

# VISION-BASED AUTONOMOUS VEHICLE GUIDANCE IN INDOOR ENVIRONMENTS USING ODOMETER AND HOUSE CORNER LOCATION INFORMATION\*

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## ABSTRACT

An approach to vehicle guidance using odometer and house corner location information is proposed for vision-based vehicle navigation in indoor environments. A small vehicle with wireless control and image grabbing capabilities is used as a test bed. A camera with the pan-tilt-zoom capability is equipped on the vehicle. The vehicle is guided to follow a path consisting of nodes learned in advance, which include the information of travel distances and turning angles provided by the odometer. A vehicle location method using house corners is proposed to estimate vehicle location which can be used to correct vehicle location, thus preventing mechanic error accumulation in long-distance navigation. Good experimental results show the feasibility of the proposed approach.

**Keywords:** Vehicle, patrolling, security surveillance, location, danger condition, painting.

## 1. INTRODUCTION

To design a vision-based autonomous vehicle for navigation in complicated indoor environments, a flexible guidance method is required. Many methods have been proposed for this purpose [1-10]. It is popular to use landmarks for robot or vehicle location [5-7] whose results can be used for vehicle guidance. The information of house ceiling corners (called simply house corners in the sequel) is a good feature for vehicle location [6]. Use of house corners for vehicle guidance has several merits. One is that house corners exist at higher positions and so will not be occluded by objects and people surrounding the vehicle. Another merit is that house corners have simple "Y-shaped" structures composed of three lines which are easy to detect in images. A third merit is that house corners appear at fixed locations which facilitate vehicle location estimation. In this study

we use house corners as landmarks for vehicle guidance, in addition to the information provided by the odometer equipped in the vehicle.

More specifically, we use two types of vehicle location information in the proposed vehicle guidance method. One is the vehicle location information in each navigation cycle recorded with an odometer in the vehicle. The other is the vehicle location information extracted from house corner images captured with a pan-tilt-zoom (PTZ) camera on the vehicle. The former is the main information utilized to guide the vehicle in a navigation session, while the latter is used as auxiliary information for navigation path correction at appropriate spots. It is noted that the odometer information, though precise enough for most applications, cannot be used solely for the guidance process because mechanical errors might accumulate and so deviate the vehicle from its normal paths. The house corner information is thus used, whenever necessary, for locating the vehicle and correcting errors at proper navigation spots.

A robot location technique using house corner information was proposed by Chou and Tsai [6]. We modify their method in this study and apply the resulting technique to the application of indoor vehicle guidance which has the properties of *on-floor* navigation and image taking with a *zero-swing* camera. The resulting estimation of the vehicle location is thus simpler than those derived by Chou and Tsai [6]. The estimation formulas are *analytic* and so speed up the vehicle guidance process.

In the remainder of this paper, we first describe the vehicle navigation principle in Section 2. Then we describe the proposed vehicle location method using house corners in Section 3. Some experimental results are described in Section 4, followed by conclusions in Section 5.

## 2. NAVIGATION PRINCIPLES

The appearance of the vehicle used a test bed in this study is shown in Fig 1. Before the vehicle is allowed to navigate in an indoor environment, a navigation map is created first in a learning stage. The map consists of sev-

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eral vehicle navigation paths. In the learning of a path, the vehicle is instructed to navigate through the path by the use of a separate notebook PC. The PC issues appropriate commands via wireless communication to drive the vehicle. Each path is composed of several *nodes*, and each node represents a spot along the path, where the vehicle is stopped to collect information about the node and save it in the map. The information of a node includes: (1) the travel distance of the vehicle from the last node; (2) the turning angle of the vehicle at the node, and (3) if necessary, the command to instruct the vehicle to conduct a path correction operation by house corner location. After the manual learning stage is completed, a set of learned data, including all node information, are organized as a navigation map.



Fig. 1 The test bed used in this study. (a) The vehicle. (b) The PTZ camera.

