Application of vision aided strapdown integrated navigation in lane vehicles

Qi Wang*

School of Computer and Software,
and
Jiangsu Engineering Center of Network Monitoring,
Nanjing University of Information Science and Technology,
Nanjing 210044, China
Email: wangqiseu@163.com
*Corresponding author

Chang-song Yang

School of Automation,
and
Jiangsu Engineering Center of Network Monitoring,
Nanjing University of Information Science and Technology,
Nanjing 210044, China
Email: c.s.yang@163.com

Shaoen Wu

Department of Computer Science,
Ball State University,
Muncie, USA
Email: swu@bsu.edu

Abstract: The application of global navigation satellite system (GNSS) is extensive in lane applications with the development of science and technology. Vision aided strapdown integrated navigation is an effective aided-navigation method in the case of GNSS failure in lane vehicles, which plays an important role in realising high-precision navigation of lane navigation system. A vision-aided navigation system based on GNSS positioning is constructed using the electrical powered platform as the research object. The hardware platform of vision navigation system is presented and digital image processing is used to segment the collected lane image. The image pre-processing operation, including denoising filtering and greyscale processing, is carried out to complete the segmentation and get the effective navigation area. According to the effective area of navigation, a navigation datum line is extracted by the least squares linear fitting and Hough transform. According to the camera imaging model and the camera's internal and external parameters, the navigation datum line in the image coordinates is transformed into the world coordinates, and the heading angle is calculated. Kalman filter algorithm is used to fuse the navigation parameters of the vision navigation module and the GNSS positioning module, and the integrated navigation model is established.

Keywords: lane vehicle; vision aided strapdown integrated navigation; image segmentation; navigation line detection; Kalman filter.

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Biographical notes: Qi Wang received his PhD in Instrumental Science and Engineering from Southeast University in 2009. He has worked on inertial navigation, integrated navigation, lane navigation and lane terrain matching.

Chang-song Yang received his PhD in Instrumental Science and Engineering from Southeast University in 2007. He has worked on inertial navigation, integrated navigation, lane navigation and lane terrain matching.

Shaoen Wu is an Associate Professor of Computer Science at Ball State University, and the Director of the Intelligent Computing and Communication Systems (ICCS) research group. He is an IEEE senior member. He received a PhD in Computer Science in 2008 from Auburn University. His main research is intelligent internet of things, cyber-physical systems, and wireless and mobile networking.

1 Introduction

With the rapid development of positioning technology, the demand is becoming more and more obvious, the market is also growing, and the application occasions are also increasing. For example, the most common navigation service can help people quickly make travel routes, greatly facilitating people's travel. To achieve these, the first step is to achieve real-time positioning (RTP). In fact, the application of RTLS is very extensive. Recently, more and more demands have been made. There are four more practical applications. Nowadays, lane vehicles are playing more and more irreplaceable roles in civil and military fields. Main roles of the military are reconnaissance, combat and information collection (Gulmammadov, 2009). The application in civilian areas is mainly to develop offshore oil and natural gas (Chen et al., 2011). At present, most of the lane vehicles for military use are equipped with GNSS navigation system and inertial navigation equipment (Qu et al., 2013). RTK-GNSS uses carrier phase dynamic time difference algorithm, the accuracy can reach centimetre level, which can meet the accuracy requirements of civilian equipment automatic navigation system (Shen et al., 2010). However, the price of RTK-GNSS is relatively high, and small and medium-sized farms and individual contractors are hard to undertake. What's more, the GNSS navigation system can only travel according to the route. The working efficiency is related to the artificial route, the intelligence level is not high, the anti-interference ability is poor, and it is easy to cause problems.

Machine vision uses digital image processing technology to analyse the image information collected from the external environment, to obtain useful data, and ultimately achieve the purpose of practical application. This method has the advantages of simple equipment, low cost, convenient design, fast running speed and high accuracy, and is widely used in various fields. The navigation system based on machine vision takes the industrial camera as the position measurement tool of the target object, and uses image processing technology to identify and plan the forward route.

