A Novel Line Feature Description and Matching Method for Visual-Aided Inertial Navigation System

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Abstract. With the rapid development of machine vision technology, more and more attention has been paid to the visual-aided inertial navigation system. It is important that to extract and track the line features at the dynamic situation in the visual-aided inertial navigation system which is based on visual line feature information to compensate attitude errors. A novel line feature description is proposed that use the SURF points to mark the LSD lines. Then, through coarse matching and fine matching, the function of continuously tracking the one line features in different images was realized. These line feature description and tracking method are applied in the visual-aided inertial navigation system, and its effectiveness is verified by the vehicle experiment.

1. Introduction

It is known the reason why GPS cannot offer accurate position information at the center of city is that denseness buildings will obstruct some, or all, of the satellite signals. Do not worry about it, there are other methods used to position and navigate, like inertial navigation system (INS), and other methods that fusion inertial and other sensors into the integrated navigation system. INS is to obtain the motion state and position of the object by integrating the measurement information of gyroscopes and accelerometers. However, the integral calculation method will bring a serious error that increases with time. The most widely used method is the INS and other sensors integrated navigation system when GPS is unavailable.

One of the most widely method is inertial and doppler radar integrated navigation system [1][2][3]. This method used the radar information to compensate the velocity error of Strap-down Inertial Navigation System (SINS). Celestial and inertial integrated navigation system is a good method to improve the accuracy of INS [4][5][6]. However, complex environment and severe weather have great influence on the Celestial sensor. INS/Wifi hybrid localization system is used to smart-phone and robotic localization indoors [7][8][9]. This method will be affected by Wifi signal quality and vehicle speed when it used outdoors. Another important method is inertial/visual integrated navigation system [10][11]. With the development of computer vision, visual technology will be more applied in the navigation system.

In reference [11], we proposed a method combining inertial with visual to solve the positioning and navigation problem when GPS is unavailable. The visual information to compensate the attitude error of SINS. However, we just discussed the static condition. At motion condition, how to recognize line
2. How to describe the line feature

First of all, to extract the LSD features [12] and SURF point features, respectively. These two features are used to define the new description line features in dynamic condition. Through Coarse matching and fine matching, the function of continuously tracking the same line features in dynamic images was realized.

2.1. The line feature description method
Hough transform is used to extract the line feature for visual-aided inertial navigation system when vehicle stops [11]. In this study, we use the faster and more accurate line segment detector, LSD [12], to replace Hough transform. Let $L$ be the line feature symbol, it includes two parameters of line feature, $\theta$ and $\rho$ [13].

Images in vehicle data recorder is changing with the vehicle moves. So that the line features in different time are not entirely same. Even if a line feature exists in different images at the different time, its feature angle in different images may be different. To describe the same line feature in different images, we introduce SURF [14] points with rotational invariant to label line feature. Set $P_{SURF}$ includes all of the SURF points in one image.

In one image, for each line feature $L$, the neighbourhood $S_L$ is the set includes the pixels located in the rectangle $H_L$. $H_L$ has the same midpoint and slope with $L$, and its width and length are $2d$ and $L+2d$, where $d$ defined as the neighborhood width parameter. So $S_L$ can be described as below:

$$S_L = \{ \text{Pixel} | \text{Pixel} \in I, \text{Pixel} \subset H_L \}$$

(1)

Therefor, we define the set $S_{LP}$, includes all pixels located sets both $P_{SURF}$ and $S_L$.

$$S_{LP} = \{ p_i | p_i \in S_L, p_i \in P_{SURF}, i = 1,2,...,n \}$$

(2)

Then, we use both $L$ and $S_{LP}$ to describe the line feature at dynamic condition. The description is named as line marked by SURF points. For convenience, we still use $L$ to name line features.

2.2. Line feature matching
Line feature matching includes two steps: Coarse matching and Fine matching.

2.2.1. Coarse matching rule. Through SURF feature matching between the neighbouring two images’ $S_{LP}$, Lines corresponded to the matched SURF feature points were classified as the same line feature.

After coarse matching, we can get the appearance time and disappearance time of the line feature $L$, Define the existence time interval of $L$, as $\Delta l_j$.

The result of coarse matching is expressed as $L_j : \{t^1_j, t^2_j, ..., t^m_j, L_m' \}$, where $L_m'$ is the lines set which is not the same line with $L_j$, $m \neq j$. The lines $L_m'$ mixed into the set of $L_j$ is cased by the matched SURF points in different images marked with different lines. In order to solve this problem, we will continue to fine matching.

