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Model-based Guidance of Autonomous Land Vehicles in Indoor Environments by Structured Light Using Vertical Line Information[1]

以結構光源偵測垂直線位置作模式比對式之室內自動車導航

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ABSTRACT

A new approach to autonomous land vehicle (ALV) guidance by model matching is proposed. Locations of vertical lines in indoor environments are used as the model. Two laser light sources, each of which can emit a plane of light, are employed to reduce the processing time for computing the vertical line positions by triangulation. The vertical line position information is matched with the model to locate the ALV exactly. A matching scheme is proposed which searchs possible matching point pairs and select the pair that produces a maximum correlation between the sensed and model patterns. Distance weight correlation is used as the correlation measure. The strategy for adjusting the driving wheel of the ALV to keep the vehicle close to a given path is also described. A real ALV was constructed as a testbed. Lots of successful navigation experiments confirm the effectiveness of the proposed approach.

Key Words: ALV guidance, model matching, vertical lines, structured light.

摘 要

本論文提出一種用於室內自動車導航的模式比對技術。我們將室內隨處可見的垂直線預先建立比對模式，並使用二根雷射管形成結構光源，利用雷射光形成的平面與攝影機間的三角關係，迅速而有效的取得輸入影像中垂直線的空間位置，並利用此資訊與模式作對比，以正確的定位自動車。另本論文提出的比對方法是：首先利用相互距離量度(DWC)來定義一個比對的可信度標準，然後搜尋可能的配對方式，找出最合乎這個可信度標準的配對。本文亦提出一個控制自動車前輪的策略，使自動車能儘量的沿著指定的路徑前進或倒退。最後實際應用本論文所提的方法在一輛自動車的導引上，並成功的使自動車在無人駕駛之下自動航行於走廊之中。

關鍵詞：自動車導航，模式比對，垂直線，結構光源。

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1. INTRODUCTION

A fundamental autonomous land vehicle (ALV) should be able to reach its destination and to return to its starting position. To achieve this goal, the location of the ALV must be solved. Model-based approach is suitable for the solving of location problem. To avoid the correspondence problem faced by stereo matching which are often used in 3-D computer vision techniques for ALV guidance, the use of structured light for acquiring 3-D information is a simpler alternative. This paper describes a model-based guidance approach in indoor environment by the incorporation of structured light technology.

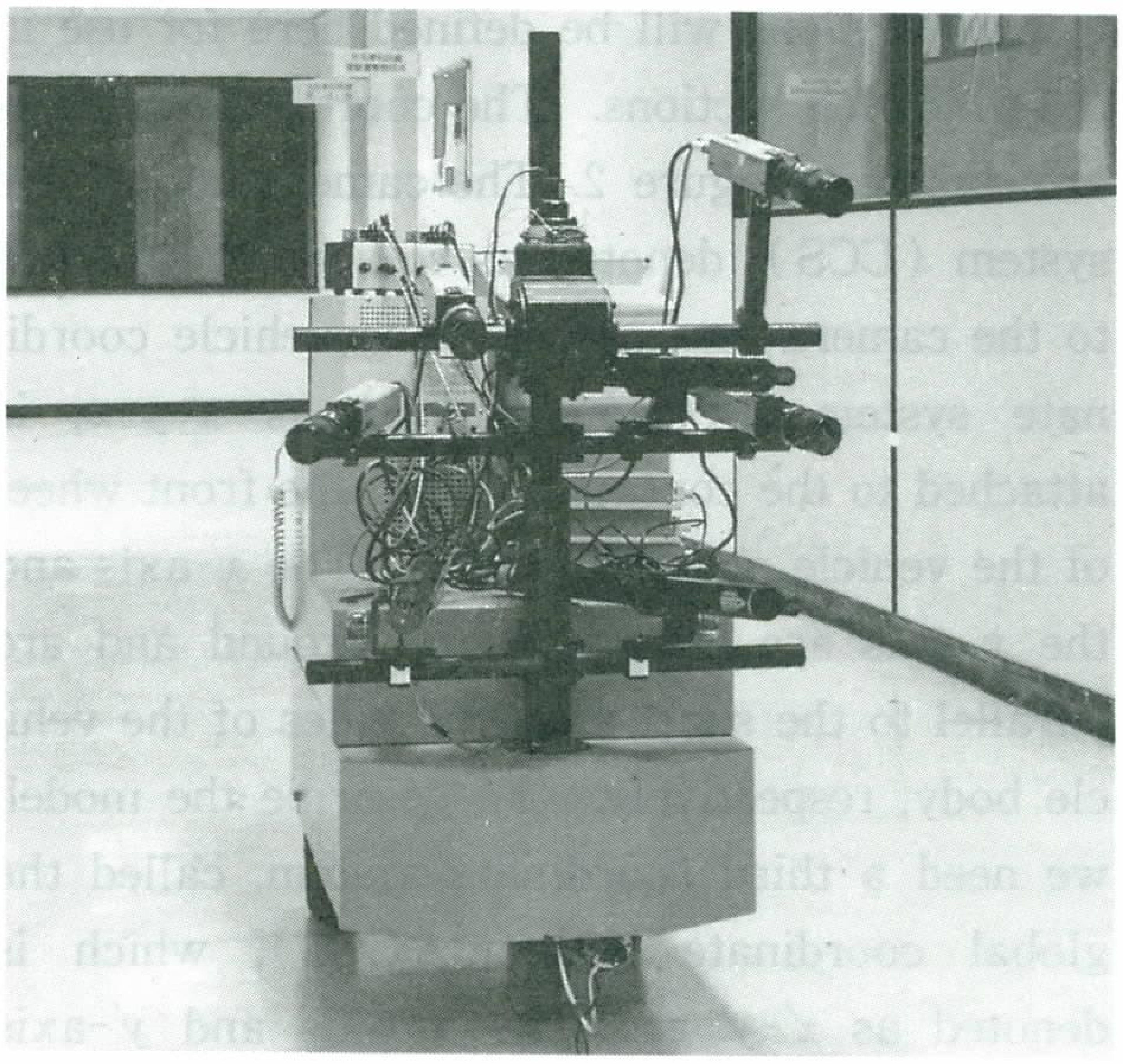
As a general rule, model-based approachs try to use a pre-learned model of the environment to guide an autonomous vehicle. Blanche of the AT&T Bell Laboratory[1,2]is an experimental robot cart for indoor environments. The maps of environments were stored as a collection of line segments. An odometer is used to estimate positions and orientations, and an optical range finder provides the vehicle with the 2-D maps of its environment. An iterative matching approach was used in order to correct vehicle location inaccuracy due to accumulated errors of the odometer. Each iteration of the matching approach finds the congruence that minimizes the total squared distance between the sensed points and their nearest line in the model. Object vertices were used in the approach proposed by Chatila and Laumond [3]. The matching is done by exhaustive comparison between the distances of any two points in the sensed pattern and the environment model. In [4], Yachida et al. stored information like the floor position, the lengths and positions of vertical lines, etc., in the model. The model is projected onto an image and is matched with the image grabbed from a camera. The slant angle of the ALV is determined from the vanishing point of the floor, and the location of the ALV is determined by matching the vertical lines and the image model. The matching approach sets a search range for each vertical line detected in the image and checks if a vertical line of similar length exists in each search range. The length of the vertical line must be measured exactly, therefore it is less reliable for vehicle location.

