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COMPUTER CONTROL OF WHEEL CHAIR BY USING LANDMARKS

Hongbo WANG Shin-ichirou TANAKA
Cheolung KANG Takakazu ISHIMATSU

Mechanical Systems Department, Nagasaki University , Bunkyo-machi, Nagasaki 852, JAPAN
Tel: +81-958-47-1111; Fax: +81-958-47-3247; Email: Hongbo@welcome.mech.nagasaki-u.ac.jp

Abstract. The paper describes computer control of a wheel chair by using landmarks. Firstly, the approach of landmark detection and recognition is described and the image coordinates are obtained by the primary component analysis method. Subsequently, the self-localization of the wheel chair is determined on the basis of a three-dimensional image processing method. Finally, the control system of the wheel chair is described and a navigation experiment is given. Experimental results indicate the effectiveness of our approach.

Keywords. Landmark, Self-Localization, Wheel Chair, Image Processing, Control

1. INTRODUCTION

The commercial electric wheel chair has been widely used by handicapped persons suffering from lower extremity amputations. However, it is difficult for handicapped persons ,having both upper and lower extremity amputations, to drive a wheel chair. For this reason, an automatic wheel chair with the capability of self-localization has been developed in our laboratory so that daily tasks can be coped with easily.

The capability of self-localization is critical to reliable performance of the wheel chair. It can be used to recover from failures during navigation. There are many methods that can determine the self-localization of the wheel chair. One simple and reliable method is by providing landmark features of the workspace as external reference sources. Several researchers have approached the self-localization problem of mobil robots by employing "standard marks" [1-4]. The key idea is to use special marks that include a wealth of geometric information under perspective projection such that the camera location can be easily computed from the image of the guide-marks.

In our research, we have chosen "ceiling lights" as landmarks because they can be easily detected due to the high contrast between the light and the ceiling surface and do not require special installation. Dulimarta [5] used "ceiling light" as landmark. However, the "ceiling light" was used only for light counter. In this paper, we propose a 3D localization algorithm using "ceiling light" as landmark. In section 2, the approach of landmark detection and recognition is described and the image coordinates are obtained by the primary component analysis method. In section 3, the self-localization of the wheel chair is performed using a three-dimensional image processing method. The control system of the wheel chair is described and a navigation experiment is given in section 4. Finally, we give the conclusion of the paper.

2. Image processing of landmark recognition

In our experimental environment, the "ceiling lights" are two fluorescent lights having a length of 1175mm that are installed parallel. In order to detect and recognize the landmarks effectively, the input image must be reprocessed as follows: (1) stretch the gray level values to increase the contrast, (2) impose a threshold level on the gray level image to obtain a binary image, (3) use a labeling method to obtain the area and coordinates of every image and (4) retrieve the two fluorescent lights used for landmark on the basis of the area and coordinates of the image.

2.1 The acquirement of the boundary points of ceiling light

The contour of two lights obtained using the above method is shown in Fig.1. The image coordinates of upper and lower sides of the external quadrilaterals of each contour are v_{min} and v_{max}, and the image coordinates of left and right are u_{min} and u_{max}. Suppose $v_{max}-v_{min}>(u_{max}-u_{min})/2$, we consider 10 horizontal

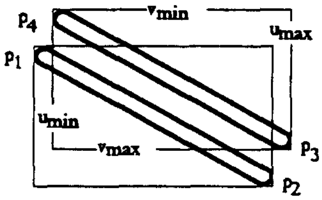
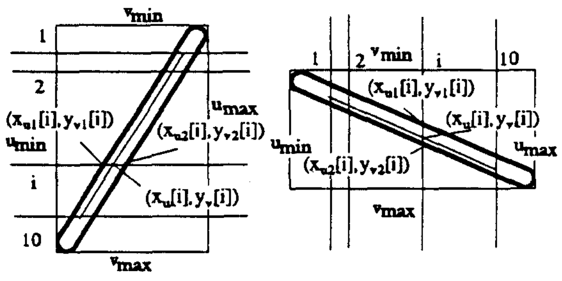


Fig.1 Image obtained by labeling



(a) (b)

Fig.2 Calculation of the boundary points lines at the distance associated with 1/11th, 2/11th ... 10/11th of the whole image height as shown in Fig.2(a). Also in the case $v_{max}-v_{min} \leq (u_{max}-u_{min})/2$, we consider 10 vertical lines as shown in Fig.2(b). From the cross points of these lines and the contour of the light image, 20 points can be obtained as featuring points.