2.2.2. Fine matching rule. For coarse matching results error that put the different line feature into one set, we give a precise matching rule. For SURF point $p_i$, $f = \alpha D(p_i, L_j) + (1 - \alpha) v(p_i, P_{SURF})$

(3)
Where $f$ is the trust value of fine matching. Line feature $L_j : u \sin \theta_j + v \cos \theta_j - \rho_j = 0$, SURF point $p_i(u,v)$, $D(p_i,L_j)$ is the distance between $p_i$ and $L_j$, $D(p_i,L_j)=|u \sin \theta_j + v \cos \theta_j - \rho_j|$. We introduce $\nu(P_j,M_P)$ to enhance the robustness of the matching process [15].

$$\nu(P_j,M_P) = -\sum_{j=1}^{N_{\Delta l}} N_{p_i}^{N_{\Delta l}} \log N_{p_i}^{N_{\Delta l}}$$  (4)

Where, during $\Delta l$, the number of line features is $N_{\Delta l}$, the times of SURF point $P_j$ is $N_{p_i}^{N_{\Delta l}}$.

The description of the SURF feature is a $16 \times 4$ vector, in which four kinds of intensity variation: $\sum dx$, $\sum dy$, $\sum |dx|$ and $\sum |dy|$, are calculated over sixteen regions. We use $P_i$, a $64 \times 1$ vector to store the 1-64 element in the description of SURF, suppose there are $N$ SURF features during $\Delta l$, put them in matrix $M_P$, 

$$M_P = [P_1, P_2, ..., P_N]$$  (5)

Equation (4) is built in the spirit of Fisher information which is a classic method to evaluate the compactness of a probability distribution. In general, a low score of $\nu$ implies that elements in SURF point $P_i$ tends to be identical, indicating that the feature is less distinctiveness. In the process of matching identity lines, the matching results with the higher $f$ value is preferred.

3. Visual-aided inertial navigation system

3.1. The visual-aided inertial navigation system

![Figure 1. The schematic diagram of inertial-visual integrated navigation system [11].](image)

The SINS and camera are fixed on the vehicle. $\Delta \theta$ is the attitude error information from camera. It is used to compensate the SINS attitude errors. The Kalman Filter (KF) is used to fusion the visual attitude information and SINS attitude information together. The schematic diagram of inertial-visual integrated navigation system is shown in Figure 1.

3.2. The attitude information from camera

As the proposed method, first of all, to extract the LSD lines and SURF points for all images. Then, using the SURF points to mark LSD lines. The marked LSD lines are the line features which can be traced. Next, to calculate the $\Delta \theta$ of each line feature. In the overlap part of lines, the $\Delta \theta$ of is replaced with the mean of overlap $\Delta \theta$. Working like these, the visual attitude error is obtained.
In Figure 2, \( L_{y}^{2} \) and \( L_{x}^{2} \) are the start time and end time of line \( L_{y} \), \( n \) is the total number of line features. \( \Delta t_{i} \) is the overlap time of lines \( L_{i} \) and \( L_{y} \). During the overlap time, \( \Delta t \) is the mean of the overlap lines’.

4. Experiment

4.1. Visual-aided inertial navigation system

During the experiment, the vehicle is started and stop. In this experiment, the GPS is used to provide a coarse alignment of position system and to provide a position reference. In the experiment, the frequency of the IMU is 2Hz, the frequency of the video is 2Hz, and the run time length is 50s.

4.2. LSD line marked by SURF points

For the extraction of LSD line features in the experiment, in order to reduce the amount of calculation and increase the availability of line features, we limited number \( n_{i} \) of the LSD, to a certain extent to reduce the useless line features, \( n_{i} \geq 2 \).

The LSD lines marked by SURF points in one image are shown in Figure 3.
The neighborhood width $d$ affects the marketability of line features. During the experiment, it was found that not all LSD lines could be marked by SURF points. As shown in figure 4, there are six line features but only two marked by SURF points. In this case, the neighborhood width parameter $d$ could be modified to select an appropriate range and mark enough line features.

5. Results

5.1. The attitude error

![Figure 5. The attitude error of only INS.](image)
As shown in Figure 5 and 6, in the case of only INS, the attitude error given by the positioning system has obvious zero deviation. After 35 seconds, the rolling error and heading error are diverging. The visual-aided inertial method can restrain the deviation of zero and the divergence of rolling error and heading error, although the accuracy of pitch is sacrificed.

5.2. Position information

The GPS position is the refer information. It can be clearly seen from the figure 7 that in the case of only INS, the position has a significant divergence, that is, with the time goes, the position error of only INS is increase. However, the position divergence of visual-aided inertial system is obviously smaller than only INS.

6. Conclusion

In this paper, it is proposed that a novel line feature description for visual-aided inertial navigation system. LSD and SURF are used to describe the line feature. Through Coarse matching and fine matching, the function of continuously tracking the same line features in dynamic images were realized. This feature tracking method is applied to the visual-aided inertial navigation system, and its effectiveness is verified by experiments. The experiment results shown that the proposed line
description works well for visual-aided inertial navigation system. The visual-aided inertial navigation system can work to offer position information when the GPS is unavailable.

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