During the navigation stage, the vehicle moves sequentially from one node to another according to a selected path in the navigation map. While the vehicle navigates cycle after cycle, whether the vehicle reaches the next node or not is checked continuously. And after a node is reached, whether a vehicle location operation is needed is checked. If so, the operation is conducted after a house corner image is taken, and the *real* vehicle location is estimated. By comparing the real vehicle location with the desired location computed from the odometer information recorded in the current path node, whether the vehicle has gone astray or not is decided. If so, the navigation path is corrected by moving the vehicle to the desired location specified in the path node before the navigation to the next node is started. A more detailed description of the learning and navigation stages is given in the following.

- Step 1. Drive the vehicle through desired indoor spots and record the odometer information and vehicle location commands as node information.
- Step 2. Create a navigation map by the learned node information.
- Step 3. Start the navigation session and guide the vehicle to the next navigation node.
- Step 4. Whenever the vehicle reaches a node, acquire a house corner image, if necessary, and conduct the vehicle location operation.
- Step 5. If the estimated vehicle location indicates that the vehicle deviates from the navigation node too far, guide the vehicle to the correct location computed from the learned node data.

Step 6. Repeat the above steps until the goal of navigation is reached.

### 3. VEHICLE LOCATION USING A HOUSE CORNER DETECTION TECHNIQUE

Three edge lines compose a house corner, as shown in Fig. 2. We use only two of them to locate the vehicle in this study. The vertical one is not used. The principle is to use the coefficients of the equations of the edge lines through the corner point to estimate the vehicle location.



Fig. 2 Illustration of house corner. (a) A real house corner. (b) The two edge lines of a house corner used for vehicle location in this study (vertical dotted line is not used).

Let  $(X, Y, Z)$  denote the global coordinate system which is built on a corner of the house with the  $X$  and  $Y$  axes being the two used edge lines and the origin being just the corner point. The equations of the three lines in terms of image coordinates  $(u, v)$  may be described by  $u_p + b_i v_p + c_i = 0$  where  $i = 1, 2, 3$ . On the other hand, the vehicle location may be described by the three position parameters  $(X_c, Y_c, Z_c)$  and two direction parameters  $\psi$  and  $\theta$  of the camera with respect to the global coordinate system, where  $Z_c$  is the height of the ceiling with respect to the camera and is assumed to be known in advance, and  $\psi$  and  $\theta$  is the pan and tilt angles of the camera. The five vehicle location parameters can be derived in terms of the four coefficients  $b_1, c_1, b_2, c_2$  of the equations of the two “v-shaped” edge lines in the corner image. The details are described as follows.

At first, we transform the global coordinate system (GCS) into the camera coordinate system (CCS) by four steps: (1) translate the origin of the GCS to the origin of the CCS; (2) rotate the  $X$ - $Y$  plane about the  $Z$ -axis in the GCS; (3) rotate the  $Y$ - $Z$  plane about the  $X$ -axis; and (4) reverse the  $Z$ -axis. The 4-step transformation may be represented by a matrix  $T_r$  composed of four smaller matrices  $T, R_z, R_x, F_z$  (not shown below) as follows:

$$T_r = T(X_c, Y_c, Z_c)R_z(\psi)R_x(\theta)F_z$$

$$= \begin{bmatrix} \cos \psi & -\sin \psi \cos \theta & -\sin \psi \sin \theta & 0 \\ \sin \psi & \cos \psi \cos \theta & \cos \psi \sin \theta & 0 \\ 0 & \sin \theta & -\cos \theta & 0 \\ x_0 & y_0 & z_0 & 1 \end{bmatrix}$$

where

$$\begin{aligned}x_0 &= -X_c \cos \psi - Y_c \sin \psi; \\y_0 &= (X_c \sin \psi - Y_c \cos \psi) \cos \theta - Z_c \sin \theta; \\z_0 &= (X_c \sin \psi - Y_c \cos \psi) \sin \theta + Z_c \cos \theta.\end{aligned}$$

Let  $P$  be a point on the  $X$  axis, which is one of the two used edge lines, with global coordinates  $(x, 0, 0)$ . Then its camera coordinates  $(u_x, v_x, w_x)$  can be derived to be:

$$\begin{aligned}(u_x, v_x, w_x, 1) &= (x, 0, 0, 1) \cdot T_r \\&= (x \cos \psi + x_0, -x \sin \psi \cos \theta + y_0, -x \sin \psi \sin \theta + z_0, 1).\end{aligned}$$