2.2 The calculation of central line of light

Here the primary component analysis method is used to calculate the central line of the ceiling light. There are two contour points on every line for one light. The middle coordinate of every two points is expressed as $(x_u[i], y_v[i])$. The average values of $x_u[i]$ and $y_v[i]$ are expressed as $\bar{x}$ and $\bar{y}$. The variance and covariance of $x_u[i]$ and $y_v[i]$ can be expressed in the following equations [6]

$$s_{xx}=\frac{1}{9}\sum_{i=1}^{9}(x_u[i]-\bar{x})^2 \qquad s_{yy}=\frac{1}{9}\sum_{i=1}^{9}(y_v[i]-\bar{y})^2$$

$$s_{xy}=s_{yx}=\frac{1}{9}\sum_{i=1}^{9}(x_u[i]-\bar{x})(y_v[i]-\bar{y}) \tag{1}$$

The maximum of variance s_{ff} of composition score can be expressed as

$$s_{ff}=[w_1 \;\; w_2]\begin{bmatrix} s_{xx} & s_{xy} \\ s_{yx} & s_{yy} \end{bmatrix}\begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \tag{2}$$

If the weight w_1 and w_2 do not be limited, the variance will probably become infinity. Therefore, we give the restriction equation $w_1^2+w_2^2=1$. To calculate w_1 and w_2 when s_{ff} is maximum, we structure the following function

$$f(w_1, w_2)=s_{ff}-\lambda(w_1^2+w_2^2-1) \tag{3}$$

Let the partial derivative of above equation relative to w_1 and w_2 equal to zero, the following equation can be derived

$$\begin{bmatrix} s_{xx} & s_{xy} \\ s_{yx} & s_{yy} \end{bmatrix}\begin{bmatrix} w_1 \\ w_2 \end{bmatrix}=\lambda\begin{bmatrix} w_1 \\ w_2 \end{bmatrix} \tag{4}$$

From the characteristic equation of above equation , the eigenvalue λ can be calculated in following equation

$$\lambda=\frac{1}{2}\left(s_{xx}+s_{yy})+\sqrt{(s_{xx}+s_{yy})^2-4(s_{xx}s_{yy}-s_{xy}^2)}\right) \tag{5}$$

Substituting λ into equation (4), w_1 and w_2 can be obtained as follows

$$w1=\frac{s_{xy}}{\sqrt{s_{xy}^2+(\lambda-s_{xx})^2}} \qquad w2=\frac{\lambda-s_{xx}}{s_{xy}}w1 \tag{6}$$

The straight line equation of the primary component can be written as

$$\frac{y-\bar{y}}{x-\bar{x}}=\frac{y_1-\bar{y}}{x_1-\bar{x}}=k \tag{7}$$

Where $x_1=\bar{x}+w_1c$, $y_1=\bar{y}+w_2c$ and c is an any constant.

2.3 Calculation of the end point of light

The central line of light and the four lines of light external quadrilateral intersect at four points as shown in Fig.3. Let it be supposed that the four straight lines of quadrilateral are $x_1'=u_{min}$, $x_2'=u_{max}$, $y_1'=v_{min}$, $y_2'=v_{max}$. Substituting x_1' and x_2' into equation (7), y coordinates of two points are obtained