The information collected by the vision system is abundant and the processing speed is fast, which can make up for the deficiency of GNSS navigation system (Zhang et al., 2010). The fusion of the two navigation modes can better realise the function of lane vehicle navigation system and improve its positioning accuracy and real-time. For this reason, this study uses information fusion technology based on a variety of navigation methods to fuse vision navigation parameters and GNSS positioning parameters. Kalman filtering algorithm is introduced in the study of vision aided strapdown inertial navigation system combined with digital image processing, machine vision and GNSS positioning technology (Yan et al., 2013). The aim of this paper is to realise the real-time identification of lane vehicle in the lane to get the vision navigation parameters, and to adjust its navigation path.

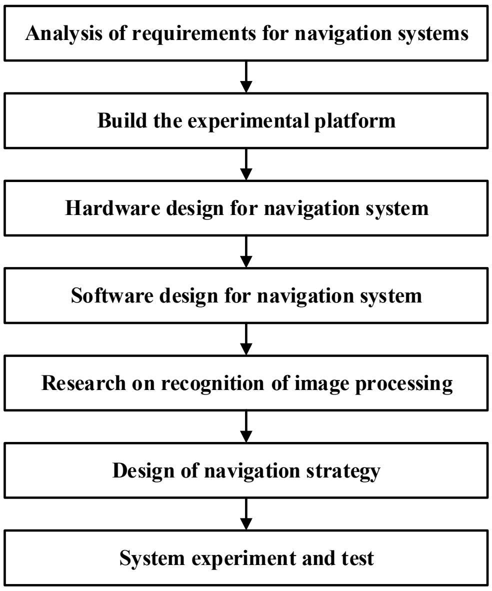
Section 2 first analyses the performance requirements and the design process of the navigation system according to the working environment of the lane vehicle, and proposes the design flow chart of the vision aided navigation system, and introduces the modules and their performance parameters of the system hardware platform, including the paddle wheel power platform, the CCD industrial camera and the ARK industrial control. Machine and ARM11 development board provide hardware basis for the main function realisation of vision aided navigation module (Zhou et al., 2012; Hui et al., 2018). Section 3 first completes the previous work of greyscale and filtering and noise reduction of lane grasses, and then obtains the effective area of navigation by processing mathematical morphology and effective connectivity of the image, so as to prepare for the extraction of the navigation reference line in the next chapter. In Section 4, the least squares straight line fitting, Hough transformation straight line fitting and improved straight line detection algorithm are applied to the navigation reference line fitting experiment of the effective navigation area in the two value image. The wavelet transform and the improved Haugh transform are combined to effectively reduce the image noise and improve the efficiency of the line detection algorithm. And the results of several groups of experiments prove that the navigation datum line fitting algorithm can process the images collected in the natural environment, and can get the navigation datum accurately, so as to achieve the real-time and accuracy conditions needed by the navigation system, and has certain applicable value.

2 Preliminaries

The design and construction of the lane vehicle navigation system experimental platform is the basis for the study of the vision aided navigation system (Xu et al., 2017). Its ultimate goal is to realise the navigation function of the lane vehicle in the natural environment when carrying out marine operations (Li et al., 2017). The experimental platform designed in this paper is mainly aimed at realising the navigation function of the vision aided navigation system and laying the foundation for further research and experiment of the navigation system of the lane vehicle. This paper mainly studies the image processing methods and the extraction of navigation reference lines for lane vehicle vision aided navigation, and designs a Kalman filtering model of integrated navigation parameters to improve the navigation performance of the system.

