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AUTONOMOUS LAND VEHICLE GUIDANCE IN COMPLEX ROOM ENVIRONMENTS BY COMPUTER VISION TECHNIQUES*

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ABSTRACT

An integrated approach to autonomous land vehicle (ALV) guidance in complex room environments by judging the conditions of routes to generate appropriate navigation paths using computer vision techniques is proposed. The judgement of the existence of a route or a collision is based on the information of route surfaces which is learned in advance. Techniques for model learning are proposed to extract the route features, record the information about turnings, and learn the park location environments. And techniques for path generation are proposed to generate paths among objects in rooms automatically and to guide the ALV to the central path of a route. Furthermore, three strategies for the ALV to park in desired locations are also proposed. Lots of successful experiments with a real ALV confirm the feasibility of the proposed approach.

1. Introduction

The guidance of autonomous land vehicles (ALV's) by computer vision techniques has been intensively studied in recent years because of its wide applications. Although a lot of guidance approaches have been developed for ALV navigation in indoor or outdoor environments [1-9], little research has been conducted on automatic navigation in complex room environments.

Soueres, Fourquet, and Laumond [4] proposed the use of a set of reachable positions for a model car that moves forward and backward with a constant velocity and a lower bounded turning radius. Taylor and Kriegman [5] proposed some exploration strategies for movable robots. By using visually distinctive configurations of features in the world as natural landmarks, a series of local maps is constructed. Ishiguro, et al. [6] proposed a strategy for acquiring an environmental model with panoramic sensing by a mobile robot.Vacherand [7] proposed a real time local path planner based on specific environment modeling with square grid tessellation. Nashashibi et al. [8] proposed a 3D navigation system for providing specific treatments needed for the perception and the navigation of an all-terrain mobile robot. Feiten, Bauer, and Lawitzky [9] proposed a novel local obstacle avoidance method based on the idea of the steer angle field, which discards all steer angles that, given the non-holonomic kinematics of the robot, would lead to collisions within a certain hit distance.

In this study, a model learning approach to guidance for ALV navigation in complex room environments is proposed. The information of route features, turnings, and park location environments are learned in advance. The ALV can be guided to correct destinations by such information. The proposed approach consists generally of five stages. The first stage is to perform model learning of navigable paths. The second is to use the learned model data to set up the navigation system. The third stage is to steer the ALV to navigate in a room by path generation techniques, and the ALV is guided to the central path of the route in each navigation cycle. The fourth is to perform a vehicle turning process when a turning is visited. The fifth stage is to park the ALV in a desired location when a destination is reached. There are three ways to park the ALV. The first is to park the ALV in a square parking frame. The second is to park the ALV at a dead end of the route. The third is to park the ALV in a fixed location where the environment features have been learned in advance.

A prototype ALV used for this study is shown in Figure 1. Three cameras are used in this study to take pictures with a resolution of 512×486 elements. The bottom camera is used to grab the route corners at turn-

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ings. The middle camera is used to grab the forward view far from the ALV. The top camera is used to grab the forward view near the ALV. In addition to the cameras, we use an odometer to measure the distance for each navigation cycle.

In the remainder of this paper, the proposed model learning techniques are described in Section 2. The proposed techniques for path generation and ALV guidance are described in Section 3. The experimental results are described in Section 4. Conclusions can be found in Section 5.

2. Strategies for Model Learning

Three types of learning are proposed in this study. The first is to learn the route feature. The second is to learn the information of turnings in a navigable path. And the third is to learn the stop location environment.

2.1 Steps of Learning Process

The learning process proposed in this study can be described by the following algorithm.

Algorithm 1. The learning process.