$$y_1=k(u_{min}-\bar{x})+\bar{y} \qquad y_2=k(u_{max}-\bar{x})+\bar{y} \tag{8}$$

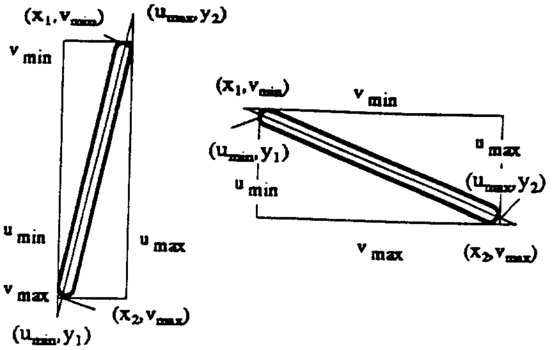


Fig.3 Calculation of ends of light

Substituting y_1' and y_2' into equation (7), x coordinates of two ends are obtained

$$x_1=\frac{1}{k}(v_{min}-\bar{y})+\bar{x} \qquad x_2=\frac{1}{k}(v_{max}-\bar{y})+\bar{x} \tag{9}$$

From equation (8), the coordinates of two ends are (u_{min}, y_1) and (u_{max}, y_2). From equation (9), the coordinates of two ends are (x_1, v_{min}) and (x_2, v_{max}). The distances of the two points are respectively

$$d_1=\sqrt{(u_{max}-u_{min})^2+(y_2-y_1)^2} \qquad d_2=\sqrt{(x_2-x_1)^2+(v_{max}-v_{min})^2} \tag{10}$$

When $d_1<d_2$, the coordinates of two ends are taken as (u_{min}, y_1) and (u_{max}, y_2). Otherwise, (x_1, v_{min}) and (x_2, v_{max}) .

3. Determination of self-localization of wheel chair

3.1. The position vector q_i of both ends of light

On the basis of the image of the ceiling light, the position and posture of the camera can be determined as follows. From perspective transformation, the relation between q_i and p_i can be expressed as (Fig.4)

$$q_i=k_ip_i \qquad (i=1,2...4) \tag{12}$$

Where $q_i=(x_i \; y_i \; z_i)$ indicates the position vector of light end in camera coordinate system, $p_i=(u_i \; v_i \; f)$ represents the raster coordinate of correspondent point, k_i is the proportion coefficient between two vectors. Since the two light are parallel and the lengths of the two light are equal, following vector equation can be obtained

$$k_1p_1-k_2p_2=k_4p_4-k_3p_3 \tag{13}$$

From the above equation, the following equation can be derived

$$k_1p_2\cdot(p_4\times p_1)=-k_3p_2\cdot(p_4\times p_3) \tag{14}$$

From the above equation, the ratio of k_3 and k_1 can be obtained

$$k_3=c_{31}k_1 \qquad c_{31}=-\frac{p_2\cdot(p_4\times p_1)}{p_2\cdot(p_4\times p_3)} \tag{15}$$

Using similar procedure, we can obtain $k_4=c_{41}k_1$, $k_2=c_{21}k_1$. The distance between q_1 and q_2 is the length of light, namely, $|q_i-q_1|=1175$mm. It can also be expressed in following form

$$|k_2p_2-k_1p_1|=k_1\sqrt{p_1^2-2c_{21}(p_1\cdot p_2)+c_{21}^2p_2^2} \tag{16}$$

From above equation, the proportion coefficient k_1 can be calculated

$$k_1=\frac{1175}{\sqrt{p_1^2-2c_{21}(p_1\cdot p_2)+c_{21}^2p_2^2}} \tag{17}$$

Since k_1 is known, the k_2, k_3 and k_4 can be obtained. From the equation (12), the q_i can be calculated.

