Research on Robot's Road Detection Technology Based on Machine Vision

Jianzhong Zhang *
Department of Mechanical Engineering,
Hefei University,
Hefei, China
zjzfirst@sohu.com

Qiang Xu
Department of Mechanical Engineering,
Hefei University,
Hefei 230601, China

ABSTRACT

In order to enhance the early-warning performance for the walk-aided service robot, this paper reviews the current states of the road detection method, and does an analysis on the principle of road detection method based on machine vision.Firstly, the recent advances of the road detection method based on machine vision are reviewed, including the structured and unstructured road, as well as the application of artificial intelligence algorithm in road detection system. Secondly, analyses the principle of road detection technology based on machine vision.Finally, analyses the problems of the road detection method based on vision technology, some solutions to improve detection efficiency and accuracy of the vision method are given, which have the extensive applicability and practical significance to improve the autonomous navigation design of the walk-aided service robot.

CCS CONCEPTS

CCS → Theory of computation → Design and analysis of algorithms → Approximation algorithms analysis → Scheduling algorithms

KEYWORDS

Road detection, service robot, machine vision, SVM

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1. INTRODUCTION

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Road detection technology is an important research subject integrated with machine vision, pattern recognition, sensor and other technology. The mobile robot RAVON was developed by the Institute of Industrial University in Kaiserslautern and Germany and Belgium Royal Military.There is a set of stereo vision system at the top of the robot, equipped with two cameras and shown in Fig. 1.Since the 1980s, the United States, Britain and Canada are leading the way in the field of rehabilitation robot. Chinese Academy of Science Institute of automation successfully designed and manufactured mobile robot CASIA-I with road detection system.An other intelligent mobile service robot developed by Harbin Institute of Technology is equipped with a stereo vision system,ultrasonic sensor and pyroelectric infrared sensor,shown in Fig. 2. [1]

Fig. 1. RAVON mobile robot

Fig. 2. Intelligent mobile service robot

The road detection technology also can be further integrated into the exoskeleton service robot, which can afford the impaired people an early alert of detected road and help them to avoid the obstacles on the road. Wei-Min L [2] proposed a stair climbing mobile robot method using an autonomous cross floor navigation system with wireless and vision sensors. Ni, DJ [4] proposed a

design scheme of walking robot aided computer vision and perception based on the actual, and walking with wearable vibration assisted robot system helps the visually impaired people to walk independently.

2 PRINCIPLE OF ROAD DETECTION TECHNOLOGY BASED ON MACHINE VISION

Vision detection method is to observe the road scenes and conditions through the camera, which has the characteristics of low cost and high precision.The process of image fitting and matching is always used in road detection technology.

(1) Image fitting algorithm. Taking the detection of road line as an example, image fitting process can be divided into the following three steps:

1) Preprocessing and denoising. Collect the original image sequentially and transform into grayscale image, then denoise and enhance the grayscale image;
2) Calculate the segmentation threshold, then extract the road from the image;
3) Fitting and tracking the road line.

Further, taking the blind road as an example, the road line is analyzed by fitting method to ensure the minimum of the between the real image points and the fitting line. Assume the linear equation is $S = aT + b$, and suppose the set of points is (Ti,Si) i=1,2,⋯,N.The sum of the deviation between the road fitting line and the real points is

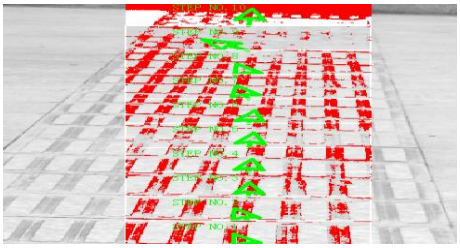
$$\Phi(a,b) = \sum_{i=0}^{n} (aT_i + b - S_i)^2 \tag{1}$$

In order to obtain the minimum value of the function $\Phi(a,b)$, make the formula $\frac{\partial \Phi(a,b)}{\partial_a} = 0, \frac{\partial \Phi(a,b)}{\partial_b} = 0$ true,then calculate the two parameters

$$\begin{cases} a = \dfrac{(n+1)\sum_{i=0}^{n} T_i S_i - \sum_{i=0}^{n} T_i \sum_{i=0}^{n} S_i}{(n+1)\sum_{i=0}^{n} T_i^2 - (\sum_{i=0}^{n} T_i)^2} \\ b = \dfrac{\sum_{i=0}^{n} T_i^2 - \sum_{i=0}^{n} S_i}{(n+1)\sum_{i=0}^{n} T_i^2 - (\sum_{i=0}^{n} T_i)^2} \end{cases} \tag{2}$$

In this way, the blind road line is fitted and the location of the road line is found,which is shown in Fig. 3. Bssides straight line, it can also be fitted with the fold line or two curves line. In road detection system, image fitting analysis method is feasible in principle and has the characteristics of higher speed in computation, but the ability to judge the road tends to be poor.