To conduct the ALV guidance research, two ALV's were developed by Tsai, et al. [5,7]. In Chang and Tsai [5], a road folowing approach was proposed. The baseline in a corridor which is the intersection of a wall and the ground is extracted and used. A method based on a principle similar to that of the cross ratio is used to find the baseline location with respect to the vehicle. The system can be driven at about 17 cm / sec. But the global location of the ALV was not derived. In Ku and Tsai [6], a model-based navigation approach is proposed, and the corridor contour is used as the model. An extended concept of the generalized Hough transform is used to match the model and the input pattern extracted from the video camera image. So, the global location of the ALV can be known. A corner tracking approach was proposed in Ke and Tsai [7], where the house corners are stored as the model, and a method for rotating the camera to track house corners was proposed.

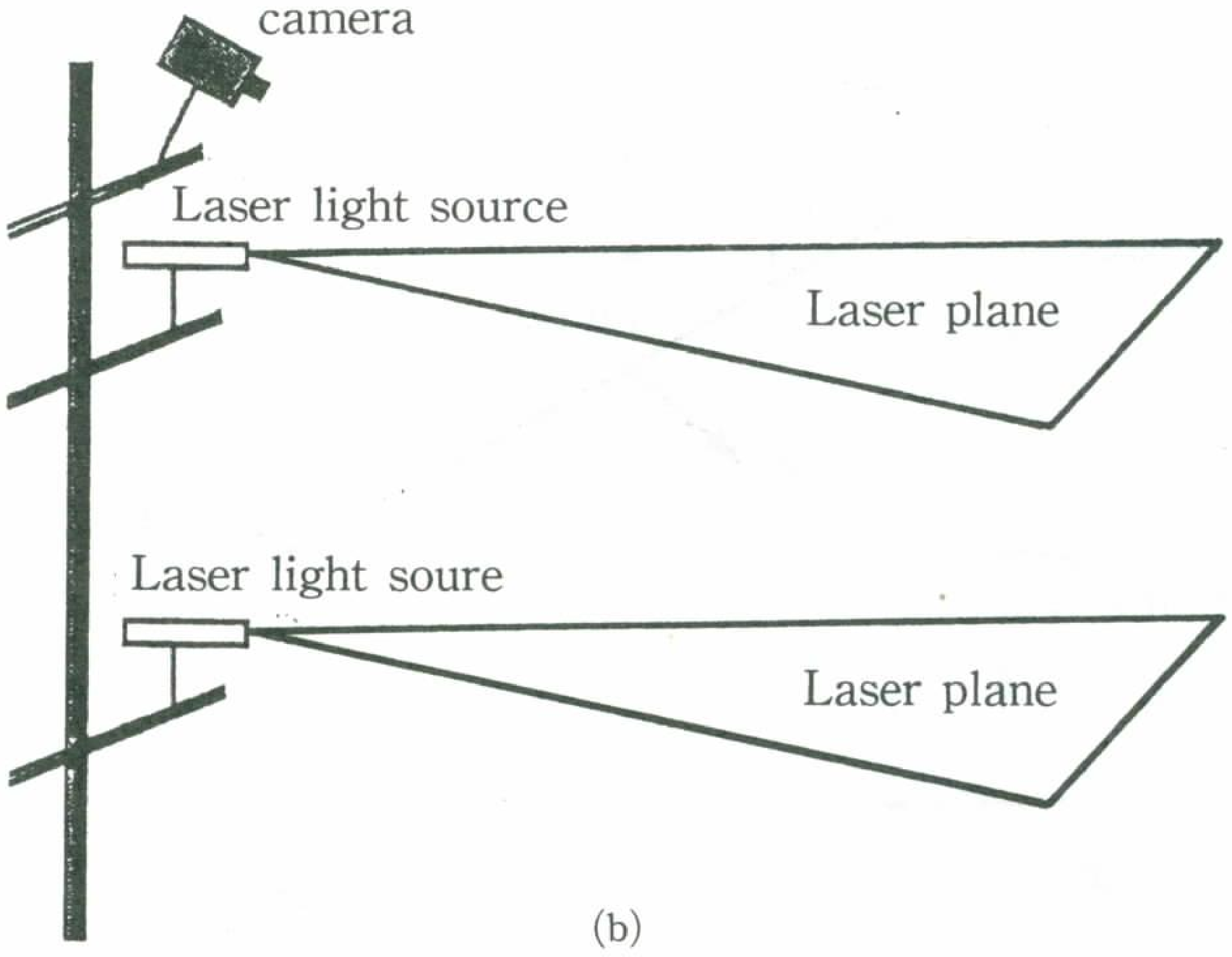
In this paper, the global positions of vertical lines in indoor environments are used as the model for automatic ALV navigation, which are measured by hand before navigation. Two laser light sources, each of which can emit a plane of light, are employed for locating the vertical lines with respect to the vechile. A matching scheme is proposed to locate the vertical lines in the global coordinate system. And the ALV location can be implied by the positions of the vertical lines with respect to the vehicle and the global coordinate system.

More specifically, after an intial camera calibration procedure based on the method proposed by Ku and Tsai [6], a navigation task proceeds in a cycle by cycle manner where the vehicle location at image taking in a navigation cycle is obtained from a matching process with respect to the model. The positions of the vertical lines on the wall of a corridor with respect to the vehicle are obtained by using the triangular relation between the laser planes and the camera. A matching scheme is then applied to locate these vertical lines in the global coordinate system. Since the coordinates of the top views of the vertical lines (called the coordinates of the vertical lines for simplicity henceforth) can be represented by coordinates of points two-dimensional space, the matching problem can be regarded to be a typical point set matching problem. We present a matching scheme by using distance weight correlation (DWC) [8] as the match measure. Through the matching procedure, the ALV can be located accurately. Once the location of the ALV is determined, a control strategy is required to drive the vehicle toward a favorable direction in order to proceed further safely. For this, a control criterion is proposed to keep the vechicle colse to a given path.

A prototype ALV constructed for this study is shown in Figure 1 (a). The ALV has three wheels: the front one is the driving wheel and the two rear ones are free. Above the front wheel is a rack with three horizontal bars which may be used to carry cameras and laser light sources. In the experiments of this study, one camera and two laser tubes are mounted on the vehicle as illustrated in Figure 1(b). The camera is mounted on the highest horizontal bar. One of the laser tubes is mounted on the lowest horizontal bar, and the other is mounted on the middle horizontal bar. Each laser tube can emit a plane of laser light. In our experiments, we adjust the laser tube to get a laser plane which is parallel to the ground. When the laser plane is projected onto the wall, some bright line segments the contour of the wall can be detected. We will call the line segments resulting from projecting the upper laser plane on the wall the *projected-upper-laser* and the line segments resulting from projecting the lower laser plane on the wall the *projected-lower-laser*. The projected-upper-laser, projected-lower-laser, and vertical lines are the features which we want to detect in each input image.



(a)



(b)

Figure 1. A prototype ALV used in this study. (a) The outlook of prototype ALV.(b) The equipments mounted on prototype ALV.

In the remainder of this thesis, we investigate the vertical line location problem in Sec. 2. The ALV location and guidance methods are described in Sec. 3. Experimental results are described in Sec 4. Conclusions and suggestions for further study can be found in Sec. 5.

2. LOCATING VERTICAL LINES FOR VEHICLE GUIDANCE

2.1 Coordinate Systems and Transformations

Several coordinate systems and coordinate transformations will be defined here for use in the following sections. The coordinate systems are shown in Figure 2. The camera coordinate system (CCS), denoted as u-v-w, is attached to the camera lens center. The vehicle coordinate system (VCS), denoted as x-y-z, is attached to the contact point of the front wheel of the vehicle and the ground. The x-axis and the y-axis are placed on the ground and are parallel to the short and long sides of the vehicle body, respectively. To describe the model, we need a third coordinate system, called the global coordinate system (GCS), which is denoted as x'-y'-z'. The x'-axis and y'-axis are defined to lie on the ground.