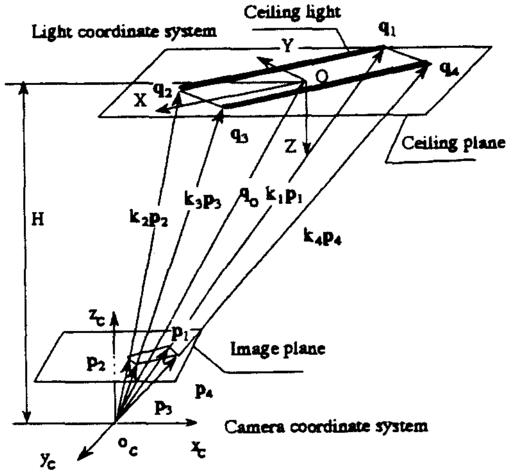


Fig.4 Relation between the camera and light coordinate systems

In our study, the plane of the light and the plane of the camera are always parallel, the vertical distance from camera to light is a constant. However, under the practical condition, the z coordinate of point q_i calculated by equation (12) often fluctuates, which will influence the precision of relative position between camera and light. Therefore, we suppose that the z coordinate of point q_i is equal to the vertical height H from camera to light, that is, $q_{iz}=H$.

3.2 Establishment of light coordinate system

Since the light is installed on the ceiling of the building, it is static. Therefore, we take the light coordinate system as the base coordinate system. The base system is set up as follows (Fig.4): The origin O of the base system is chosen at the middle point of points q_1 and q_3, that is, $q_o=(q_3+q_1)/2$. X-axis is along with the direction from q_1 to q_2; Z-axis is along the normal line of the plane that is determined by three points q_1, q_2 and q_3. The unit vector of X-axis can be obtained using following equation

$$e_x=\frac{q_2-q_1}{|q_2-q_1|} \tag{18}$$

Z-axis is determined using the normal line of the plane which is composed of three points q_1, q_2 and q_3. . The normal vector of the plane can be derived as follows

$$\bar{n}=\left\{\begin{matrix}(q_{1y}-q_{3y})(q_{2z}-q_{3z})-(q_{2y}-q_{3y})(q_{1z}-q_{3z})\\-(q_{1x}-q_{3x})(q_{2z}-q_{3z})+(q_{2x}-q_{3x})(q_{1z}-q_{3z})\\(q_{1x}-q_{3x})(q_{2y}-q_{3y})-(q_{2x}-q_{3x})(q_{1y}-q_{3y})\end{matrix}\right\} \tag{19}$$

The unit vector of Z-axis can be obtained in the following equation

$$e_z=\frac{1}{\sqrt{n_1^2+n_2^2+n_3^2}}(n_1,\ n_2,\ n_3)^T \tag{20}$$

The unit vector of Y-axis can be determined by right hand rule, namely, $e_y=e_z \times e_x$.

3.3 The position and orientation of camera relative to light coordinate system

After e_x, e_y and e_z are obtained, the transformation matrix of the base coordinate system relative to camera system can be formed

$$[A]=[e_x\ e_y\ e_z] \tag{21}$$

The relation between two coordinate systems can be expressed as follows

$$(x_c\ y_c\ z_c)^T=[A](x\ y\ z)^T+q_o \tag{22}$$

Where x_c, y_c and z_c indicate the coordinates in camera system, x,y and z indicate the coordinates in base system. Let $x_c=y_c=z_c=0$, the position of camera in base coordinate system can be calculated

$$(x\ y\ z)^T=-[A]^Tq_o \tag{23}$$

Since the planes of camera and light are parallel, the transformation matrix rotates only about Z-axis. The rotation angle of the base system relative to camera system can be calculated as follows

$$\alpha=\tan^{-1}\left(\frac{\sin\alpha}{\cos\alpha}\right)=\tan^{-1}\left(\frac{e_{x2}}{e_{x1}}\right)=\tan^{-1}\left(\frac{e_{y1}}{e_{y2}}\right) \tag{24}$$

Where $-\alpha$ is the rotation angle of camera system relative to base system.

4. Control system and experimental results

4.1 Control system

The control system of the wheel chair is shown in Fig.5. CPU Z80 is used to control the navigation of the wheel chair.

Two rotary encoders (resolution 40 degrees) are installed at two drive wheels respectively so that the distance which the wheel chair has traveled can be measured.

To know the direction of the wheel chair, the geomagnetic azimuth instrument is employed. The sensor can measure two vertical geomagnetic components on horizontal. From the output analogue volts of the geomagnetic azimuth instrument, the direction angle can be calculated after A/D transformation.