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Step 1. Put the ALV in the start navigation position.
Step 2. Take an image of the environment with the first
    camera.
Step 3 Extract the route feature by the image grabbed in
    Step 2.
Step 4. Drive the ALV to the destination. At each turning,
    use the keyboard to key in the turning type, and
    meanwhile record the distance from the start
    navigation position to the beginning of this turning
    using the odometer.
Step 5. Key in "e" to represent the end of the turning
    when the ALV finishes the turning, and meanwhile
    record the distance from the start navigation position
    to the end of this turning using the odometer.
Step 6. Back the ALV until the ALV reaches a proper
    position in order to start the next turning in the case
    that two neighboring turnings are too close such that
    the ALV cannot be in a proper location to start the
    next turning. Use the odometer to record the backing
    distance, too.
Step 7. Repeat Steps 4, 5, and 6 if there exist other
    turnings before the ALV reaches the destination.
Step 8. Decide the ALV parking strategy when a
    destination is reached. There are three parking
    strategies described in Section 2.4.
Step 9. Learn the stop location environment if the third
    parking strategy is chosen.
Step 10. The work of model learning of the path is
    finished now. If there are other paths to learn, repeat
    Step 1 to Step 9 again.
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2.2 Learning of Route Feature

Because the gray level of the route is different from the gray levels of most pieces of furniture in a room, we can easily discriminate them by judging the gray level. The proposed method for learning the route feature is mainly to compute the average gray level in a selected square region of the route in the image. The route feature can be used to extract the route region of an image by thresholding. An example is shown in Figure 2.

2.3 Learning of Turning Information of Paths

There might exist many paths and many destinations for the ALV to traverse in a complex room environment. So learning of the turning information in a navigable route is necessary.

In the proposed process of learning turnings, we not only record the turning types but also record the distance of the turning from the start point. There are two types of distances which should be recorded. One is the distance of the location where a turning is started (called start turning distance) and the other is the distance of the location where a turning is ended (called end turning distance). Both types of distances are measured from the start location of a navigation session to the ALV s current location. On the other hand, we figure out in this study thirteen turning types which are often seen in a room environment. The thirteen turning types are shown in Figure 3.

2.4 Three Strategies for Parking ALV

Three strategies to park the ALV are proposed for more flexible use when the ALV reaches a destination. The first strategy is to park the ALV in a square parking frame. It is appropriate at a location with sufficient space to put the frame. The second is to park the ALV at the dead end of the route. It is an intuitive way to determine whether the ALV should be stopped or not by judging the area of the route in the front view. When the area of the route in the view is less than one third of the total area of the image view, it is a time to stop the ALV. The third is to park the ALV in a fixed location where the environment features have been learned in advance. To use this strategy, the destination environment must be complicated enough to facilitate extraction of sufficient features, and stable matching of features. The proposed feature extraction method is discussed in Section 2.5. And the proposed matching method, called min-max brightness matching, is discussed in Section 3.6. The reason for using the min-max brightness matching method is its generality.

2.5 Learning of Stop Location Envi-ronment

The proposed process of feature extraction for a stop location environment is described by the following algorithm.

Algorithm 2. Feature extraction for a stop location environment.

Step 1. Put the ALV in a fixed location which is a destination for the ALV to park.

Step 2. Grab an image by the first camera as shown in Figure 4(a).

Step 3. Divide the image into four parts, as shown in Figures 4(b) through 4(e).

Step 4. Sum all pixels' gray levels for each column of the upper part of the image. A histogram curve generated from these summations is shown in Figure 4(f). Do similar operations to the other parts of the image to get their respective histogram curves as shown in Figures 4 (g), (h), and (i).

Step 5. Record the positions where the maximum summation and the minimum summation are found for each part of the image. The positions are used as the features of the stop location environment.

Because translation and rotation will always occur when the ALV reaches a destination in two different times, it is necessary to learn more images from other locations and other directions around the stop location. The process of model learning for the stop location environment is described by the following algorithm.

Algorithm 3. The model learning process for a stop location environment.

Step 1. Put the ALV at a start learning location in the stop space as shown in Figure 5.

Step 2. Move the ALV automatically through the path as shown in Figure 5. The moving sequence is 1, 2, 3, 2, 1, 4, 5, 4, 1, 6, 7, 8, 9, 10, 9, 8, 11, 12, 11,8, 13, 14, 15, 16, 17, 16, 15, 18, 19, 18, 15, 20, 21.

Step 3. Grab images at the dotted positions as shown in Figure 5. The number at each dot represents the sequence number.