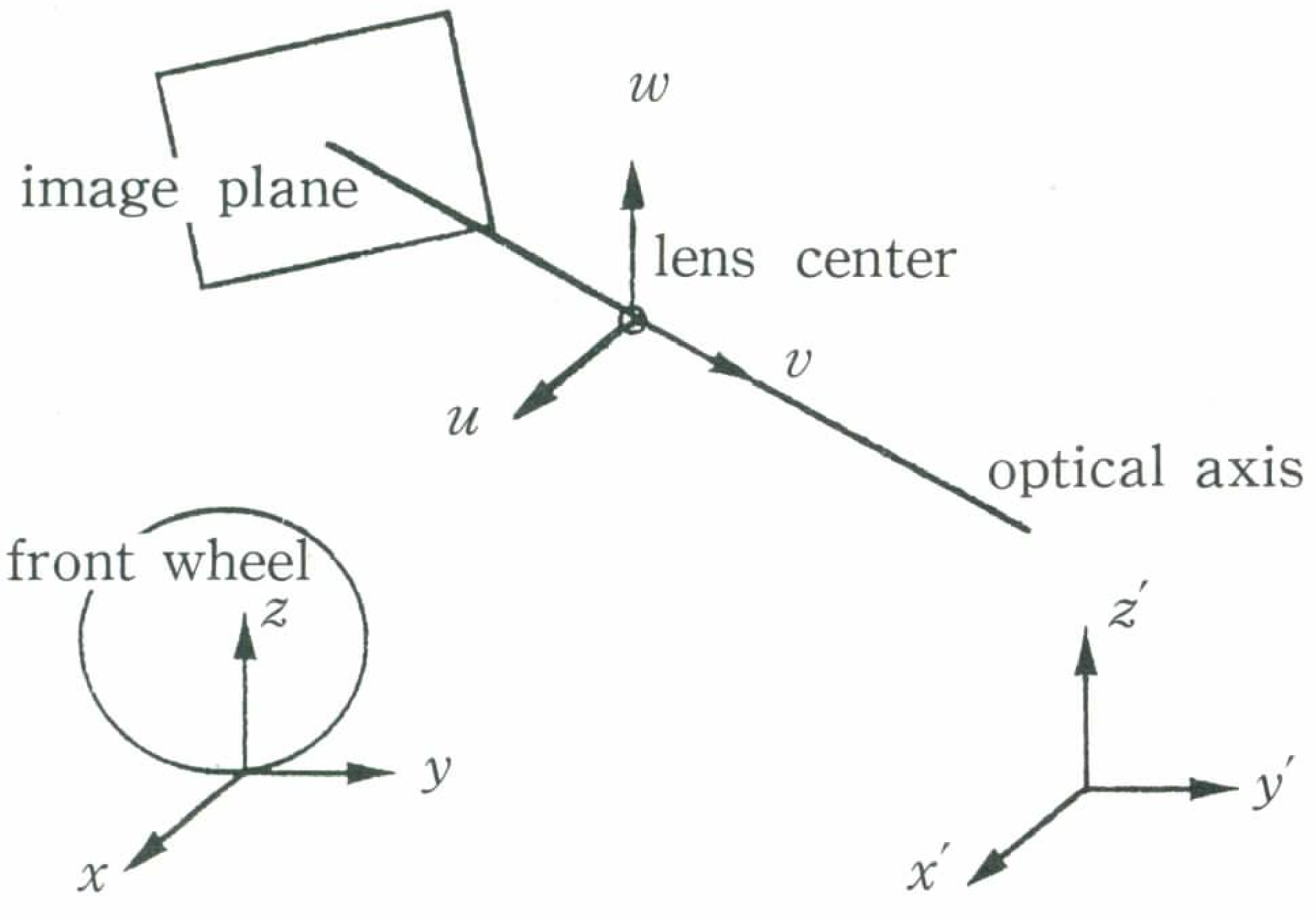


Figure 2. The camera coordinate system u-v-w, the vehicle coordinate system x-y-z, and the global coordinate system x'-y'-z'.

The GCS is assumed to be fixed all the time, while the VCS is moving with the vehicle during navigation. The location of the vehicle can be assured once the relation between the VCS and the GCS is found. Since the vechicle is on the ground all the time, the z-axis and the z'-axis can be ignored. That is, the relation between the 2-D coordinate systems x-y and x'-y' is sufficient for determining the position and orientation of the vehicle, which is illustrated in Figure 3. The position of the vehicle in the GCS is represented by the translation vector from the origin of x'-y' to the origin of x-y and is denoted as (x'_p , y'_p). The direction of the vehicle in the GCS is represented by the relative rotation angle of x-y with respect to x'-y' and is denoted as ω. Once the (x'_p, y'_p) and the ω can be determined, the transformation between the two 2-D coordinate systems x-y and x'-y' can be determined as follows:

$$
\begin{aligned}
x' &= x\cos\omega - y\sin\omega + x'_p \\
y' &= x\sin\omega + y\cos\omega + y'_p.
\end{aligned}
\tag{1}
$$

On the other hand, once the camera has been calibrated, the coordinates of any point rep-resented by the CCS coordinate system can be transformed to VCS coordinate system by a coordinate transformation [6].

