Develop a Vision Based Auto-recharging System for Mobile Robots

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Abstract: The article develops a vision based auto-recharging system that guides the mobile robot moving to the docking station. The system contains a docking station and a mobile robot. The docking station contains a docking structure, a control device, a charger and a safety detection device and a wireless RF interface. The mobile robot contains a power detection module (voltage and current), an auto-switch, a wireless RF interface, a controller and a camera. The controller of the power detection module is Holtek chip. The docking structure is designed with one active degree of freedom and two passive degrees of freedom. In image processing, the mobile robot uses a webcam to capture the real-time image. The image signal transmits to the controller of the mobile robot via USB interface. We use Otsu algorithm to recognize the distance and orientation of the docking station from the mobile robot. In the experiment results, the proposed method can guided the mobile robot moving to the docking station.

Keywords: **auto-recharging system. mobile robot. docking station. degrees of freedom. USB interface. Otsu algorithm**

I. INTRODUCTION

Mobile robots have been widely applied in many fields with passing year. Such as factory automation, dangerous environment detection, office automation, hospital, entertainment, space exploration, farm automation, military, education, learning and security system and so on. The mobile robot has been working in long time, and the power of the mobile robot is weakness, and moves to the docking station autonomously before under control.

In the past literature, many researches have been proposed power detection methods. Levi was one of the first to comment upon the characteristics of CMOS technology which make it special amenable to I_{DD} Testing [1]. Malaiya used I_{DD} testing and estimating the effects of increased integration on measurement resolution [2]. Frenzel proposed the likelihood ration test method applying on power-supply current diagnosis of VLSI circuits [3]. Horning *et al* reported on numerous experiments where current measurements have forecast reliability problems in devices which had previously passed conventional test procedures [4]. Maly *et al.* proposed a build-in current sensor which provides a pass/fail signal when the current exceeds a set threshold [5]. In image processing, many techniques have been proposed. Weszka *et al.* use the valley sharpening method to restrict the histogram on the pixels with large absolute value [6]. Watanabe used the different histogram method to select the threshold at gray level with the maximal amount of difference [7].

The article is organized as follows: Section II describes the system structure of the auto-recharging system for the mobile robot, and explains the functions of the power detection module and the power measurement and prediction algorithms. Section III presents hardware structure and docking processing of the station. The section IV explains the image processing method to find out the docking station. Section V presents the experiment results of the auto-recharging processing for the mobile robot moving to the station using the proposed method. Section VI presents brief concluding remarks.

II. SYSTEM ARCHITECHTURE

The hardware structure of the auto-recharging system is classified two parts: one is designed in docking station. The other is designed in the mobile robot. The relation is shown in Fig. 1. In the docking station, there are a limit switch, a landmark, a safety detection device, a wireless RF interface and a charger. The landmark can guide the mobile robot moving to the docking station using vision system. The safety detection device contains safety switch and power detection module. The limit switch can detect the mobile robot touching the station or not. The wireless RF interface can communicate with the mobile robot via RS232 interface, and transmits the status of the recharging processing between the docking station and the mobile robot.

The power of the mobile robot is weakness on the free space. The camera can find out black bars of the docking station using the proposed method. The mobile robot decides the direction from the docking station according to the relation position of the two black bars.

The wireless RF interface can communicate with the docking station, and transmits and receives the real-time signal. The power detection module can measures current and voltage values of the auto-recharging processing, and transmits to the controller of the mobile robot via RS232 interface. The prototype of the power detection module is shown in Fig. 2. The IR sensor can decides the mobile robot touching the docking station, and transmits the signal to the controller of the mobile robot. The mobile robot opens the auto-switch, and touches with the connective pins of the docking station.

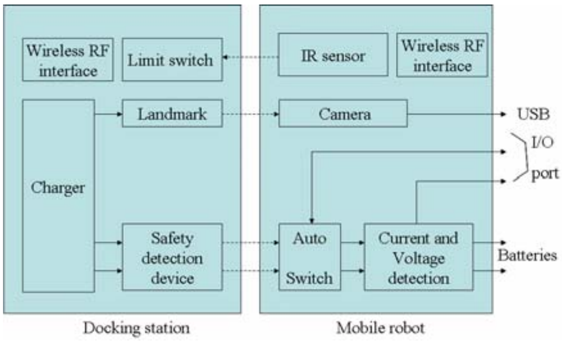


Fig. 1. The auto-recharging system

The mobile robot has the shape of cylinder and its diameter, height, and weight are 40 cm, 70 cm, and 25 kg, respectively. It has four wheels to provide the capability of autonomous mobility [8]. The mobile robot contains six systems, including structure, motion and driver system, software development and supervised system, detection system, auto-recharging system and camera.