Step 4. Extract features from each grabbed image in Step 3 by Algorithm 2 to get twenty-one sets of features. Each set has four parts of features.

Step 5. Turn the ALV to the left direction, and repeat Step 1 through Step 4.

Step 6. Turn the ALV to the right direction, and repeat Step 1 through Step 4.

Step 7. Combine the sixty-three sets of data into a file.

3. Strategies for Path Generation and ALV Guidance

3.1 Generation of Central Path and Collision Avoidance

The idea of guiding the ALV to follow the central path of the route is one of the main concepts used in this study. The method for de-ciding the central path of a route can be summarized by the following algorithm.

Algorithm 4. Generation of the central path of a route.

Step 1. Grab an image with the first camera. For example, a grabbed image is shown in Figure 6(a).

Step 2. Perform region growing [16] to extract the route region by the learned route feature. The region growing result for the example is shown in Figure 6(b).

Step 3. Put two parallel horizontal scanning lines in the bottom of the grown image.

Step 4. Decide the central points of the parts of the two parallel lines within the route region. The found central points are A and C as shown in Figure 6(c) for the example.

Step 5. Average the two central points to get a middle point as B as shown in Figure 6(c) for the example.

Step 6. Backproject point B in the image coordinate system(ICS) to point B' in the vehicle coordinate system(VCS).

Step7. Generate a straight navigation path through the origin of the VCS and point B'. The generated path for the example is shown in Figure 6(d).

In addition to the idea of keeping the ALV in the central path of the route, we also need to check three regions of an image to avoid dangerous collision conditions. An example is shown in Figure 7.

If region A is occupied with some objects like the condition shown in Figure 7(b), it means that possible collisions will occur in front of the ALV and the ALV cannot avoid them only by the method of keeping the ALV in the central path of the route. The proposed strategy for deciding the turn direction is as follows. First cut the view of the image into two parts, the left part and the right one. If the route's area of the left part is greater than the route's area of the right part, it means that turning to the left direction is a correct decision and the turn angle is set to 30 degrees. Otherwise, decide to turn to the right direction and set the turn angle to 30 degrees, too. If the ALV finds some objects in region B like the condition shown in Figure 7(c), it means that possible collisions will occur on the left side of the ALV and they are too close for the ALV to avoid. In order to solve this problem, just turn the ALV to the right direction with a turn angle of 30 degrees. Similar actions are taken to handle the condition shown in Figure 7(d).

3.2 Strategies for Turning

In order to finish a turning process, a strategy for blotting out some parts of the route is proposed, by which the ALV can be guided to the non-blotted part of the route. An example of turning to the left direction is shown in Figure 8. The rules for blotting out the route depend on the turning types. We categorize the thirteen turning types into three classes.

Class 1 (from turning types 1, 7, 8, 10 , 13).

The distance from the start turning location to the end turning location of a turning is divided to two parts, one part being three fourths of the distance, and the other part the remaining one fourth of the distance. In the first part, we blot out the right half of the view as shown in Figure 9(a). The reason is to make the ALV turn rapidly. In the other part, we blot out the right one fourth of the view as shown in Figure 9(b). The reason is to make the ALV navigate closer to the central path of the route.

Class 2 (from turning types 3, 5, 6, 11, 12).

The distance from the start turning location to the end turning location of a turning is divided to two parts, one being three fourths of the distance, and the other the remaining one fourth of the distance. In the first part, we blot out the left half of the view as shown in Figure 9(c). The reason is to make the ALV turn rapidly. In the other part, we blot out the left one fourth of the view as shown in Figure 9(d). The reason is to make the ALV to navigate closer to the central path of the route.

Class 3 (from turning types 2, 4, 9).

We blot out the left one fourth of the view as shown in Figure 9(d) for turning type 2, the right one fourth of the view as shown in Figure 9(b) for turning type 4, and the left one fourth and the right one fourth of the view as shown in Figure 9(e) for turning type 9. The reason for blotting out parts of views for these turning types is to keep the ALV in the central path of the route, avoiding the influence of the crossroad.