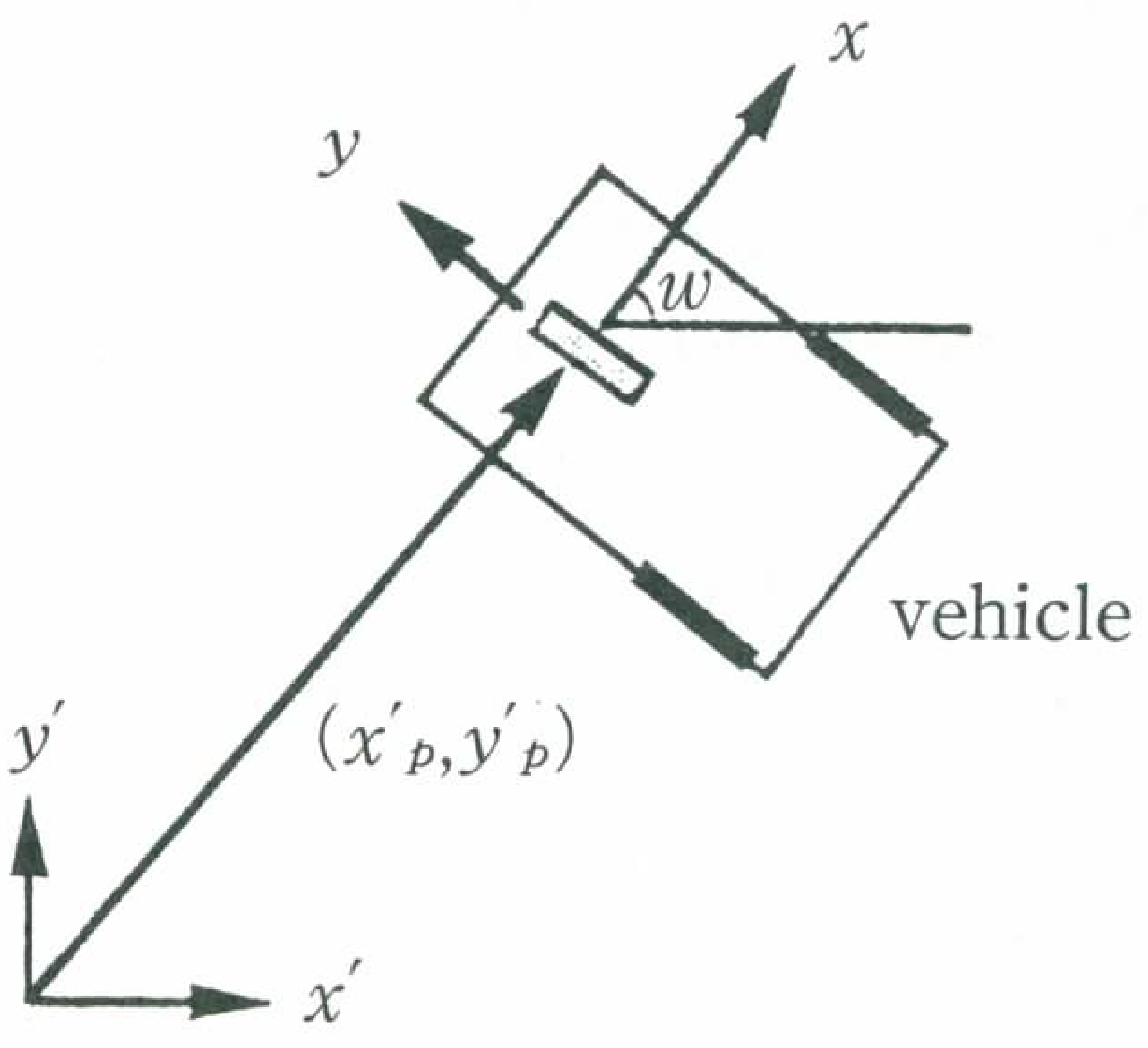


Figure 3. The relation between 2-D coordinate systems x-y and x'-y' represented by a translation vector (x'_p,y'_p) and a relation angle ω.

2.2 Locating Vertical Lines

In this section, the geometric properties of structured light are used to calculate the VCS coordinates of the vertical lines detected from an input image. An vertical edge detection operator and the Hough transformation is applied to the area enclosed by the projected-upper-laser and projected-lower-laser to find the vertical line candidate in the image. For any vertical line candidate detected in the image, two points on the vertical line are sufficient to calculate the 3-D coordinates of the line to locate it in the VCS. The steps are as follows. First, get the intersection point of the vertical line and the projected-upper-laser. Then, backproject the intersection point to the VCS. Because the intersection point is located on the projected-upper-laser, the VCS coordinates of this point can be solved by the triangulation principle. The intersection point of this vertical line and the projected-lower-laser can be handled similarly. Thus, for any vertical line candidate detected in an image, we can get two points and their VCS coordinates. Such information can then be used to check whether the line is really a vertical line in the VCS. If the x and y coordinates of one point are almost equal to the x and y coordinates of the other point, this line is assured to be a vertical line, and the position of this vertical line can be denoted by the x and y coordinates of the first intersection point. Otherwise, this line is treated as noise. The formula to calculate the VCS coordinates of a point which is located on the projected laser is derived in the following.

As shown in Figure 4, after backprojecting the point P in the image into the VCS, we can get a line L which passes the lens center and P. The intersection point of this line L and either of the laser planes (denoted by II) is the corresponding space point of P which is what we desire. Denote this point as P'.

The equation of laser plane II can be set to be $z=h$ by measuring its height h before navigation. The CCS coordinates of point P can be obtained from its position in the image. For example, if the position of P in image is represented by (uP,wP), the point P the CCS coordinates $(uP,-f,wP)$, where f is the focal length. By a coordinate transformation [6], the VCS coordinates (xP,yP,zP) of point P in the image can be obtained. So, the equation of line L in the VCS coordinate system can be solved to be:

$$\frac{x-x_d}{x_p-x_d}=\frac{y-y_d}{y_p-y_d}=\frac{z-z_d}{z_p-z_d}=k. \tag{2}$$

where (x_d,y_d,z_d) are the coordinates of the lens center in the VCS.

Since point P' is the intersection point of laser plane II and line L, by substituting $z=h$ into Eq. 2, the desired VCS coordinate (x_P',y_P',u_P') of point P' can be solved to be:

$$\begin{aligned} x_p' &= x_d+\frac{h-z_d}{z_p-z_d}(x_p-x_d). \\ y_p' &= y_d+\frac{h-z_d}{z_p-z_d}(y_p-y_d) \\ z_p' &= h. \end{aligned} \tag{3}$$

To summarize, the VCS coordinates of the correspond space point for any pixel located in the projected laser can be solved by using Eq. 3. So we substitute the intersection points of the vertical lines and the projected laser into Eq. 3 to find the VCS coordinates of the vertical lines.

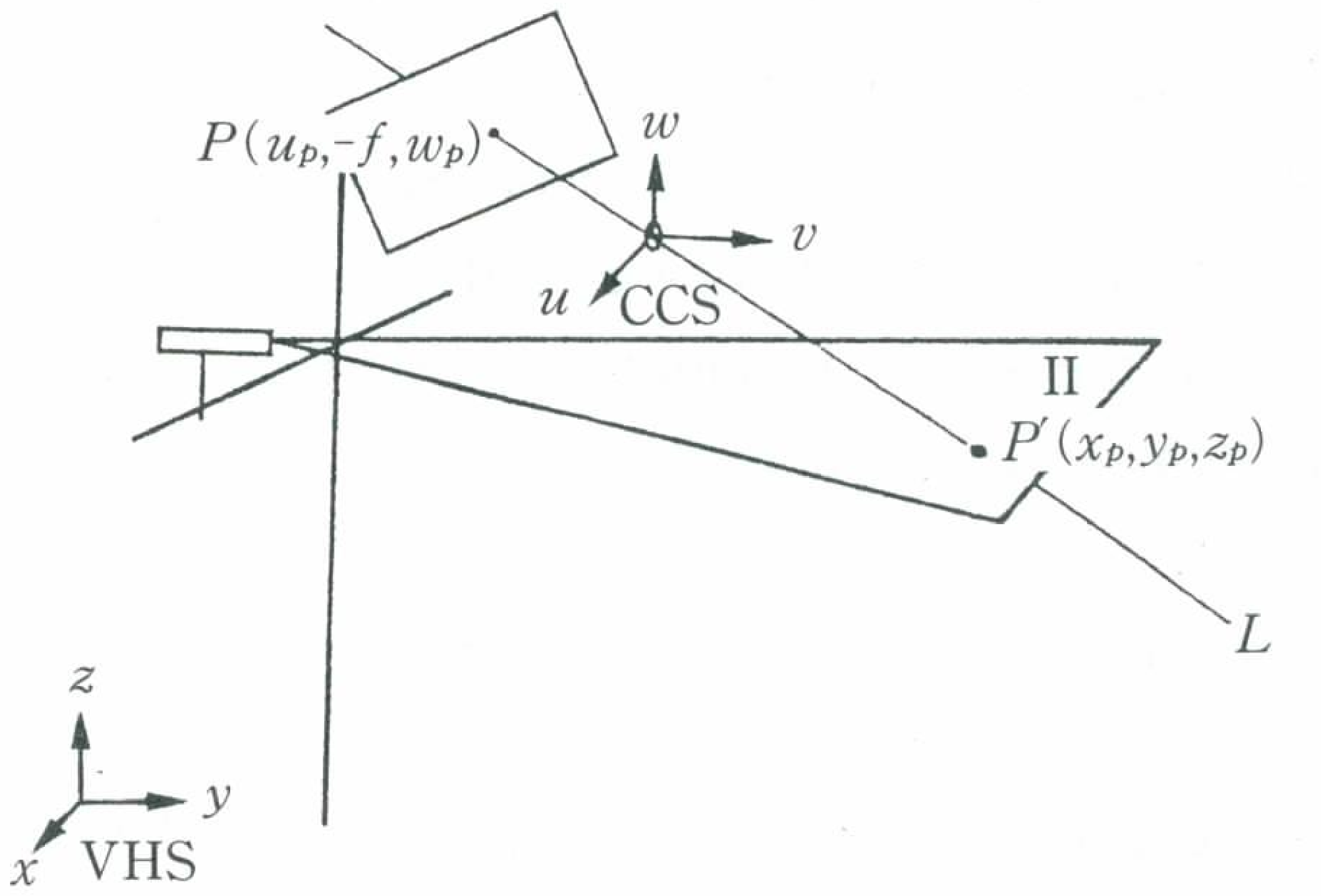


Figure 4. Configuration of the system for finding the back-projection point for an image pixel.

