Electric Vehicle Charging Terminal 3D Docking Method Using Stereo Camera

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Abstract**—** With the growth of battery-based electric drive platforms and intelligent control technologies, the diversity of smart EV related industries is increasing. A number of companies are competing to develop and commercialize electric vehicle charging robots. In this paper, we propose a three-dimensional docking method for the charging terminal of a multi-articulated robot electric vehicle based on stereo vision. Based on the stereo image, docking is performed by calculating the relative positions of the docker center, the degree of inclination and the degree of distortion using the calibration information of camera 1 and camera 2 and the position of the marker.

Keywords—electric vehicle charging; unattended automation; stereo vision; multi-joint robot; 3D docking

I. Introduction

With the growth of battery-based electric drive platforms and intelligent control technology, the diversity of industries related to smart EV and electronic components is increasing. Continuous technology development for improving battery capacity and efficiency for electric drive platforms is in progress, improving the performance of key parts such as batteries and drive systems to increase the mileage of one charge to more than 500km, and improving motor and inverter technology that influences driving performance. In order to increase the charging capacity and shorten the time, the development of super charger technology such as high voltage cables, connectors, and converters is actively progressing[1, 2, 3]. The trends in electric vehicles, small electric trucks, agricultural transport carts, wheelchairs, commercial and specially equipped vehicles, and construction equipment industries using electric drives are also changing[4].

Companies such as 'EVAR', 'KUKA', 'MOBI' and 'CarLa' are competing to develop and commercialize electric vehicle charging robots. CarLa has the technology that the multi-joint robot connects the charging cable by itself when the driver stops the electric vehicle in a designated parking space.

In this paper, we propose a 3D docking method for electric vehicle charging terminals using a stereo vision-based multi-joint robot, which is one of the core technologies of the electric vehicle unmanned robot charging system.

II. Electric vehicle charging terminal 3D docking method

A. Docking Method

In this paper, we propose a method of accurately grasping the geometry of the docker inserted in the electric vehicle using stereo images, and docking the charging terminal to the docker using a fixed or moveable multi-joint robot based on the determined geometry. The proposed electric vehicle 3D docking method is shown in Fig. 1.

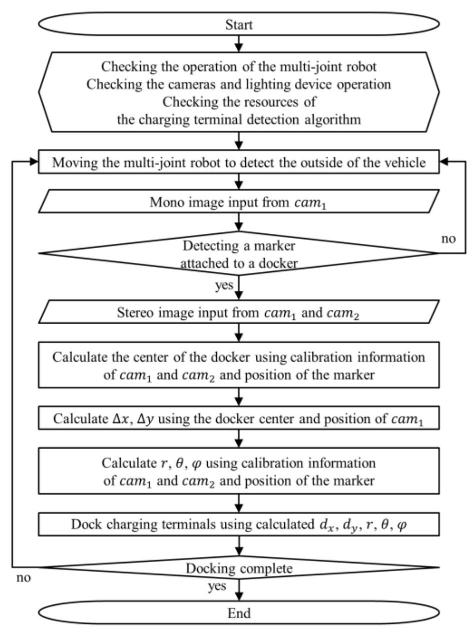

Fig. 1. A Flowchart of 3D docking method for electric vehicle

The starting points of Fig. 1 are limited to two situations.

- A movable multi-joint robot moves around the parked electric vehicle and waits for charging.
- Electric vehicles parked around the fixed multi-joint robot to wait for charging.

When docking starts, check the operation status of the multi-joint robot, check the resources for charging terminal detection algorithms such as stereo camera calibration maps, and check the operation status of cameras and lighting devices. When it is ready to detect the charging terminal, the multi-joint robot moves and detects the exterior of the vehicle. When the multi-joint robot detects the exterior of the vehicle, it receives a mono image from camera 1 and determines whether the marker[5] to be searched in the field of view. If the marker is not in the field of view, vehicle exterior detection continues, else if the marker is in the field of view, a stereo image is input using camera 1 and camera 2. Based on the stereo image, docking is performed by calculating the relative positions of the docker center Δx , Δy , r , the degree of inclination θ , and the degree of distortion φ using the calibration information of camera 1 and camera 2 and the position of the marker[6]. When docking is complete, the situation is terminated. Otherwise, the vehicle exterior detection using camera 1 is performed from the beginning.

B. Marker Position Detection Using Stereo Camera

In order to perform the 3D docking of the electric vehicle charging terminal described in the previous section, the position of the marker attached to the docker must be accurately identified. Using the image information obtained from camera 1 and camera 2 in the same way as in Figure 2, the location information of $\mathbf{x}$ - each point can be expressed as a vector starting from the origin, so point and vector expression can be mixed-, the center point of the marker, can be calculated.