3.3 Occasions for ALV Back Moves

If two turnings are so close that the start turning distance of the second turning is smaller than the end turning distance of the first turning, it means that if the ALV can pass the first turning, it is impossible for the ALV to pass the second turning because the ALV is not in a proper location to pass the second turning. In order to solve this problem, a strategy of backing the ALV is proposed to adjust the direction and the location before the ALV passes the second turning.

The strategy of backing the ALV is classified into two types. If the second turning is one of the first class (turning types 1, 7, 8, 10, and 13), the first type of backing is performed. For the other types of turnings, the second type of backing is performed.

In the first type, the ALV is backed to the right direction with a right turning angle of ten degrees until the ALV “grabs the route corner”. In the second type of backing the ALV is backed to the left direction with a left turning angle of ten degrees until the ALV “grabs the route corner”. We use the third camera to grab the image of a turning, and image processing techniques to extract the route corner in the image.

3.4 Path Generation for Entering Square Parking Frame

When the ALV is far from the square parking frame, we use the second camera to grab the image of the frame, as shown in Figure 10(a). We then use image processing techniques to compute the four corners of the frame, as shown in Figure 10(b). We backproject the coordinates of the four corners in the ICS into the VCS, and average the locations of the upper two corners and those of the lower two corners. By the two averaged points we can get a straight line as shown in Figure 10(c). The straight line is then adopted as the navigation path for use in ALV guidance when the ALV is far from the square parking frame. When the ALV is near the square parking frame or is going to enter the square parking frame, we use the first camera to grab the image of the frame, as shown is Figure 10(d). We use image processing techniques to get the four corners of the frame, as shown in Figure 10(e). We backproject the coordinates of the four corners in the ICS into the VCS. Again, we average the locations of the upper two corners and those of the lower two corners. By the two averaged points we get a straight line ,as shown in Figure 10(f). The straight line is then adopted as the navigation path to guide the ALV to go closer to the square parking frame. If the upper averaged point is checked to be near the ALV location, then it means that the ALV is reaching the end of the square parking frame. The ALV is then stopped and the work of entering the square parking frame is finished.

3.5 Min-max Brightness Matching for ALV Stop in Destination Environ-ments

After learning the features of the stop location environment, we have sixty-three sets of features which specify the positions of the maximum and the minimum brightness in the environment. When the ALV reaches a location near the destination, the proposed min-max brightness matching method is activated. The min-max brightness matching method is described as follows.

Every set of features of the stop location environment contains four parts, which are the upper, lower, left, and right parts. We match the extracted features of an input image with the sixty-three sets of learned features. If all four parts of features match, then the matching condition is met.

More specifically, if the extracted features are ($upper_{max}$, $upper_{min}$, $lower_{max}$, $lower_{min}$, $left_{max}$, $left_{min}$, $right_{max}$, $right_{min}$), we give an integer variable δ and form the ranges of

$$[upper_{max}-\delta, upper_{max}+\delta], [upper_{min}-\delta, upper_{min}+\delta],$$
$$[lower_{max}-\delta, lower_{max}+\delta], [lower_{min}-\delta, lower_{min}+\delta],$$
$$[left_{max}-\delta, left_{max}+\delta], [left_{min}-\delta, left_{min}+\delta],$$
$$[right_{max}-\delta, right_{max}+\delta], [right_{min}-\delta, right_{min}+\delta].$$

If some sets of the learned features fall in any of the above ranges, it means that the matching condition is met, and it is decided that the ALV has reached the destination.

3.6 Steps of Navigation Process

A navigation process can be described by the following algorithm.

Algorithm 5. The navigation process for a selected path.

Step 1.Perform calibration for the three cameras mounted on the ALV.

Step 2. Read the learned model data for a se-lected path, including the route feature, the turning types, and the parking strategy.

Step 3. Activate the first camera.

Step 4. Start the ALV.

Step 5. Use the techniques discussed in Section 3.1 to keep the ALV in the central path of the route and to avoid possible collisions.

Step 6. Use the techniques discussed in Section 3.2 to solve the turning problem. If the ALV needs back moves, then activate the third camera to find the route corner of a turning using the technique discussed in Section 3.4.