2.3 Matching Sensed Vertical Lines with Model

Applying the approach proposed in Section 2.2, the VCS coordinates of the vertical lines detected from the input image can be calculated. By estimating the ALV location (described later) and substituting it into Eq. 1, we can get the GCS coordinates of these vertical lines. Since the estimated ALV location is not exact due to control errors, ther GHS coordinates of detected vertical lines are not exact, either. Proposed in this section is the method that matches these detected vertical lines with the model to get the exact coordinates of these vertical lines.

More specifically, the estimated GCS coordinates of the input vertical lines constitute an input pattern, which we denote by a point set S $=\{s_1,s_2\cdots,s_n\}$,where each point s_i denotes the estimated GCS coordinates of a vertical line. Within a reasonable distance tolerance range, a model pattern M can be extracted from the entire model. Now, consider any point s_i in S. The points in the model that are possible to match s_i form a subset of M, which we denote by $M_i=\{m_{i1},m_{i2},\cdots\cdots m_{ik}\}$. The points in M_i are these points that are within the area of circle whose center is s_i and the radius is the distance tolerance.

The proposed method determines which point in M_i matches s_i in the following way: for any point m_{ij} in M_i, shift all of points in S so that s_i is superimposed on m_{ij}, and estimate the correlation between S and M using a correlation measure. If superimposition of s_i on m_{ij} gets a maximal correlation measure value, we say that s_i and m_{ij} is a best match pair.

The distance weighted correlation (DWC) proposed by Fan and Tsai [8] is used as our correlation measure. A brief review of DWC is as follow:

Let M and S are two point-type patterns to be matched in a two-dimensional space. After M and S are registered and overlapped, the minimum distance d_p of a point p in S is defined to be the distance between p and its closest point q in M. And the weight $W_p\ (K)$ of a point p in S is defined to be

$$W_p(K)=\begin{cases}1/(d_p^2+1) & \text{if } 0\leq d_p\leq K,\\ 0 & \text{otherwise,}\end{cases} \tag{4}$$

where K is a constant that defines a distance limit within which the closest feature point q in M of p is searched for.

The DWC value between M and S is defined as

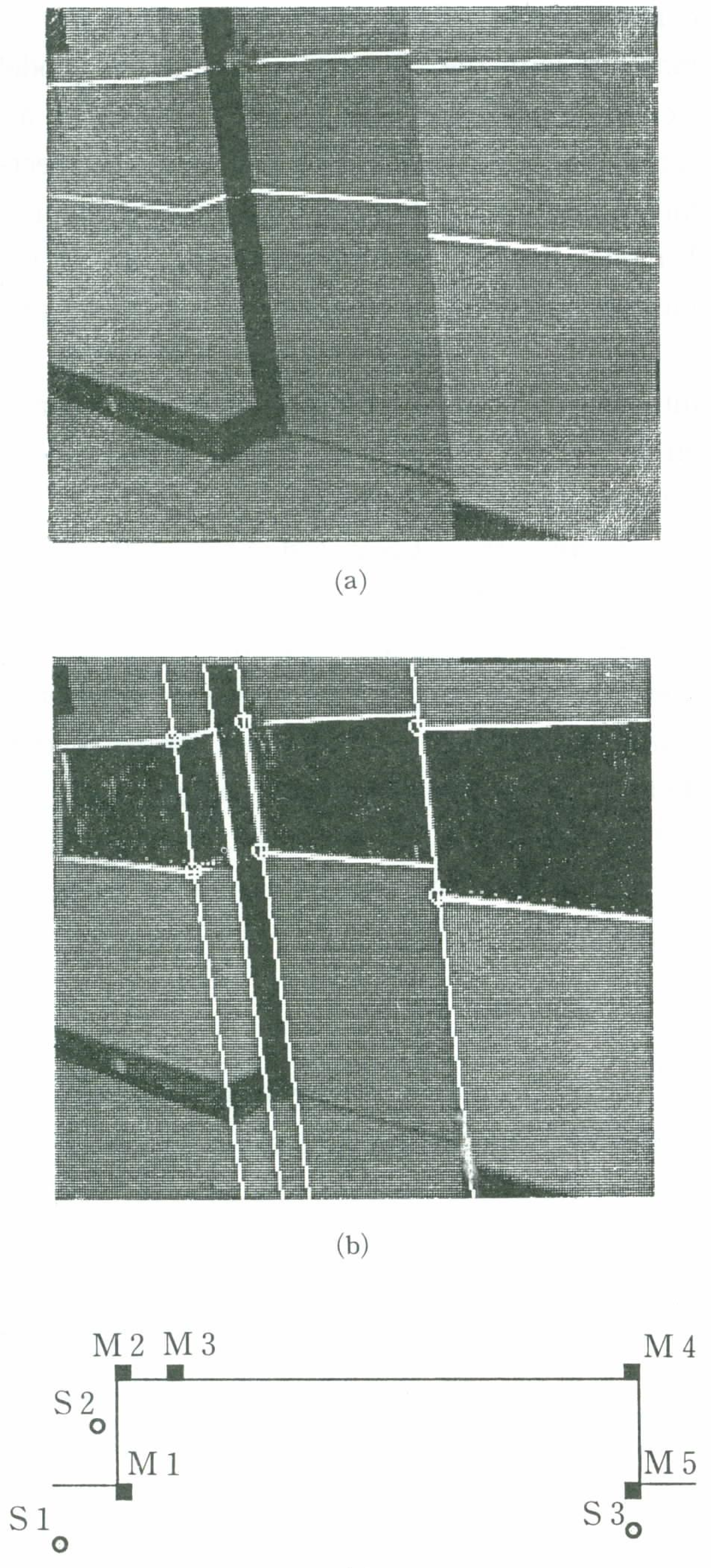
$$C(M,S)=\sum_{p\epsilon S} W_p(K)/N_t \tag{5}$$

where N_t is the total unmber of feature points in S.

An example of the matching result is shown in Figure 5. An image grabbed by the camera is shown in Figure 5 (a). Three vertical lines are detected in the image, and are shown in Figure 5 (b). Note that only the lines with small circles, which denote the intersection points of the vertical lines and the reflected laser, are regarded as vertical lines. Within an error range, the input pattern and the model pattern can be obtained as shown in Figure 5 (c). The possible match pairs and the result of matching are shown in Figure 5 (d). Each point in the input pattern is first assigned a set of points in the model pattern (called the candidate model points). After matching, one point in the candidate model points is selected for each input point.

3. ALV GUIDANCE

After the input image matching steps, each of the vertical lines detected from the input image is assigned to a model point to get the GCS coordinates of the corresponding vertical line. In this chapter, the exact ALV location will be derived from the matching result, and a wheel control strategy is then proposed to adjust the ALV location to the desired path.