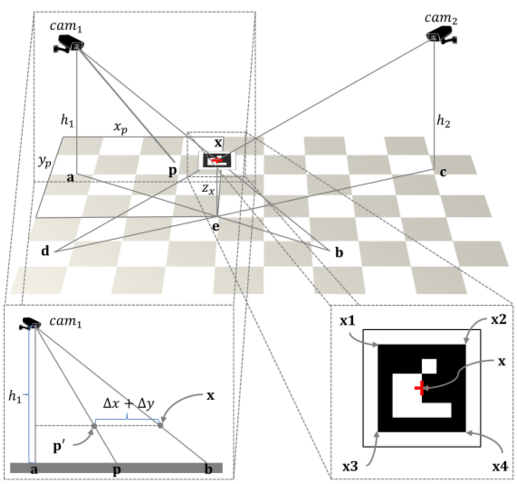

Fig. 2. Calculation of object position in 3D using stereo camera

The intersection of camera 1 and camera 2, $\mathbf{e}$, can be calculated using $\mathbf{a}$, $\mathbf{b}$, $\mathbf{c}$ and $\mathbf{d}$, and the formula is (1).

- $\mathbf{a}$: The point at which camera 1 is projected onto a 2D plane.
- $\mathbf{b}$: The point where the line passing through the center of camera 1 and the marker intersects the 2D plane.
- $\mathbf{c}$: The point at which camera 2 is projected onto a 2D plane.
- $\mathbf{d}$: The point where the line passing through the center of camera 2 and the marker intersects the 2D plane.

$$(x_x, y_x) = (x_e, y_e) = \left(\frac{(x_a y_b - y_a x_b)(x_c - x_d) - (x_a - x_b)(x_c y_d - y_c x_d)}{(x_a - x_b)(y_c - y_d) - (y_a - y_b)(x_c - x_d)}, \frac{(x_a y_b - y_a x_b)(y_c - y_d) - (y_a - y_b)(x_c y_d - y_c x_d)}{(x_a - x_b)(y_c - y_d) - (y_a - y_b)(x_c - x_d)} \right) \quad (1)$$

Where, x_v and y_v are the elements of the x-axis and y-axis of the vector $\mathbf{v}$, respectively. The vector $\mathbf{e}$ is the point where the vector $\mathbf{x}$ is projected onto the 2D plane, so the elements of the x-axis and y-axis of the vector $\mathbf{e}$ and the vector $\mathbf{x}$ are the same.

The z-axis element of the vector $\mathbf{x}$, z_x , can be obtained from both viewpoints of camera 1 and camera 2. The distance from point $\mathbf{b}$ to $\mathbf{a}$ is $|\mathbf{b} - \mathbf{a}|$, and the distance from point $\mathbf{e}$ to $\mathbf{b}$ is $|\mathbf{e} - \mathbf{b}|$, so it becomes $|\mathbf{b} - \mathbf{a}| : h_1 = |\mathbf{e} - \mathbf{b}| : z_x$. Therefore, z_x can be calculated as follows.

$$z_x = \frac{|\mathbf{e} - \mathbf{b}| h_1}{|\mathbf{b} - \mathbf{a}|} = \frac{|\mathbf{e} - \mathbf{d}| h_2}{|\mathbf{d} - \mathbf{c}|} \quad (2)$$

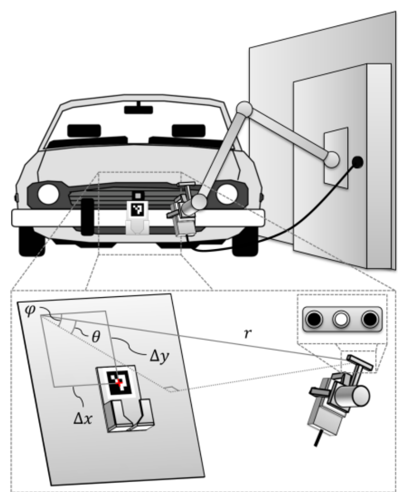

Fig. 3. Electric vehicle terminal 3D docking method

C. Calculation of Polar Coordinate System Between Charging Terminal and Docker

For docking using a multi-joint robot, it is necessary to convert the vector $\mathbf{x}$, an absolute coordinate based on the origin, into a relative coordinate based on the camera 1 and the gripper- for convenience, set the geometry of camera 1 and gripper the same- attached to the multi-joint robot. In this paper, the relative coordinates between the charging terminal and the docker are expressed by the polar coordinate method as shown in Fig. 3, and for this, Δx , Δy , r , which are the relative positions of the docker center, θ , which is the degree of inclination, and φ, which is the degree of distortion, are calculated.