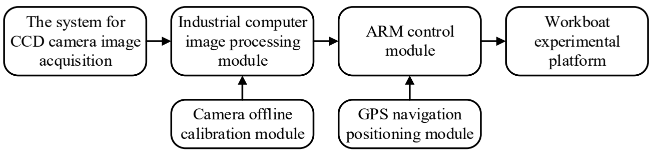
In order to realise the function of lane vehicle (Meng et al., 2018) vision aided navigation and ultimately achieve the purpose of automatic navigation, a vision aided navigation system applied to lane vehicle is developed and its overall structure design flow chart (Figure 1). First, the hardware structure and related software of image acquisition, image processing and motor control system are loaded on the power platform of the PWM platform as the hardware basis for realising the function of vision assistant navigation of the model ship, and then the debugging and performance analysis of various parameters are carried out.

Figure 1 Flow chart of vision aided navigation design



The experimental platform of vision aided navigation system is installed with image acquisition module (Sukkarieh et al., 1999; Zhang et al., 2012) industrial computer image processing module, GNSS positioning module and ARM control module, and its overall structure is Figure 2.

Figure 2 The sketch map of the whole structure of the vision-aided navigation system



The experimental platform of the vision aided navigation system is based on the paddle wheel power platform (Xiong and Shi, 2018). The CCD industrial camera is installed on the front end of the test platform and tilted downward from a certain angle, which is mainly responsible for collecting the environmental information in front of the driving path. When the lane vehicle is working normally, the image acquisition module collects the lane environment in front of the operation chip, and the industrial computer image processing module processes and identifies the data information obtained by the industrial camera, extracts useful navigation information, gets the navigation baseline information, and transmits the navigation data to the control system. Combining with the navigation parameters obtained by GNSS positioning module, the trajectory of the test platform is controlled by ARM control module.

The experimental platform of this subject is the power platform of the open-wheel, and the platform is used to simulate the route of the automatic navigation experiment (Zhang et al., 2015). The platform is equipped with satellite mobile station, monitoring station (Wei et al., 2017; Yu et al., 2012), driving motor and vision navigation module. It is driven by brushless DC motor and controlled independently by two wheels. It controls starting, stopping and steering by controlling the speed difference between the two wheels. Its working power is 600 W.

The structure of the image acquisition and processing system is: using industrial cameras to connect with the computer through the USB interface on the motherboard, and transmit the image data directly to the industrial computer image processing software, and process and recognise the image (Duan et al., 2016; Wang et al., 2019). The performance of industrial cameras has an important impact on the accuracy of machine vision, and the selection of the type of industrial cameras needs to consider the characteristic parameters needed in the working environment.

Table 1 Main characteristic of camera

Parameter	*Definition*
Resolving power	Measure the camera ability to distinguish between light and dark details of an object
	The number of pixels on the CMOS chip
Speed	According to the measured object motion speed, size, field of view size and measurement accuracy and other parameters
	A camera that selects the corresponding speed
Sensitivity	Depending on the sensitivity of the chip, the photoelectric conversion capability of the optical sensor
Pixel velocity	Bit number of pixel grey value of digital camera output
Fixed noise	It is mainly dark current noise and does not change with the spatial coordinates of pixels.
Dynamic range	The range of the camera to detect the light signal
Optical interface	C, CS, and F are common
Spectral response	The ability of the camera to respond to different wavelengths of light

Considering the conditions of application and working environment of vision aided navigation system, the camera used in this research platform is MV-VS078 FC high speed digital industrial camera. The industrial camera uses digital row CCD scanning mode to get higher definition, and adopts standard lens interface (CS port and C). The transmission speed is high and stable (Hui and Cai, 2007; Qu et al., 2018), and has multiple resolution modes, and occupies less memory. It supports a single IPC access to multiple industrial cameras, and supports the development of programs under Windows and Vista (Li et al., 2015; Shu, 2016). Compared with the CMOS industrial camera, the camera has higher sensitivity and resolution, lower system noise and higher image quality, and is not easy to distort. It is widely used in industrial production online detection, intelligent transportation, etc.

Machine vision, military science, aerospace and many other fields (Zhou et al., 2009). The image processing industrial control machine used in this project is the

ARK-2121 embedded fan free industrial control machine, which is used as the upper computer of the automatic navigation system to complete the work of image processing and parameter calculation.