(a) Original image



(b) Detected blind road

Fig. 3. The blind road line's fitting result

(2)Image matching algorithm. According to the characteristics of algorithm, image matching algorithm can be divided into two categories

1) NGC (Normalized Grayscale Correlation). NGC method is based on the gray value of the image, and the similarity between the template image and the real image is calculated to search the real road's pose parameters.This method is characterized by high accuracy, good robustness and computational stability, but more calculation which slows down the processing speed of the road detection system.

2) GPM (Geometric-based Pattern Matching).With this method, the constant factor of image features is calculated to measure the similarity between the template image and the real image, such as key points, the closing center of the regions, the contour shape and others.This method has smaller amount of calculation, which speeds up the road detection system, and has good ability to resist geometric or intensity distortion, but sometimes sensitive to the noise.[5]

In order to improve the calculation speed and efficiency of image matching, multi-resolution image matching algorithm has been proposed. In 1971, Roserfeld et al. proposed the use of multi-scale operator for image edge detection.In 1973, Hanson and Riseman [6] proposed different spatial resolution of the image. In 1981, Crowley [7] developed the idea of image multi-resolution, and propounded multi-resolution image of pyramid for the first time.

The blind road line's matching result is shown in Fig. 4.

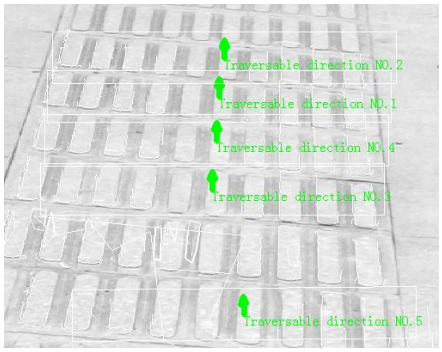


Fig. 4. The blind road line's matching result

The image matching analysis has the characteristics of higher precision and good computational stability, but it's hard for the computer to be trained out-line with the limited known templates.

3 VISION DETECTION METHOD FOR DIFFERENT TYPE OF ROAD

3.1 Structured road detection method

The road can be divided into two types, i.e., structured and unstructured road. The structured road is usually more obvious with road marking and clear edge, the road is basically straight, and the environment has little effect on the result of the detected road.In road detection system, the vision detection algorithm for structured road is a basic and useful research target.

At present, the main vision detection methods for structured road include

1) ROI (Regions of Interest). With this road detection method, a small part of region is selected as ROI ,the feature points in the ROI are calculated and the detected area are reduced, which greatly improve the computational efficiency,such as Ohio State University's Visionex Smart-eye I system,French Peugeot system,and so on.

2) Road characteristics. Since the structured road has clear road characteristics, the background of the road is always single, the road has obvious structural features, including color, texture and edge, the analysis of these features in the image can help to extract the edge and track the passable path.

3) Road model. In order to improve the accuracy of road recognition, researchers introduced some basic assumptions to simplify the detected road.The road model with these assumptions incldes flat and consistent road hypothesis,and most of the application systems offered the consistent assumption of road surface characteristics or road flatness.The road is detected with the simplified road model, such as TaMP, SCARF,VaMoRs and LOIS system,which uses clothoid as a road model, MOB-LAB system designed by Italy Parma University,which uses triangle road model,and in MOSFET system designed by University of Michigan,the road is assumed to be parabolic shape,and so on.

As the structured road has sufficient and clear environmental information (including geometric shape, color and texture features, and so on.), it is quite successful for structured road detection method.

3.2 Unstructured road detection method

The unstructured road refers to the road in nature, such as beach, desert, forest, the lunar surface. Since the unstructured road has no road marking or sign, which is severely affected by the natural environment, it is hard to distinguish the road area or non-road area.