Step 7. Activate the first camera again after the process of back moves.

Step 8. Decide the parking strategy by the learned data when the ALV is approaching the destination.

Step 9. If the selected parking strategy is "parking in the frame", then the method discussed in Section 3.4 is used.

Step 10. If the parking strategy is to park the ALV in a deadend of the route, then judge the area of the route. If the area of the route is smaller than one third of the view grabbed by the first camera, then stop the ALV; otherwise, continue moving forward.

Step 11. If the parking strategy is to park the ALV in a fixed location where the environment features have been learned in advance, then the min-max brightness matching method discussed in Section 3.5 is performed.

Step 12. After the ALV stops in a proper location, the navigation process for a path is terminated.

4. Experimental Results

We use our laboratory as a place for the experiments. The layout of the laboratory is shown in Figure 11. There are four paths for the ALV to go. The navigation speed of the vehicle is about 13 cm/sec. The reason of using the slow speed is to give more computing time to the ALV. The computation time of a navigation cycle ranges approximately from 1.2 to 1.8 seconds for different images.

A lot of navigation sessions have been performed successively in the four paths without collision with the objects in the laboratory. Figure 12(a) shows that the ALV parks in a square parking frame. Figure 12(b) shows that the ALV parks in a deadend of a route. Figure 12(c) shows that the ALV parks in a fixed location where the environment features have been learned in advance.

5. Conclusions

An integrated approach to ALV guidance has been proposed for ALV navigation in complex room environments. This approach has been implemented on a prototype ALV and satisfactory results have been obtained. The main idea of this study is to keep the ALV in the center of the route and avoid possible collisions with objects along the route. Some contributions of this study are as follows. First, model learning for paths have been proposed, by which route feature information is obtained for use in ALV guidance. Second, parking strategies for the ALV have been proposed to meet different conditions. Third, model learning for the stop location environment have also been proposed. Therefore the ALV can park in fixed locations where environment features have been extracted in advance. Fourth, path generating methods have been proposed for the ALV to navigate in complex room environments. Fifth, a method for parking the ALV in the square parking frame have been proposed, by which the ALV can search the frame and park in it automatically. Finally, collision avoidance techniques have also been investigated in this study. Lots of successful navigation experiments confirm the effectiveness of the proposed approach.

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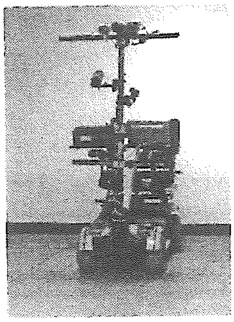

Figure 1: Prototype ALV used in this study.

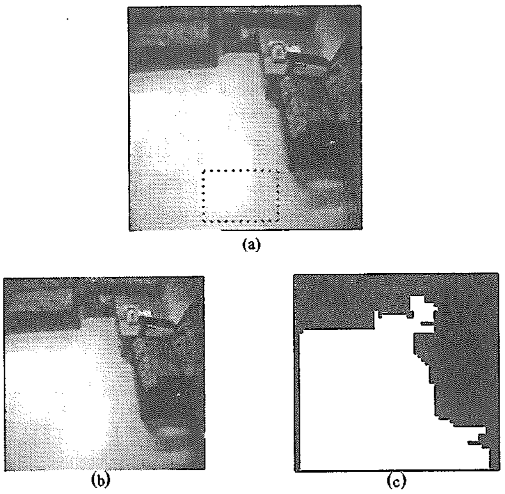

Figure 2: An example of extraction of the route. (a) A square region for computing the average route gray level. (b) An input image. (c) Extracted route region of (b).

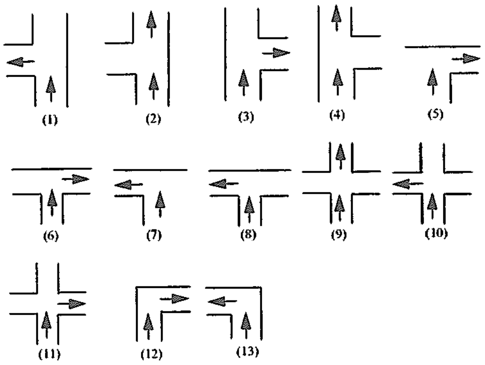

Figure 3: Thirteen turning types which are often seen in a room environment.