The industrial computer uses a rugged, compact embedded system with Intel Celeron J1900 2.00 GHz quad-core processing (Li and Zhao, 2011; Liu et al., 2010). It has the advantages of small size, less power consumption and powerful function. It is widely used in intelligent transportation system, industrial automation and various fields such as the internet of things. This topic chooses ARM11 (S3C6410) development board as the main control module (lower computer) to build a vision aided navigation system based on GNSS positioning module to execute the operation commands of the host computer (Hui and Cai, 2007; Biswas et al., 2018). The S3C6410 model development board adopts ARM1176JZF-S core, which has faster processing speed, has a large number of hardware peripheral interfaces, supports video and audio processing, two-dimensional graphics display operation and scaling processing, has higher performance and lower power consumption, and can meet the requirements of lane vehicle for control system (Wu, 2010).

3 Image processing

The vision navigation system of lane vehicle uses vision processing and extraction technology to get key information that can be used to navigate from graphics, thereby extracting moving or stopped moving targets in graphics. Objects or images can’t be directly extracted from vision sensors. Image preprocessing is usually needed because of particular susceptibility to noise or background. Image preprocessing includes image denoising, greyscale, two-value and morphological operations.

The original image directly captured by the camera is a three channel image composed of three colour components. It will cost much time if we operate the image directly, we need to process the colour component data of the three channels sequentially, and it will cost much time. In order to improve the efficiency of image processing algorithm, it is necessary to reduce the total amount of data processed by the object. The usual method is to grey the colour image. Greyscale processing is the operation of transforming RGB three-channel image information into single channel greyscale image data. The main methods used are single component method, average value method and weighted average method.

This topic is to collect and process image in lane in natural environment. In the process of image acquisition and transmission, the noise in image data is unavoidable due to environmental factors, camera distortion and other factors such as electromagnetic interference in image transmission. It has many kinds of image noise. According to the way of production, including electrical noise, mechanical noise, channel noise, etc., according to the amplitude characteristics, it can also be divided into Gauss noise, salt and pepper noise, etc.

Digital image denoising is one of the most important steps in image preprocessing. In this paper, the common median filtering method and wavelet denoising method in spatial domain are applied to denoise the collected lane images respectively, and comparative analysis is carried out.

In the same hardware condition and running environment, the same image is used for noise reduction. Considering the efficiency of the algorithm, the median filtering method is used to denoise the lane image when the processing effect is close.

In the field of machine vision, image segmentation is one of the most critical and difficult processes. It requires classification of all the pixels in the image according to the similarity of some features of the image, which is the premise and core step of vision navigation, and the segmentation effect seriously affects the subsequent image processing steps.

The significance of image segmentation is to divide the image space into some meaningful regions, so as to facilitate the computer to judge the image information and provide the basis for the next operation. In the process of image segmentation, the way of segmentation mainly depends on the problems to be solved. The advantages and disadvantages of segmentation need to be weighed according to the specific application environment and technical requirements. No image segmentation algorithm can be universal and meet the requirements of various occasions, and there is no set of standard technical parameters to determine the image whether the segmentation process is successful or not.

Now there are many algorithms for digital image segmentation, but they are based on different application backgrounds and objects to choose different evaluation criteria and segmentation methods, and their application ranges are different. On this issue, for different situations, we need to carry out targeted analysis and design respectively, in order to obtain satisfactory results. Generally, the basis of image segmentation mainly includes parameters such as gray value, shape feature and texture feature. Preliminary preparations are made for the following work, such as the fitting of effective navigation area and navigation path.

4 Recognition of navigation lines

Most of the research on lane vision navigation is applied to military and navigation fields due to the limitations of hardware cost and technical level. A lot of research has been done on the vision navigation system and path planning applied to ridge field on the ground. A vision aided navigation strategy is proposed to detect the lane environment on the basis of the research on the application of path recognition on the ground.