(a)

(b)

(c)

point in input pattern	points in model pattern
S1	{M1,M2,M3}
S2	{M1,M2,M3}
S3	{M4,M5}

point in sensed pattern	point in model pattern
S1	M1
S2	M3
S3	M5

(d)

Figure 5. The steps of matching procedure. (a) An input image (Estimated ALV position: $x'_p = 106, y'_p = 54, \omega = 16.34^o$). (b) Three Vertical lines are detected. (c) The sensed pattern {S 1,S 2,S 3}and the model pattern{M 1,M 2,M 3,M 4, M 5}. (d) Possible match pairs and the matching result. (ALV position after matching: $x'_p = 123, y'_p = 72, \omega = 18.14^o$).

3.1 Locating ALV by Matching Result

As mentioned in Section 2.1, the ALV location is described by the ALV slant angle ω and the ALV position (x'_p, y'_p). In our approach, the ALV slant angle ω will be solved first, and the ALV position (x'_p, y'_p) is solved accordingly. The main idea of our approach is that if we can select some features such that the VCS information and GCS information can be known, then the relation between the VCS (vehicle) and the GCS (world) can be determined. For this, we select the position of a vertical line as the feature to find the position of the ALV, and select the laser line segment that intersects the vertical line as the feature for finding the ALV slant angle.

In our approach, only one vertical line detected from the input image is specified in the location problem. If more then one vertical lines are detected from the input image, only the vertical line with the maximal DWC value (which is produced in the matching steps) is used. The derivation of the ALV location (including its position and direction) is described as follows.

A. Determination of ALV slant angle

Once a vertical line detected from the input image is matched with the model, the line segment (formed by the projected-lower-laser) which intersects this vertical line is used to determine the slant angle of the ALV by determining the slope of this line segment in the

VCS coordinate system as well as in the GCS coordinate system.

The slope of the laser line segment in the VCS can be determined by selecting any two points in the line segment. Because all points in the line segments are located in the projected-lower-laser, the VCS coordinates of the two points can be determined by using Eq. 3. More specifically, assume that the VCS coordinates of the two points are computed to be (x_1,y_1) and (x_2,y_2) (ignore the z coordinates), then the slope m_1 of the laser line segment in the VCS can be computed by

$$m_1=\frac{y_1-y_2}{x_1-x_2}$$

To determinate the slope of the laser line segment in the GCS, it is assumed that any two consecutive vertical lines in the environment are located in the same plane. This is reasonable because almost all of the surfaces of the walls or doors in a building are planes, and that the boundary of these planes is a vertical line. In fact, if the laser plane is projected onto a non-plane area (for example, a human being),the projected laser in this area is not a line segment. So, this kind of noise can be removed easily. Under the above assumption, we will show how to find two GCS points that lie on the laser line segment. So the slope of the laser line segment in the GCS can be determined.

The first GCS point is the intersection point of the laser line segment and the vertical line. Because the vertical line has been matched with the model, the position of the vertical line in the model can be known. The second GCS point is selected as follows.

Because any two consecutive vertical lines are located in an identical plane, it can be asserted that each laser line segment intersects at least two consecutive vertical lines in the model though in some cases only one vertical line can be found in the image due to different camera views. That is, if the vertical line is matched with the ith vertical line in the model (called model line i henceforth), it can be asserted that the laser line segment intersects model line i and intersects either model line i + 1 model line i-1 or both of them. So, if the intersection point of the laser line segment and model line i is selected as the first point, the intersection point of the laser line segment and either model line i-1 or model line i + 1 is selected as the second point.

Because the GCS coordinates of the vertical lines have been stored in the model and the two selected points are located on the vertical lines, the GCS coordinates of these two points can be determined. Assume that the GCS coordinates of the two points are (x'_1,y'_1) and (x'_2, y'_2) (ignore the z' coordinates), then the slope m_2 of the laser line segment in the GCS can be solved to be

$$m_2=\frac{y'_1-y'_2}{x'_1-x'_2}$$

After the slopes of the laser line segment in the VCS and in the GCS are determined, the slant angle of the ALV can be derived. This is illustrated in Figure 6. The angle θ_1 between the laser line segment and the positive x-axis of thc VCS and the angle θ_2 between the laser line segment and the positive x'-axis of the GCS can be derived to be

$$\theta_1=\tan^{-1}m_1,$$
$$\theta_2=\tan^{-1}m_2.$$

Then the slant angle ω of the ALV can be solved to be

$$\omega=\theta_2-\theta_1.$$

B. Determination of ALV position

The position of the vertical line in the VCS and in the GCS are used to determined the ALV position. Note that the VCS coordinates (x,y) of the vertical line cal be determined as discussed in Sec. 2.2. After matching with the model as discussed in Sec. 2.3, the GCS coordinates (x',y') of the vertical line are also determined, and the ALV slant angle ω has been solved as mentioned above. By substituting ω, (x,y), and (x',y') Eq. 1, the position of the ALV can be determined to be

$$x'_p = x' - x\cos\omega + y\sin\omega.$$
$$y'_p = y' - y\sin\omega - y\cos\omega.$$