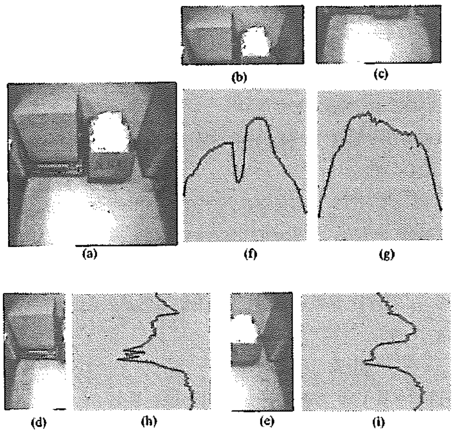

Figure 4: An example of feature extraction for a stop location environment. (a) Input image. (b)-(e) Upper, lower, left and right parts of image. (f)-(i) Histograms generated by upper, lower, left and right parts.

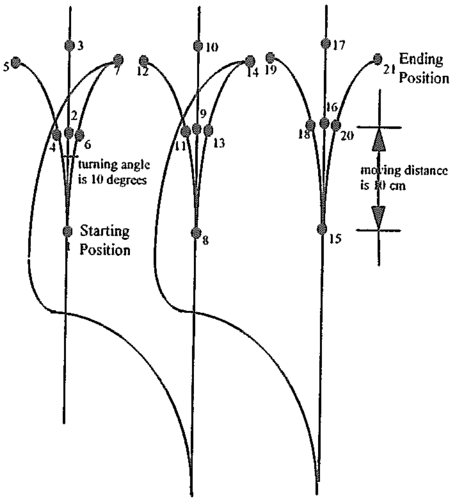

Figure 5: Learning of the stop location environment.

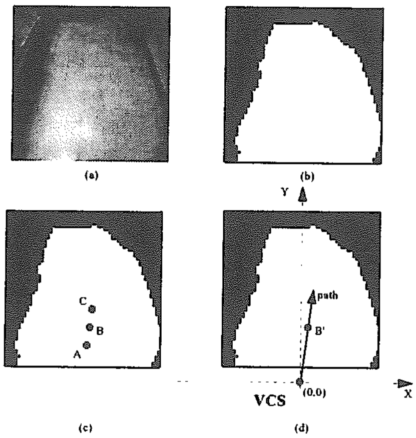

Figure 6: An example for generating the central path. (a) Input image. (b) Region growing result. (c) Decision of three points. (d) Generated path.

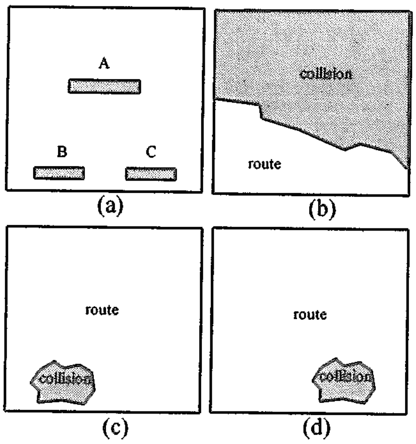

Figure 7: Illustration of avoiding dangerous conditions. (a) Three checking regions. (b) Region A occupied with objects. (c) Region B occupied with objects. (d) Region C occupied with objects.

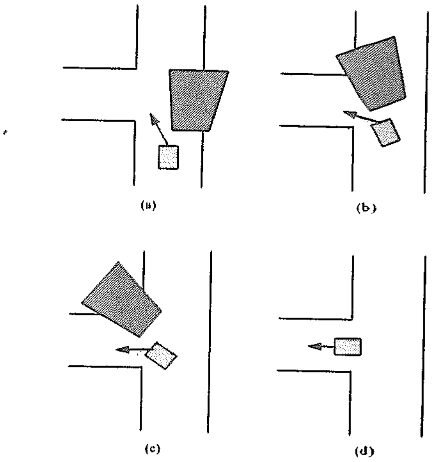

Figure 8: An example of turning by blotting out the right parts of images. (a) Start turning process. (b) Turning in progress after (a). (c) Turning in progress after (b). (d) End turning process.