In view of the complex and changeable environmental conditions on the lane under natural conditions, the vision aided navigation strategy proposed in this paper is to identify only effective navigation lines, so as to reduce the interference of various environmental noises to navigation line recognition and improve the efficiency of navigation line recognition.

In order to get the navigation line of lane vehicle, it is necessary to fit the navigation feature points and the navigation effective area linearly. Considering the complexity of the lane environment, a straight line model is proposed to fit the navigation datum. The essence of straight line detection is: for a given set of experimental data points, a straight line is used to try to pass or approach the largest number of data points, and can be simply described as the problem of calculating the optimal solution of the two parameters of the line slope and intercept. Linear detection algorithms commonly used in two value images include least square line detection and Hough transform. In this section, we study the straight line detection algorithm suitable for this topic.

The least squares straight line fitting, Hough transformation straight line fitting and improved straight line detection algorithm are applied to the navigation reference line fitting experiment of the effective navigation area in the two value image. The wavelet transform and the improved Hough transform are combined to effectively reduce the image noise and improve the efficiency of the line detection algorithm. And the results of several groups of experiments prove that the navigation datum line fitting algorithm can process the images collected in the natural environment, and can get the navigation datum accurately, so as to achieve the real-time and accuracy conditions needed by the navigation system, and has certain applicable value.

5 Simulation and experiments

In the aspect of machine vision, camera imaging model and parameter calibration are the first problems to be solved for quantitative analysis and accurate positioning of the target. For the perspective model, the camera parameter calibration is to solve the correspondence problem between the 3D object points and the two-dimensional image points in the camera imaging model, in particular, to determine the camera internal and external parameter matrix and various distortion coefficients.

Among them, external parameters refer to the projection of the calibration points in the scene to determine the position and direction of the camera in the absolute coordinate system (three rotation angles and three translational components), which is related to the installation mode of the camera. The internal parameters refer to the geometric parameters determining the camera own structure, including the location of the imaging principal point, the lens radial deformation coefficient and the eccentricity coefficient, the row and column ratio coefficient, etc. In common case, the number, meaning and calculation method of the internal and external parameters corresponding to various camera imaging models are not the same. The specific calibration methods need to be chosen according to the specific circumstances.

Compared with the lane environment, two-dimensional calibration objects can be selected. Two-dimensional calibration (calibration plate) is easy to manufacture and easy to implement. Therefore, the calibration method of camera calibration is widely used in various fields. The specific step is to detect pixels at the characteristic points in the calibration plate first. The relationship between coordinate points in coordinate and space coordinate system is established, and the imaging model is established. Then the specific parameters of the camera are calculated through the coordinates of known feature points.

After completing the calibration of the internal and external parameters of the industrial camera, the parameters of the navigation datum line obtained in the image can be converted to the world coordinate system, and then the target heading angle can be detected.

The actual calculation process of information fusion algorithm based on multiple navigation modes is the fusion of measurement parameters and estimation of state vectors of different navigation modules. The widely used state estimation method is the Kalman filtering model to improve the accuracy and robustness of the lane vehicle navigation system. The method of parameter information fusion is studied, and the Kalman filtering model is introduced to fuse and optimise the navigation parameters of vision aided navigation module and GNSS positioning module. Figure 3 show the velocity error with vision compensation and Figure 4 show the attitude error with vision compensation.

The camera coordinate system, imaging model and calibration method, uses Zhang calibration method to carry out experiments, gets its internal and external parameters, and then based on the corresponding relationship between the image coordinate system and the world coordinate system and the obtained camera parameters, calculates the expression of the guiding route in the real world, and finally gets the target. According to the navigation parameters provided by the vision navigation module and the GNSS positioning module, a Kalman filtering model of the navigation system of the working ship is designed to fuse the parameters.