A CCD cameras with 3.7mm lens is installed on the wheel chair to detect landmarks. Since the image processing of landmark need a few seconds, Computer (PC9801) is used for the image processing. Only the processing results, that is, the x, y coordinates of camera relative to light coordinate system and the angle about z axis as well as the number of landmarks are send to CPU Z80 by RS232 data communication.

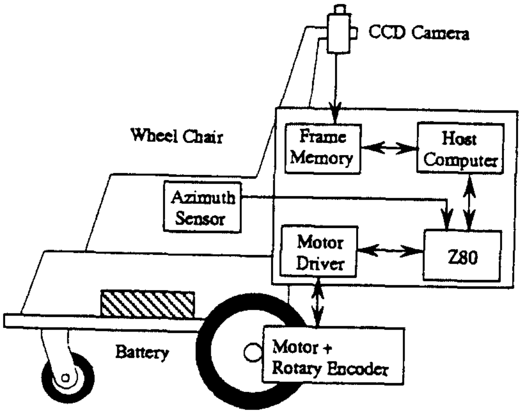


Fig.5 Control system of a wheel chair

4.2 Accuracy test

In order to test the accuracy of the detection of the ceiling light, we put the wheel chair under the ceiling light, so that the camera is located on the Z-axis of the base coordinate system. We repeated to measure the position of the camera by rotating the camera 20 times in different direction. Fig.6 shows that the error of the origin of two coordinate systems is less than 60mm.

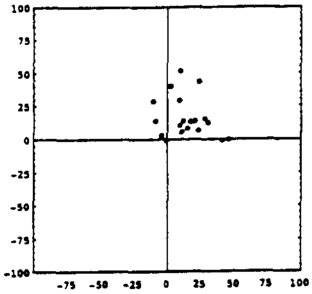


Fig.6 Accuracy Test

4.3 Experimental results

We had an experiment in a room where ten ceiling lights are installed. The navigation map of the wheel chair is shown in Fig. 7. We have tested the navigation of the wheel chair 20 times with the navigation course of the solid line. Our wheel chair is able to locate its final destination with a maximum position error of 0.35 meters and a maximum orientation error of 17 degrees as shown in Fig. 8.

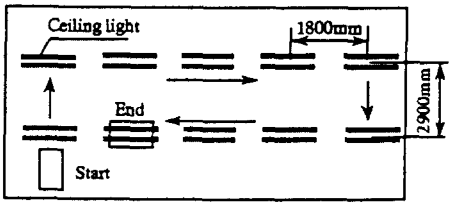


Fig.7 Navigation map of wheel chair

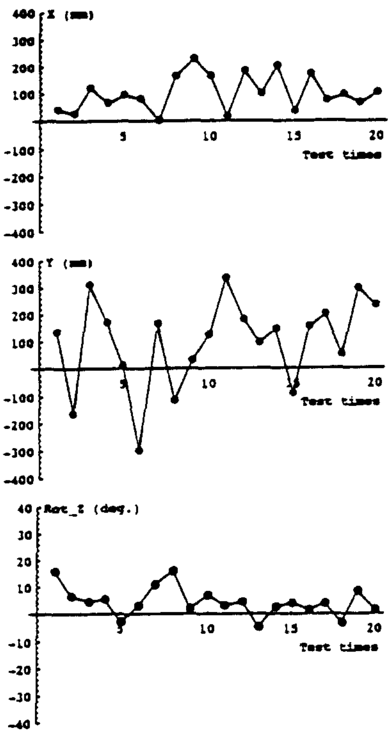


Fig.8 Error of final destination of navigational test

5. Conclusion

In this paper, we choose the ceiling light as landmark to use for the control of an indoor moving wheel chair. The approach of landmark detection and recognition and the self-localization of the wheel chair is described and the control system of the wheel chair is introduced. We had experiments of the navigation of the wheel chair in a room. The experimental results indicate the effectiveness of the approach we presented here.

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