Since point $\mathbf{x}$ must be included in the optical axis, which is the center of camera 1's field of view, the position of camera 1 must be moved by Δx and Δy in the x-axis and y-axis, respectively. The distance from point $\mathbf{p}$ to $\mathbf{a}$ is $|\mathbf{p}-\mathbf{a}|$, and the distance from point $\mathbf{p}$ to $\mathbf{p'}$ is $|\mathbf{p}-\mathbf{p'}|$, so it becomes $h_1 : z_x = |\mathbf{p}-\mathbf{a}| : |\mathbf{p}-\mathbf{p'}|$. Therefore, the point $\mathbf{p'}$ can be calculated as follows.

$$\begin{aligned}\mathbf{p'} &= \left(x_{p'}, y_{p'}, z_{p'}\right) \\ &= \left(x_p - \frac{z_x\left(x_p - x_a\right)}{h_1}, \mathrm{y}_p - \frac{z_x\left(y_p - y_a\right)}{h_1}, z_x\right)\end{aligned} \tag{3}$$

Δx and Δy calculated using point $\mathbf{p'}$ are as follows.

$$\left(\Delta x, \Delta y\right) = \left(x_x - x_{p'}, y_x - y_{p'}\right)$$

Since the distance from camera 1 to point $\mathbf{x}$ after moving camera 1 by Δx and Δy is the same as the distance from camera 1 to point $\mathbf{p'}$ before moving, r can be obtained as follows.

$$r = \left|\mathbf{p'} - \left[x_a \ \mathrm{y}_a \ h_1\right]^T\right| \tag{4}$$

The degrees of inclination between the x-axis and y-axis, θ_x and θ_y respectively, are the difference between "the angle formed by the normal vector $\mathbf{n}$ and the x and y axes of the marker plane attached to the docker based on the z-axis" and "the angle between the x and y axes of the optical axis, which is the center of camera 1's field of view, based on the z-axis" and can be obtained as follows.

$$\mathbf{n} = \left(\mathbf{x1} - \mathbf{x}\right) \times \left(\mathbf{x}2 - \mathbf{x}\right) \tag{5}$$

$$\begin{aligned}\left(\theta_x, \theta_y\right) = \Bigg(&\arctan\left(\frac{x_{p-p'}}{z_{p-p'}}\right) - \arctan\left(\frac{x_n}{z_n}\right), \\ &\arctan\left(\frac{y_{p-p'}}{z_{p-p'}}\right) - \arctan\left(\frac{y_n}{z_n}\right)\Bigg)\end{aligned} \tag{6}$$

If the horizontal axis of the marker attached to the docker is not parallel to the horizontal axis of the charging terminal, it must be pivoted by the amount of distortion φ. The result of back-projecting a vector $\mathbf{x}2 - \mathbf{x}1$ parallel to the horizontal axis of the marker with a positive value to a plane with inclinations of θ_x and θ_y respectively on the x and y axes forms an angle between the horizontal plane of the camera 1 field of view and φ. Using this to obtain φ is as follows.

$$\varphi = \arctan\left(\frac{\dfrac{y_{x2-x1}}{\cos\theta_x}}{\dfrac{x_{x2-x1}}{\cos\theta_y}}\right) \tag{7}$$

D. Charging Terminal Docking

The charging terminal can be docked to the docker by using the previously calculated Δx, Δy, r, θ, φ. First, move the charging terminal by Δx in the x-axis and by Δy in the y-axis. After that, it rotates as much as θ_x and θ_y in the x-axis and y-axis as much as r distance from the center of the docker, and then performs a pivot as much as φ. Finally, the docking is completed by moving r in the direction of the optical axis.

III. Conclusion

In this paper, we propose a method of accurately grasping the geometry of the docker inserted into the electric vehicle using a stereo sensor, and docking the charging terminal to the docker using a fixed or movable multi-joint robot based on the determined geometry. When docking starts, hardware resources such as multi-joint robots, cameras, and lighting devices, stereo camera calibration maps, and software resources such as charging terminal detection algorithms are checked. When the preparation is complete, the multi-joint robot detects the exterior of the vehicle, receives a mono image from camera 1, and determines whether or not the marker to be searched is in the field of view. If the marker is in the field of view, a stereo image is input using camera 1 and camera 2. Based on the stereo image, docking is performed by calculating the relative positions of the docker center Δx, Δy, r, the degree of inclination θ, and the degree of distortion φ using the calibration information of camera 1 and camera 2 and the geometry of the marker.

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