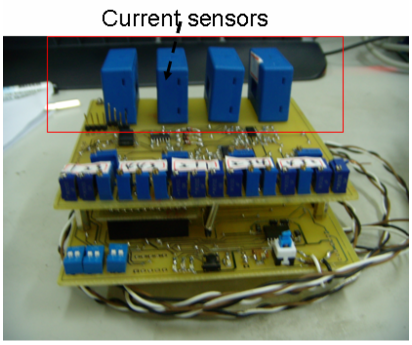


Fig. 2. The power detection module

In the power detection module, we use four current sensors to measure the current variety of the mobile robot and charging current, and use two multisensor fusion methods (redundant management method and a statistical prediction method) to detect current and voltage signals status. We can get an exact measured value for power detection [9]. Then we want to predict the residual power of the mobile robot. First we must fit the curve from the power detection value of the mobile robot. Next the user can set the critical value of the power. The main controller of the mobile robot can calculate the extrapolation value from the critical value, and can calculate the residual working time for the mobile robot.

We fit a second-order polynomial regression

$$y = a_0 + a_1 x + a_2 x^2 + e \qquad (1)$$

The sum of the squares of the error is

$$S_r = \sum_{i=1}^{n} (y_i - a_0 - a_1 x_i - a_2 x_i^2)^2 \qquad (2)$$

To generate the least squares fit, we take the derivative of Equation (2) with respect to each of the unknown coefficient of the polynomial, and we can get

$$\begin{aligned} na_0 + (\sum x_i)a_1 + (\sum x_i^2)a_2 &= \sum y_i \\ (\sum x_i)a_0 + (\sum x_i^2)a_1 + (\sum x_i^3)a_2 &= \sum x_i y_i \\ (\sum x_i^2)a_0 + (\sum x_i^3)a_1 + (\sum x_i^4)a_2 &= \sum x_i^2 y_i \end{aligned} \qquad (3)$$

Finally we can calculate $a_0, a_1,$ and a_2 from Equation (3). Then we set the power critical value to be P_S and

$$a_2 x^2 + a_1 x + a_0 = P_S \qquad (4)$$

We can calculate the x value (the unit is second) from Equation (4). The sample time of the power detection module is 1 second.

III. Docking station

The docking station is shown in Fig. 3, and provides two connective points to provide charging current to the mobile robot. The docking station is designed with two passive DOF (Degree Of Freedom) and one active DOF. It can rotate in the Z-axis and use compression spring to move for various docking condition. The weight of the docking station is almost 6 kg, and its length, and height, and width are 70cm, 50cm and 80cm, respectively. The station extends 15 cm to touch the mobile robot providing a 30^0 entry window. The connective docking mechanism is mounted on the back of the mobile robot.

The mobile robot docking mechanism is shown in left side of the Fig. 3 (c). The recharging adapters are at the inside of the holes. Each hole is shaped as a cone in order to help the docking smoothly. Since both the connection pins and adapters are rigid, the docking station is designed for providing compliance for reasonable robot docking angle and offset. When the mobile robot is approaching to the docking station with offset and docking angle, the guiding stick mounted on the docking station functions to guide the recharging pins for inserting into the adapters. We plot two black bars on the front of the docking station to be shown in Fig. 4. The mobile robot recognizes the position of the docking station according to the two black bars using vision system.

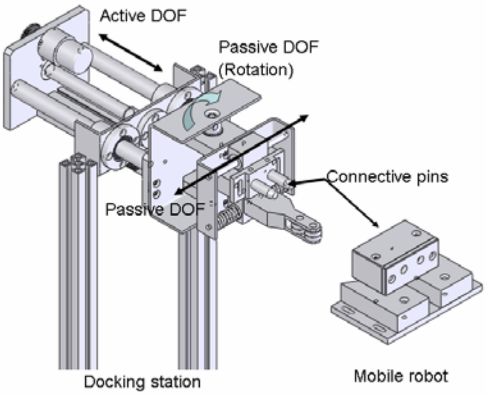


Fig. 3. The structure of the docking station

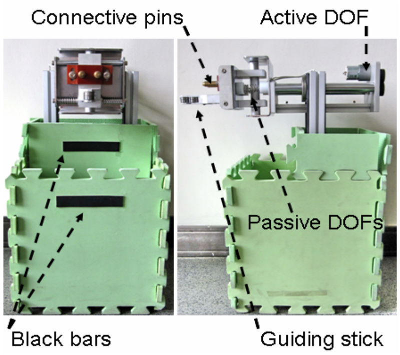


Fig. 4. The docking station

IV. Algorithms analysis

We use Otsu algorithm to recognize the landmark of the station docking. In image reorganization, we define the pixels of a given picture be represented in L in gray levels $[1,2,\ldots\ldots,L]$. The number of pixels at level i is denoted by n_i, and the total number of pixels is $N = n_1 + n_2 + \cdots + n_L$. In order to simplify the discussion, we can rewrite the gray level histogram to be normalized and regarded as a probability distribution:

$$p_i = n_i / N, \qquad p_i \geq 0, \qquad \sum_{i=1}^{L} p_i = 1 \tag{5}$$

Now suppose that we dichotomize the pixels into two classes C_0 and C_1 (back ground and objects) by a threshold at level k; C_0 denotes pixels with levels $[1,2,\cdots\cdots,k]$, and C_1 denotes pixels with levels $[k+1,k+2,\cdots\cdots,L]$. Then the probabilities of class occurrence and the class mean levels, respectively, are given by

$$\omega_0 = \Pr(C_0) = \sum_{i=1}^{k} p_i = \omega(k) \tag{6}$$

$$\omega_1 = \Pr(C_1) = \sum_{i=k+1}^{L} p_i = 1 - \omega(k) \tag{7}$$

$$\omega(k) = \sum_{i=1}^{k} p_i, \quad \mu(k) = \sum_{i=1}^{k} i p_i, \quad \mu_G = \mu(L) = \sum_{i=1}^{L} i p_i \tag{8}$$