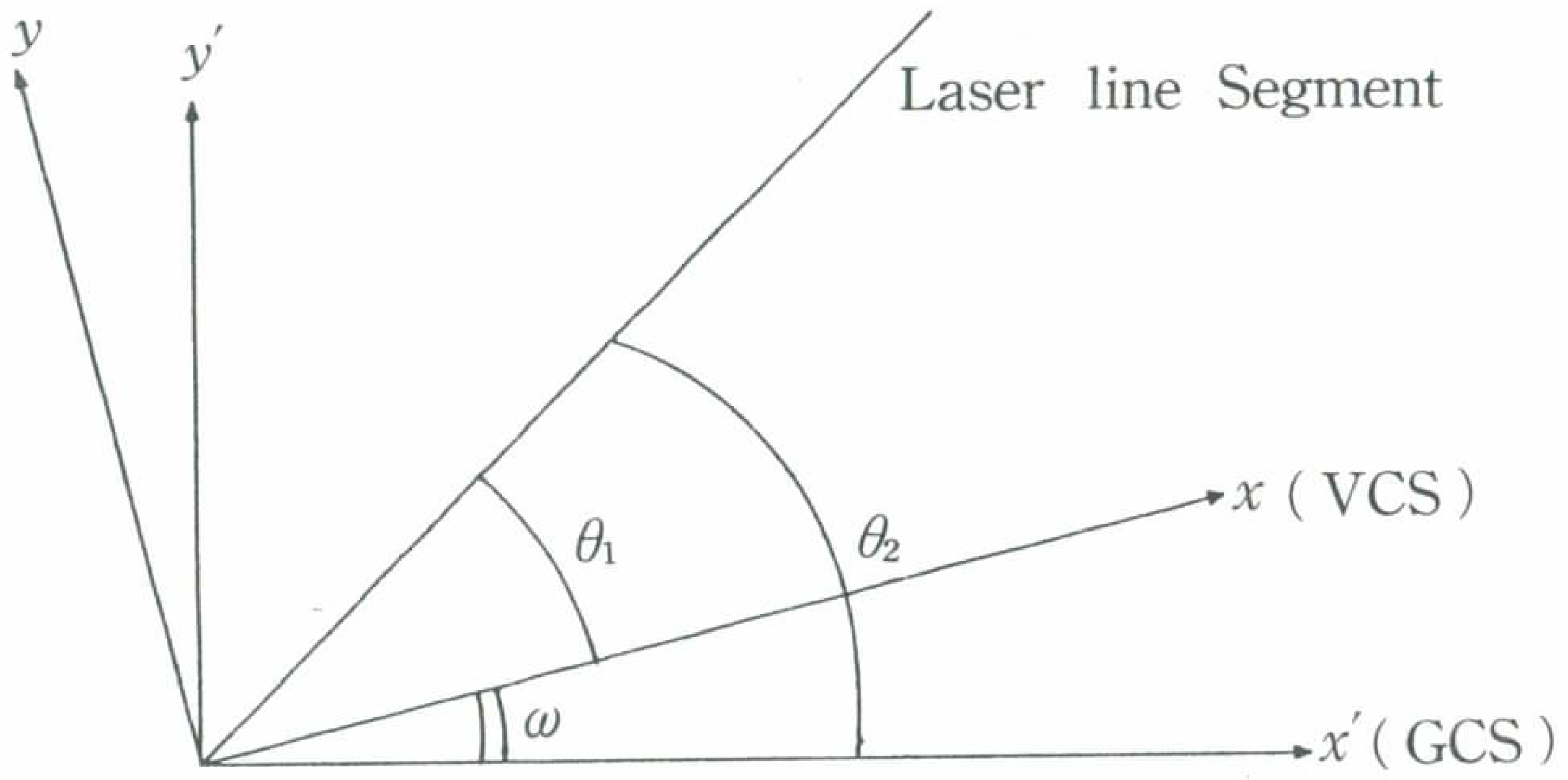


Figure 6. The slopes of laser line segment in the GCS and in the VCS are used to solve the slant angle of ALV.

3.2 Wheel Control For Vehicle Location Adjustment

The goal of ALV guidance is to drive the ALV as close to a given path as possible. A strategy to achieve this goal is proposed. The strategy are based on a reasonable assumption from basic kinematics that if the front wheel is fixed at a specific angle other than zero, then the ALV will move along a circular path[6].

A straight path is assumed in the following discussion. At a turning area, multiple line segments are used to approximate a curve path. At the end of this section, we first derive the formula that can be used to compute the ALV position by the turn angle of the front wheel and the distances the ALV navigates. Then, determination of the turn angle to make the ALV colse the given path is discribed.

3.2.1 Estimating ALV location

As shown in Figure 7(a), the vehicle is located at A. After moving a distance S forward, the vehicle will be at a new location B. What we desire to know is the relative location of B with respect to A, denoted by a vector T. By the basic kinematics of the ALV, the rotation radius R can be found to be

$$\mathrm{R} = \frac{d}{\sin\delta} \tag{6}$$

where d is the distance between the front wheel and the rear wheels, and δ is the turn angle of front wheel. And the angle γ can be determined as

$$\gamma = \frac{S}{R} \tag{7}$$

So, the length of vector T can be solved to be

$$T_1 = \mathrm{R}\sqrt{2(1-\cos\gamma)}$$

and the direction of vector T is

$$\mu = \frac{\pi}{2} - \delta - \frac{\gamma}{2}.$$

The VCS coordinates of location B with respect to location A can thus be computed by

$$x = T_1\cos\mu$$
$$y = T_1\sin\mu.$$

If the ALV moves backward, as shown in Figure 7(b), the location of the ALV can be derived similarly to be

$$x = -T_1\sin\mu'$$
$$y = -T_1\cos\mu'$$

where

$$\mu' = \delta - \frac{\gamma}{2}.$$

After the front wheel location of the ALV is determined, the rear wheel location (bx,by) of the ALV can also be determined to be

$$bx = x + d\sin\gamma'$$
$$by = y - d\cos\gamma'$$

where $\gamma' = \gamma$ if the ALV moves forward, and $\gamma' = -\gamma$ if the ALV moves backward.

3.2.2 Strategy for wheel control

Given a reasonable moving distance S and the turn angle δ of the ALV front wheel, the location of the front wheel and rear wheels can be determined as discussed above. Given a straight path P, we define $D_P^F(\delta)$ to be the distance from the front wheel of the ALV to the given path P after the ALV traverses a distance S with the turn angle δ. In general, the traverse distance S can be determined from the vehicle speed and the computation time needed for a navigaion cycle. The path P is usually given in advance or may be determined by a path planning procedure. So the value of D_P^F is determined by the turn angle δ.

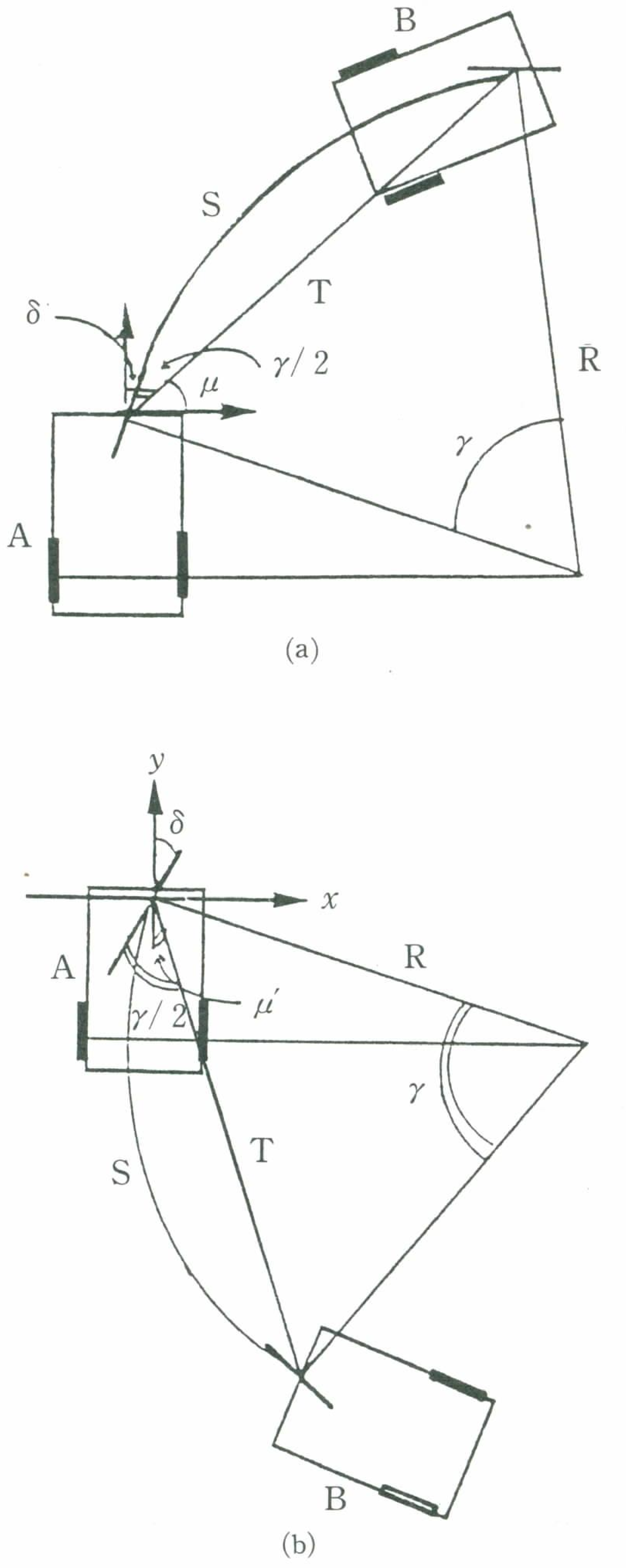


Figure 7. The vehicle locations before and after the ALV moves a distant S. (a) The ALV moves forward. (b) The ALV moves backward.

Similarly, we define $D_P^B(\delta)$ as the distance from the rear wheels of the ALV to the given path P after the ALV traverses a distance S with the angle δ. The value of D_P^B is also determined by the turn angle δ. A closeness measure $L_P(\delta)$ of the ALV to the given path is defined to be

$$L_P(\delta)=\frac{1}{1+(D_P^F(\delta))^2+(D_P^B(\delta))^2} \qquad (8)$$

A larger value of L_P means that the ALV is closer to the path P. It is easy to verify that $0<L_P\leq 1$,and that $L_P=1$ if and only if both of the front wheel and the rear wheels of the ALV are located right on the path.