Let  $(u_p, v_p)$  be the image coordinates of the projection of  $P$  in the image. Then we have the following two equations to describe  $u_p$  and  $v_p$  according to the triangulation principle:

$$u_p = f \times (u_x / w_x); \quad v_p = f \times (v_x / w_x),$$

where  $f$  is the camera focus length. Substituting the values of  $u_x$  and  $v_x$  above into the previous equation and eliminating the variable  $x$ , we get the equation for the projection of the  $X$  axis in the image coordinate system (ICS) as:

$$u_p = \frac{v_p \cdot (-z_0 \cos \psi - x_0 \sin \psi \sin \theta) + f \cdot (y_0 \cos \psi + x_0 \sin \psi \cos \theta)}{-y_0 \sin \psi \sin \theta + z_0 \sin \psi \cos \theta}.$$

After substituting  $u_p$  into  $u_p + b_1 v_p + c_1 = 0$  which describes the  $X$  axis, we obtain the coefficients  $b_1$  and  $c_1$  as follows:

$$\begin{aligned}b_1 &= \frac{Y_c \sin \theta - Z_c \cos \psi \cos \theta}{-Z_c \sin \psi}; \\c_1 &= \frac{f \cdot (-Y_c \cos \theta - Z_c \cos \psi \sin \theta)}{-Z_c \sin \psi}.\end{aligned}$$

Similarly, the coefficients of the edge line equation  $u_p + b_2 v_p + c_2 = 0$  for the projection of the  $Y$  axis in the ICS can be derived to be as follows:

$$\begin{aligned}b_2 &= \frac{-X_c \sin \theta - Z_c \sin \psi \cos \theta}{Z_c \cos \psi}; \\c_2 &= \frac{f \cdot (X_c \cos \theta - Z_c \sin \psi \sin \theta)}{Z_c \cos \psi}.\end{aligned}$$

As to the derivations of the direction parameters  $\psi$  and  $\theta$ , we eliminate  $Z_c$ ,  $Y_c$ , and  $X_c$  in the equations for  $b_1$ ,  $c_1$ ,  $b_2$  and  $c_2$  above to obtain:

$$\begin{aligned}\tan \psi &= \frac{f}{fb_1 \cos \theta + c_1 \sin \theta}; \\ \tan \psi &= \frac{-fb_2 \cos \theta - c_2 \sin \theta}{f},\end{aligned}$$

from which we get

$$\theta = \tan^{-1} \left[ \frac{-f(b_1 + b_2)}{c_1 + c_2} \right].$$

Accordingly,  $\psi$  can also be obtained from the previous equations about  $\tan \psi$ . Finally,  $X_c$  and  $Y_c$  can be derived from the previous results to be as follows:

$$\begin{aligned}X_c &= \frac{-Z_c (\sin \psi \cos \theta + b_2 \cos \psi)}{\sin \theta}; \\ Y_c &= \frac{Z_c (\cos \psi \cos \theta - b_1 \sin \psi)}{\sin \theta}.\end{aligned}$$

We use the Canny edge detection method and the Hough transform to detect the edge lines in a corner image. The peaks in the parameter space of the Hough transform are then gathered with a pre-selected threshold, and the corresponding lines are detected. An experiment result is shown in Fig. 3.

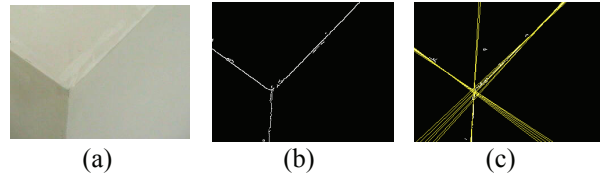


Fig 3. A result of corner edge line detection by Hough transform. (a) Input corner image. (b) Result of edge detection. (c) Result of Hough transform.

Multiple lines instead of just one are extracted by the Hough transform for each corner edge line, as shown in Fig. 3(c). To find *single* corner edge lines, we use a constrained line refitting technique to refit a group of extracted lines into a single one. The details are described as follows.