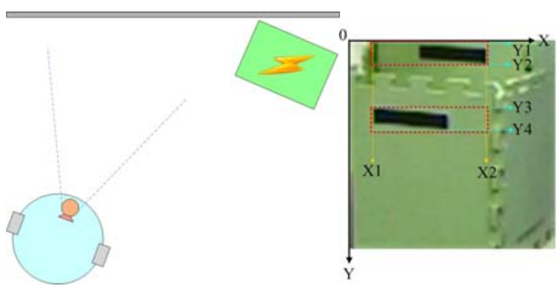
Then the optimal threshold k^* can be funded to maximize η [10,11].

$$\eta(k) = \sigma_B^2(k) / \sigma_G^2, \qquad \sigma_B^2(k) = \frac{[\mu_G \omega(k) - \mu(k)]^2}{\omega(k)[1-\omega(k)]} \tag{9}$$

$$\sigma_B^2(k^*) = \max_{1 \leq k \leq L} \sigma_B^2(k) \tag{10}$$

V. Experimental results

We make an experiment to implement the auto-recharging processing using the Otsu algorithm for the robot moving to the docking station. The power of the mobile robot is under the critical power. The mobile robot searches the docking station using camera to be shown in Fig. 5. The mobile robot finds out the landmark of the station using camera. Then it moves closed to the docking station using the proposed algorithm to decide the direction of the mobile robot. The experiment result is shown in Fig. 5(a). The original gray-level picture of the station is shown in Fig 5(b). We focus on the landmark, and set two points (X_1 and X_2) on column projection, and set four points (Y_1, Y_2, Y_3 and Y_4) on row projection. We use Otsu algorithm to process the picture from the camera, and calculate the results of the threshold, and plot the row projection image and the column projection image to be shown in Fig. 5(c) and (d). The mobile robot can calculates the direction and distance from the docking station.



(a) (b)

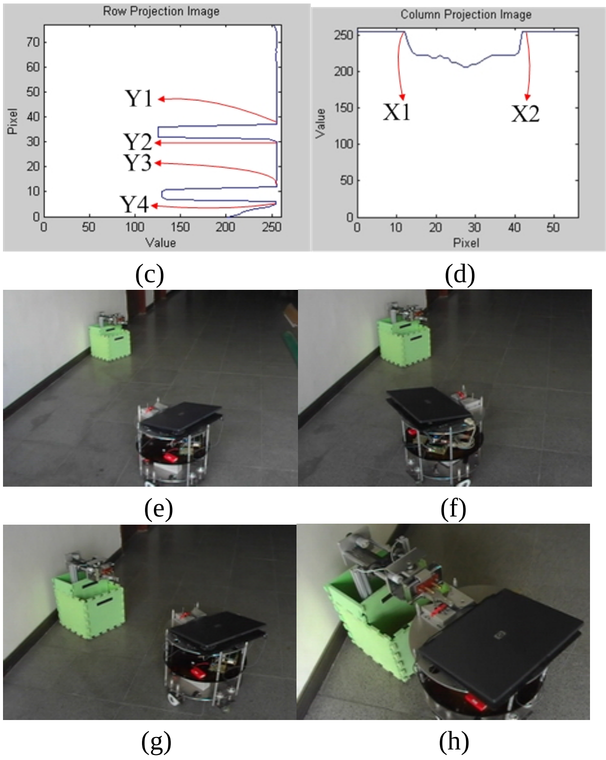


Fig. 5. The experiment result of auto-docking for the mobile robot

The mobile robot moves to the front of the docking station to be shown in Fig. 5(e), and turn left to face the station. Then it moves the station, and modifies the direction according to the position of landmark. The experiment scenario is shown in Fig 5(f). The mobile robot moves to the docking station, and touch the limit switch. The docking station transmits RF signal to the mobile robot. The mobile robot must stop, and prepares to execute the charging processing. The experimental results are shown in Fig. 5 (g) and (h). We make some tests on variety direction of the robot moving the docking station to determine the performance using the proposed method, 100 experimental results were performed, and show a 99% successful rate for the docking processing.

VI. CONCLUSION

We have developed a vision based auto-recharging system that had been integrated in the mobile robo. The system contains a docking station and a mobile robot. We can get an exact measured value for power detection, and calculate the residual working time using second-order polynomial regression. We use Otsu algorithm to recognize the two black bars of the docking station, if the mobile robot locates on the front of the docking station. The proposed algorithm can guides the mobile robot moving to the docking station. In future, we want to implement the auto-recharging processing and path planning on the multiple docking stations for mobile robots.

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