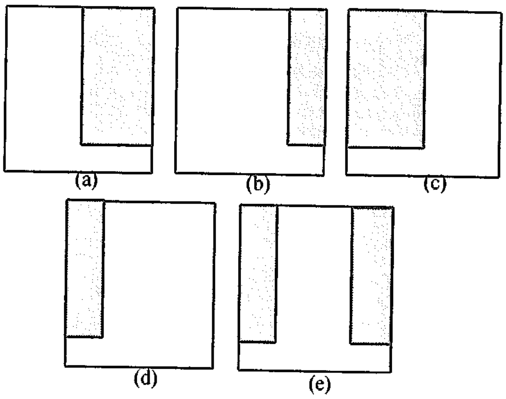

Figure 9: Five ways for blotting out the view. (a) Blotting out right half of view. (b) Blotting out right one fourth of view. (c) Blotting out left half of view. (d) Blotting out left one fourth of view. (e) Blotting out both left one fourth and right one fourth of view.

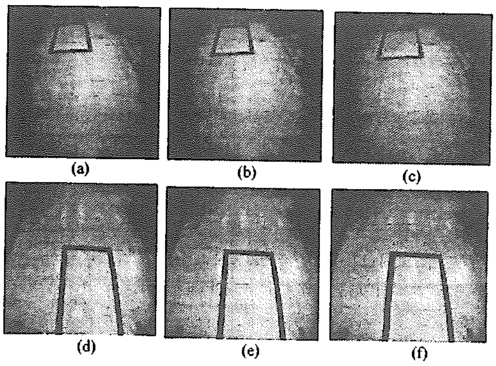

Figure 10: Example showing the three stages for the ALV to enter the square parking frame. (a) First input image. (b) Extraction of four corners of (a). (c) Path generated from (a). (d) Second input image. (e) Extraction of four corners of (d). (f) Path generated from (d).

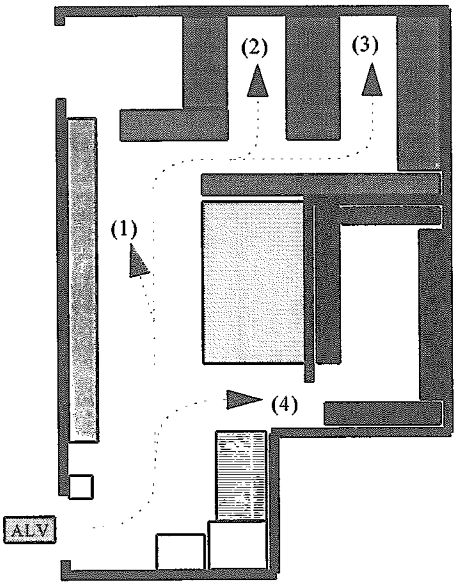

Figure 11: The environment of the laboratory where experiments were conducted.

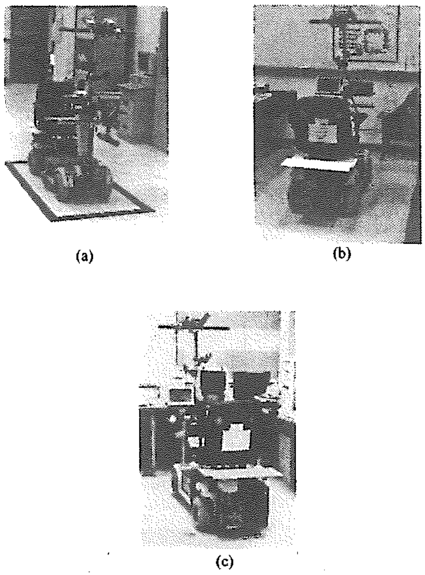

Figure 12: Examples of ALV parking processes. (a) ALV parks in the square parking frame. (b) ALV parks at the deadend of the route. (c) ALV parks in the fixed location where the environment features have been learned in advance.