- Step 1. Group lines whose Hough transform parameters are close enough into three groups.
- Step 2. Describe the lines in the form of  $u + bv + c = 0$  in the ICS.
- Step 3. Compute the intersection points of the lines in the three groups.
- Step 4. Compute the mean of the intersection points and denote it as  $P_{center}$  with coordinates  $(u_c, v_c)$ .
- Step 5. Collect edge line points in each group  $G$  into a set  $S$  denoted by  $S = \{(u_i, v_i), i = 1, 2, \dots, n\}$ .
- Step 6. Refit according to the least-square-error criterion the point data of  $S$  and  $P_{center}$  into a new line  $L$  described by  $u + b'v + c' = 0$  under the constraint that  $L$  passes  $P_{center}$ , resulting in following formulas for  $b'$  and  $c'$ :

$$b' = -\frac{\bar{U} - u_c}{\bar{V} - v_c}; \quad c' = -(u_c + b'v_c)$$

with

$$\bar{U} = \frac{\sum_{i=1}^n u_i}{n} \quad \text{and} \quad \bar{V} = \frac{\sum_{i=1}^n v_i}{n}.$$

An experimental result is shown in Fig. 4.

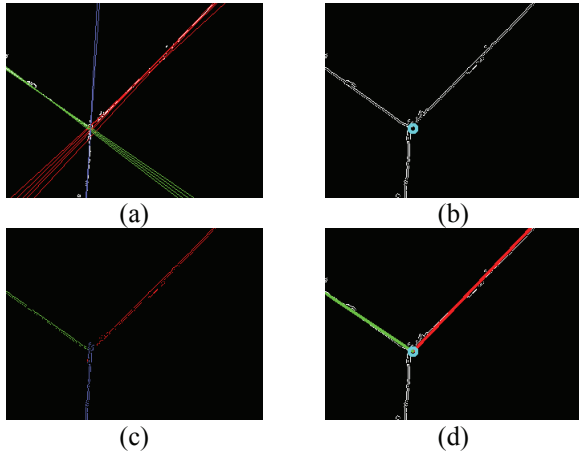


Fig 4 An experimental result of refitting house corner edge lines. (a) Each set of lines represents an identical corner edge. (b) Computed corner center point. (c) The edge points (d) Refitting result of two corner edge lines.

#### 4. EXPERIMENTAL RESULTS

Our test bed is a small vehicle named Amigo Robot made by ActivMedia Robotics Technologies, Inc. In a navigation session, a user controls the vehicle to learn paths to create a navigation map. The vehicle starts navigation according to a path selected from the navigation map. In most cases, the odometer information of the vehicle is accurate enough for short-distance guidance. Whenever the vehicle arrives at a node where the vehicle has to conduct vehicle location by house corner detection in the learning stage, it performs the required action to correct the vehicle location. An illustration of the learned node data, the navigation map, and an actual navigation path of one of our experiments is shown in Fig 5.

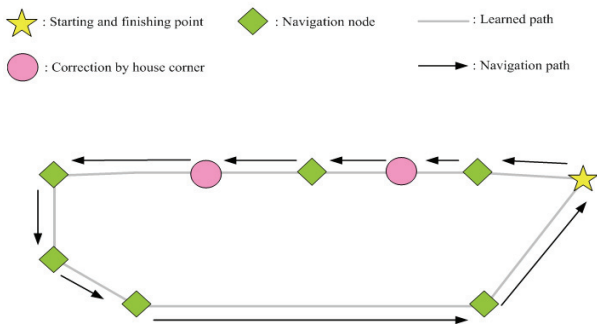


Fig 5. An illustration of learned data and navigation map.

#### 5. CONCLUSIONS

A vehicle guidance method is proposed, by which the vehicle follows the nodes in a learned map to navigate in indoor environments. The information collected from the

odometer, including travel distances and turning angles of the vehicle, is used mainly for vehicle guidance through path nodes. House corners are used for vehicle location whenever existing to prevent mechanic error accumulation in the navigation session. Use of the house corner information has several merits which are not found in other approaches using other landmarks. The experimental results have revealed the feasibility of the proposed approach. Future research may be directed to the use of more complicated house corner shapes and other ceiling shape features.

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