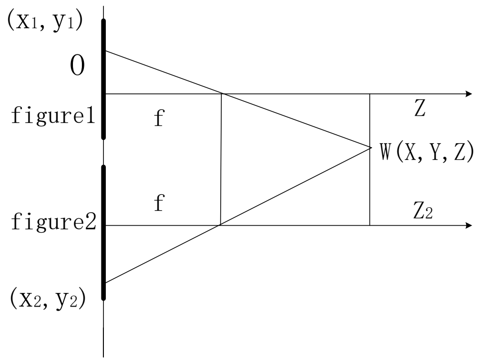

Figure 2 Parallax and depth in binocular vision system

As the LED is located in the center of the transmitting device, so it only need to locate the LED and you can achieve location of the transmitting coil. We can obtain the coordinates of the image in the pixel coordinate system after edge detection and extract the center of the contour. According to (2), the coordinates transformed to the world coordinate system are compared with the standard alignment system coordinates. Then the corresponding alignment parameters can be obtained. In the experiment. The extraction of the LED center coordinate is shown in figure 3 where the other coordinate points are noise points.

In this experiment, the CCD sensor focal length of the binocular vision system is f = 6 mm. The highest resolution is 1280 × 1024, and the size of the sensor is 4.8 × 3.6 mm. The centroid coordinate (1036,92) of the LED is shown in figure 4. Because of the presence of noise, some interference coordinates appeared. The image in binocular vision system has a size of 1200 × 400, and then we can calculate the centroid coordinate of the LED in a single image is (236,85) and (436,92) from figure 3 and figure 4.

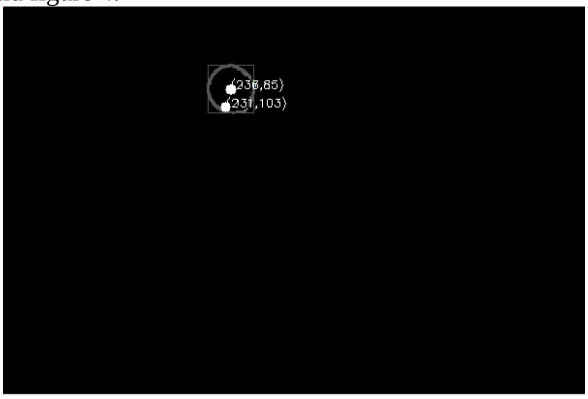

Figure 3 LED center of mass coordinates

Figure 4 The center of camera under the camera's center of mind coordinate

VI. SIMULATIONE AND EXPERIMENTAL RESULTS

In this experiment, we use a single image size of 600 × 400 collected by the binocular vision system and the size of the CCD exposure target is 4.8 × 3.6 mm. The lens focal length is 6 mm, the center distance of the lens (baseline distance) is 24 mm. The size of the transmitting device is 20.8 × 40cm, and the distance between the camera and the transmitting device is 20 cm. The center coordinate of the LED is (10.4, 20). The coordinate of projection point in transmitting device for the center of binocular vision system is (6,16). The binocular vision system was calibrated neural network calibration method. The results of the calibration were as follows:

$$w_{hj} = \begin{bmatrix} 0.6835 & 0.3693 & -0.7986 \\ 0.7819 & -0.6653 & 0.2568 \end{bmatrix}$$

$$w_{ih} = \begin{bmatrix} -0.1904 & 0.9705 & 0.1481 \\ -0.9811 & -0.1934 & 0.0062 \\ 0.0347 & -0.1441 & 0.9889 \end{bmatrix}$$

$$b_j = [638.9476, 410.1534]^T$$

$$b_h = [-0.2073, 0.4735, -0.3482]^T$$

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In this paper, a method for aligning of transmitting and receiving coils of electric vehicle wireless charging based on binocular vision and neural network has been presented. This paper put how to achieve the location in horizontal and vertical direction for this alignment method as the focus to research. We complete content through the image process, neural network calibration model training camera calibration and data analysis. Simulation and experimental results show that this system can provide reliable data for alignment of transmitting and receiving coils. It has a lower error and then the alignment parameters obtained can be transformed into the rotation parameter of the motor through the control system .Finally, it can finish an alignment operation to improve efficiency of electric vehicle wireless charging.

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