Figure 3 Velocity error with vision compensation (see online version for colours)

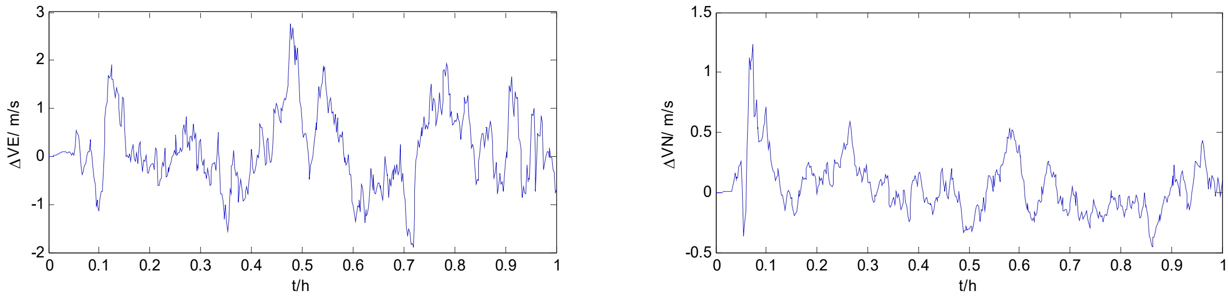
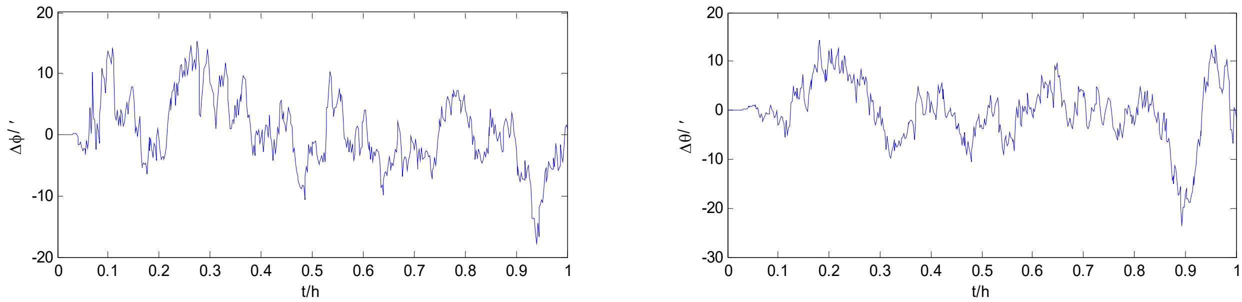


Figure 4 Attitude error with vision compensation (see online version for colours)



6 Conclusions

A vision aided navigation system is designed, and its design idea and hardware structure are introduced based on the GNSS positioning system. The segmentation effect of effective navigation area in digital image affects the accuracy of vision navigation function. First, the segmentation efficiency and efficiency of several segmentation methods are compared, and the OSTU segmentation algorithm is selected to complete the segmentation of the lane and the lane and grass area. Then an effective area of navigation is obtained through the method of mathematical morphology and maximum connectivity region reservation, which lays the foundation for the subsequent navigation reference line extraction. The extraction of the navigation datum line is completed. First of all, the least squares fitting and Hough transform linear fitting method are used to extract the navigation datum line, and the accuracy and efficiency of the results are compared and analysed. Then a straight line detection algorithm is proposed, and its superiority is verified, which can better adapt to the application object and working environment of this subject. Calibration method is used to calibrate the CCD industrial camera, and the internal and external parameters are obtained. The projection error is [0.20102, 0.190102], which meets the requirements of the navigation system. Then the navigation datum line in the image registration system is converted to the world system according to the camera imaging model and the camera internal and external parameters. In the coordinate system, the heading angle of the target is calculated as the vision navigation parameter. After obtaining the navigation parameters of the vision navigation module and the GNSS positioning module, we design a Kalman filtering navigation model to complete the fusion of the navigation parameters to improve the accuracy and real-time performance of the navigation function of the operation chip, and verify the improvement degree through the navigation experiment.

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