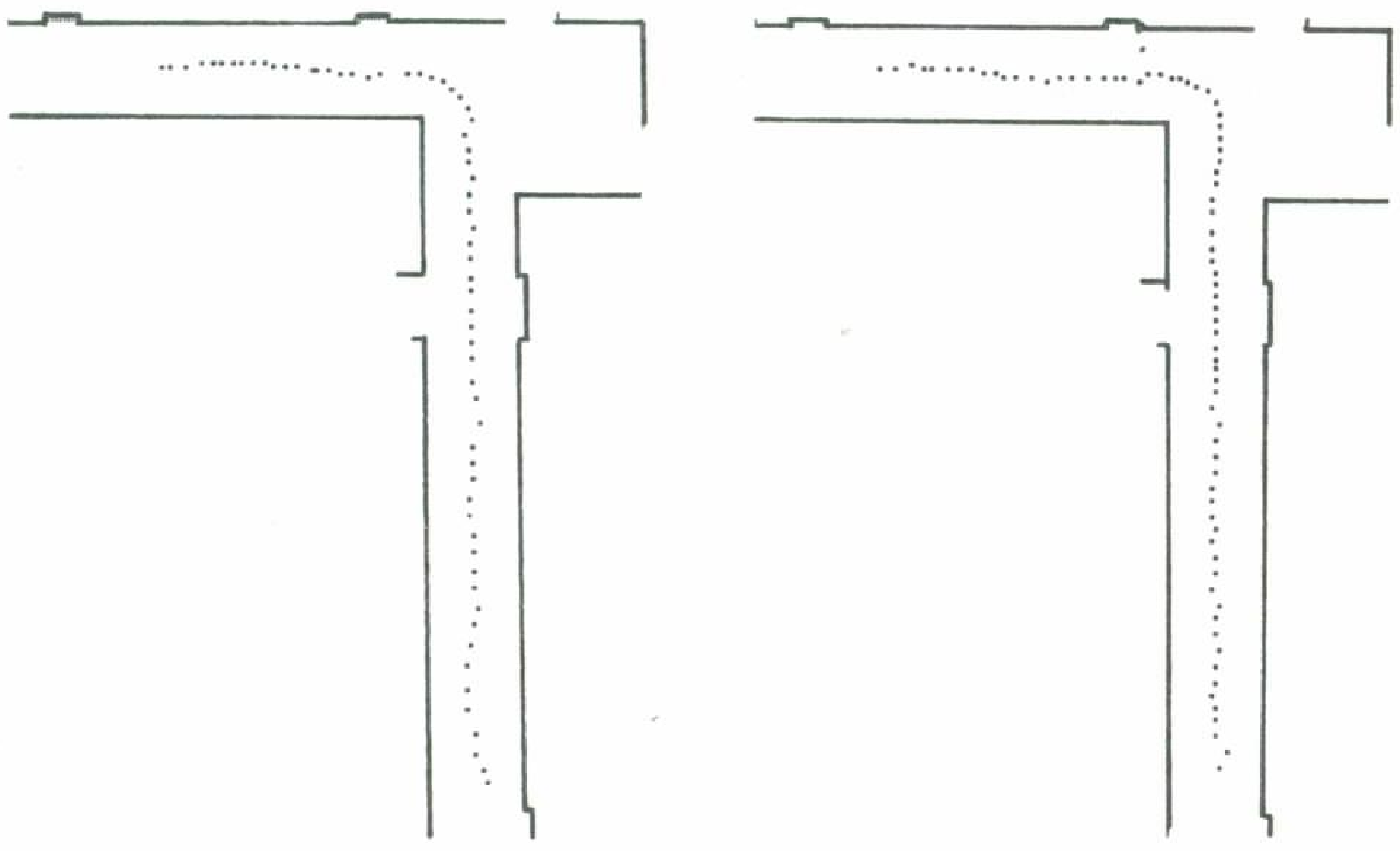
To find the turn angle of the front wheel to drive the ALV as close to the path as possible, a range of possible turn angles are searched. An angle is hypothesized each time, and the value of L_P is calculated accordingly. The angle that produces the maximal value of L_P is then used as the turn angle for safe navigation.

4. EXPERIMENT RESULTS

The navigation of the ALV was performed in an indoor environment. And 28 vertical lines in the environments are stored and used for our experiment.

The navigation path is approximately 30 m in length (so about 60 m for a go-and-return navigation). The experimental navigation session starts from a corner of the corridor, drive through a right-turn corner of the corridor, and drive backward to return to the start corner of the corridor. The navigation speed of the vehicle is about 20 cm / sec in a straight corridor and 15 cm / sec at a turning area. About 130 to 150 navigation cycles are performed in a complete navigation session. The computation time of a navigation cycle ranges approximately from 2.0 to 3.5 seconds for different images, and about 90 percent of the computing time is used in image processing.

Lots of successful navigations have been performed, Figure 8 shows the trace of a typical navigation session, where Figure 8 (a) is the trace of the ALV moving forward and Figure 8 (b) is the trace of the ALV moving backward. Each block dot in the figure represents a vehicle location which is obtained from the matching process of a navigation cycle.



(a) (b)

Figrue 8. The trace of a navigation session. (a) The ALV moves forward. (b) The ALV moves backward.

5. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

A model-based approach to ALV guidance in indoor environments by computer vision using structured light has been proposed. This approach has been implemented on a prototype ALV and satisfactory results have been obtained. The locations of the vertical lines in the environment are stored as a model in advance. Only the coordinates of the vertical lines need be stored; detailed maps of the environment are not needed, so extension of the model is easy and only a little memory space is needed. The structured light method has been used in order to reduce the time needed in vertical line coordinated computation. Only some discrete points are required to get the location of vertical lines and match with the model, so fast navigation speed can be achieved. Since one vertical line is sufficient for locating the ALV exactly and vertical line is a stable feature in most indoor environments, the approach is reliable for indoor ALV navigation. Furthermore, smooth and safe navigation has been achieved by the use of a control criterion for adjusting the driving wheel. Navigation sessions with speed up to 20 cm / sec have been performed. Lots of successful navigation experiments confirm the effectiveness of the proposed approach.

There are several directions in which the vehicle may be improved. First, the turn angle of the driving wheel is determined at the end of each navigation cycle. Due to the delay of image processing, the ALV cannot respond to the change of the path quickly. An additional processor to process the wheel control function individually is suggested to deal with this problem. Second, we assume that the vertical lines can appear anywhere in the image, so the whole image is scanned to search all the vertical lines. This is actually not necessary because the search range might be reduced by projecting the model into image. All of these improvements can reduce image processing time which is the bottleneck of our approach.

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蔡教授從事學術研究，在影像處理、電腦視覺、圖形識別及中文資訊處理等方面成果豐碩，計已發表一百多篇學術論文，其中有五十四篇著名學術期刊論文，其餘爲會議論文。並曾獲得多項學術榮譽，包括中華民國七十五年傑出資訊人才、七十六年國科會優等研究獎、七十七年及七十九年國科會傑出研究獎、七十八年教育部教學優等獎、第3屆龍騰博士論文指導獎及七十八年電腦學會優良論文獎等。蔡氏對人才培育亦不遺餘力，至八十年七月止十一年多之間，共指導碩士學生五十五人及博士學生十二位畢業。蔡氏爲世界上第一位研製中文印章鑑別系統之學者，並發展我國第一部立體物表面資料擷取系統及第一部以立體電腦視覺導航之陸上自動車。