Currently, the main detection methods for unstructured road include

1) Deformable template matching. For the unstructured road has no regular boundary, the projection and trace of the tree or building roadside significantly affect the results of the road detection,and the traditional template aforementioned should be deformed,which adapt itself to the condition of entironment. Deformable template method is used to analyse the gray value of the road image, and the road is detected by measuring the similarity between the deformable template image and the real road image.

2) Unstructured road model. With this method, the unstructured road model should be assumed, and then apply the model to match the real road. In earlier studies, color information model was used to segment the feasible regions, which is sensitive to illumination change.Due to the complexity of the unstructured road, it is difficult to establish a more accurate unstructured road model.Pedro et al. [10] proposed a method to track the natural path by using the visual saliency feature, and obtained the robust tracking results. Gu Y J [11] color model based method for detecting vegetation information. Previous research has established that it is an effective way to detect the unstructured road with this detection method.

3) Machine learning. Since the entironment of the unstructured road is often uncertain and transient, so machine learning algorithm is also applied in road detection system, including the using of genetic algorithm, BP neural network, and PSO algorithm [12].As an important artificial intelligence algorithm, Support Vector Machine (SVM) is proposed by Cortes and Vapnik in 1995, which has been successfully applied to solve the machine learning problem. Vapnik and Chervonenkis proposes the principle of structural risk minimization (SRM). The SVM method is applied to extract the geometric parameters of the unstructured road. And then the data, including the shape, the width and the position, are put into the training sample space, the unstructured road area is identified by the SVM classifier.The final road form and surrounding environment can be done by the SVM classifier.

Many scholars have conducted research on machine learning algorithm.Y.Weilong [13] proposed a multi-direction texture histogram Gabor to better characterize the texture information,which improved the performance of road recognition using histogram back projection technique.Y. Li [14] proposed a detection algorithm for the road intersection, using omnidirectional camera, through unsupervised learning characteristics to achieve robust classification of image,

classificatiing the manual marking sample road area method.Slavkovikj, V[15] proposed a method to learn discriminative features from training data in an unsupervised manner, thus not requiring domain-specific feature engineering. Giyeul S [16] presented an effective method for classifying terrain cover based on color and texture features of an image.and discrete wavelet transform coefficients are used to extract those features. D.Mingfang [17] proposed an adaptive unstructured road detection method for fast adaptive outdoor autonomous mobile robot.An improved genetic algorithm of adaptive threshold for each frame of the road image segmentation, accurate road boundary were found, the last two boundary center position in which the robot driving direction.

4 PROBLEMS AND SOLUTIONS

The robot's road detection based on machine vision should solve a complex pattern recognition problem, which has become the concerning focus in the robot research.The current road detection system solves many problems of road recognition, but a common road detection system does not exist.The research on the road detection technology with adaptive and self-learning ability is still a hot and difficult task [18]. The main problems include:

(1) The complexity of traffic environmental information reduces the calculation precision and efficiency. Some road covered with mud, shadows, or in rain and snow weather situation will inevitably increase the difficulty to improve the road detecting accuracy and efficiency.

(2) The heavy calculation load leads to the poor real-time performance of road detection system. As the changeability of the environment, the computational and the time cost of the road detection technology will inevitably increase, too.

(3) Several factors affect the stability of the road detection result. The limited number of training samples will reduce the match-learning accuracy consequently and lead to the poor self-learning ability to the changing environment, and so it is difficult to update the training sample space of changing road environment.

To solve these problems, the following solutions are worthy of our research.

(1) Further reduce the size of the road image, so as to improve the speed of image processing.
(2) Calculate the correlation with one-dimensional data corresponding to the changing sensitive region sequence.
(3) Multi-road model and concurrent-cooperative working mode should be applied in the road detection system.

Besides camera, road detection sensors should include laser radar, infrared detector and others, each sensor has its own advantage in the road detection system.

5. CONCLUSIONS

In order to enhance the early-warning performance and service level for the walk-aided service robot, this paper reviews the current states of the road detection method, and does an analysis on the principle of road detection method based on machine vision.Aiming to the current existing problems of the road detection system, some solutions to improve detection accuracy of the vision detection method are proposed. Further research on these solutions will undoubtedly have a positive significance for the improvement on the walk-aided service robot.

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