Applied Mechanics and Materials Vol 538 (2014) pp 375-378 Online: 2014-04-24

doi:10.4028/www.scientific.net/AMM.538.375

Optical Flow-based Monocular Vision/INS Integrated Navigation for Mobile Robot Indoors

Xiyuan CHEN[1,a], Jingpeng GAO[1,b], Yuan XU[1,c], and Qinghua LI[1,2,d] *

[1]School of Instrument Science and Engineering, Southeast University, Nanjing, China

[2]School of Electrical Engineering and Automation, Qilu University of Technology, Jinan, China

[a]chxiyuan@seu.edu.cn, [b]gaojinpeng1129@163.com, [c]xy_abric@126.com, [d]liqinghua1977@163.com

*Corresponding author: liqinghua1977@163.com

Keywords: Optical flow, monocular vision, inertial navigation system (INS), integrated navigation

Abstract. This paper proposed a new algorithm for optical flow-based monocular vision (MV)/ inertial navigation system (INS) integrated navigation. In this mode, a downward-looking camera is used to get the image sequences, which is used to estimate the velocity of the mobile robot by using optical flow algorithm. INS is employed for the yaw variation. In order to evaluate the performance of the proposed method, a real indoor test has done. The result shows that the proposed method has good performance for velocity estimation. It can be applied to the autonomous navigation of mobile robots when the Global Positioning System (GPS) and code wheel is unavailable.

Introduction

For today's mobile vehicles, in order to fulfill a mission, the demands for high precision land navigation are increasingly urgent. Many techniques have been widely applied to the autonomous navigation of mobile vehicles in the past decades [1]. The Global Positioning System (GPS) and the inertial navigation systems (INS) are the most famous. However, they both have limitations in some situations.

For the GPS, it is prone to signal interference and signal loss, and it is not utilizable for most indoor applications. As to INS, its errors, especial position errors, are growing over time due to sensor drifts and will cause an unbounded error characteristic [2].

In recent years, vision-based approaches have gradually become attractive alternatives for mobile robots navigation. Vision-based approaches estimate motion states of the mobile robot by tracking distinguishable features across multiple images. Since visual sensors have no contact with the terrain over which mobile robots traverse, then the error caused by the wheel slip is avoided. They are more suitable for velocity and acceleration measurements at low velocity ranges than INS due to no accumulating errors. Besides, visual sensors also have advantages of being small in size, low in power consumption, and passive in nature [3,4].

In this work, an optical flow-based monocular vision (MV)/INS integrated navigation algorithm is proposed. In this model, a downward-looking camera is used to get the image sequences, which is used to estimate the velocity of the mobile robot. Meanwhile, it is also able to obtain the yaw and the yaw variation by using INS. Then, extend Kalman filter (EKF) is employed to estimate the optimal velocity of the mobile robot by fusing the measurement of the camera and the INS. A real indoor test is used to evaluate the performance of the proposed method.

Data fusion for integration system

Velocity Estimation of Camera. In this work, the camera is attached to the mobile robot and placed vertically facing the terrain. Suppose that the ground surface is predominantly flat and the optical axis of the camera is perpendicular to the ground surface. According to the downward-looking camera, we can acquire the image sequences of the terrain. In each set of adjacent images, we select some good features from the first image and record their locations according to the feature detection method presented in [5]. Then, the selected features are tracked to the second image according to the pyramidal implementation of Lucas Kanade optical flow method [6,7]. After the tracking operation, we can get the feature locations in the second image. After that, the random sample consensus method is adopted to reject the incorrectly tracked features. Then we can compute the translation between adjacent images using the corrected tracked features. Afterwards, we can get the camera velocity using the camera geometrical projection model [8]. In this paper, the X-Y plane of the camera coordinate system is parallel to the X-Y plane of the body coordinate system, so the velocity of camera is also the mobile robot velocity. Fig.1 shows the velocity estimation of camera. Eq. 1 illustrates how the velocity and accelerometer in x and y axis can be converted to the velocity and accelerometer in east and north direction.

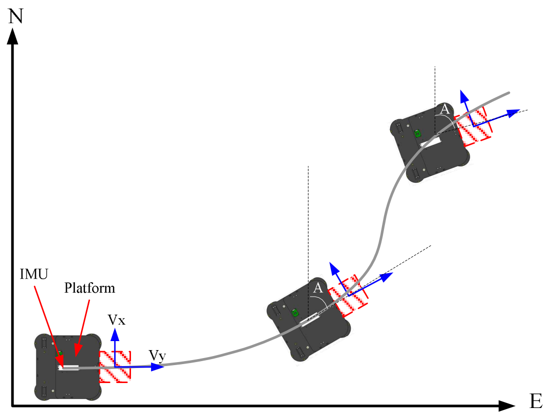

Fig.1 Velocity estimation of camera

$$\begin{bmatrix} \hat{V}_{E,k} \\ \hat{V}_{N,k} \\ \hat{A}_{E,k} \\ \hat{A}_{N,k} \end{bmatrix} = \begin{bmatrix} \cos\varphi & \sin\varphi & 0 & 0 \\ -\sin\varphi & \cos\varphi & 0 & 0 \\ 0 & 0 & \cos\varphi & \sin\varphi \\ 0 & 0 & -\sin\varphi & \cos\varphi \end{bmatrix} \begin{bmatrix} V_{x,k} \\ V_{y,k} \\ A_{x,k} \\ A_{y,k} \end{bmatrix} \tag{1}$$

Here, φ is the yaw of the mobile robot, $V_{x,k}, V_{y,k}, A_{x,k}, A_{y,k}$ are the camera velocity and accelerometer in x and y axis, while $V_{E,k}, V_{N,k}, A_{E,k}, A_{N,k}$ are the velocity and accelerometer in east and north direction at k time.

State Model. In this work, a 4-state EKF is employed for the data fusions. The discrete-time state equation of the filter is illustrated in Eq. 2.

$$\underbrace{\begin{bmatrix} V_{E,k+1} \\ V_{N,k+1} \\ A_{E,k+1} \\ A_{N,k+1} \end{bmatrix}}_{\mathbf{X}(k+1)} = \underbrace{\begin{bmatrix} 1 & 0 & T & 0 \\ 0 & 1 & 0 & T \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{\mathbf{A}} \underbrace{\begin{bmatrix} V_{E,k} \\ V_{N,k} \\ A_{E,k} \\ A_{N,k} \end{bmatrix}}_{\mathbf{X}(k)} + \omega_k^* \tag{2}$$

Here, T is the sample time; ω_k^* is the Gaussian process noise.

Measurement Model. The eastward velocity $\hat{V}_E$ northward velocity $\hat{V}_N$ and yaw variation $\hat{\omega}_Z$ are chosen as observation. The discrete-time measurement equation is expressed by Eq. 3.

$$\underbrace{\begin{bmatrix} \hat{V}_E \\ \hat{V}_N \\ \hat{\omega}_Z \end{bmatrix}}_{\mathbf{z}(k)} = \underbrace{\begin{bmatrix} V_{E,k} \\ V_{N,k} \\ \dfrac{V_{N,k}A_{E,k} - V_{E,k}A_{N,k}}{V_{E,k}^2 + V_{N,k}^2} \end{bmatrix}}_{h(\mathbf{x}_k)} + \boldsymbol{\upsilon}_k \tag{3}$$

Here, $\boldsymbol{\upsilon}_k$ is the measurement noise.

Indoor Localization Tests and Performance

To test the method, a short distance experiment was carried out in the hallway where the ground surface is predominantly flat. The mobile robot was command to move in a straight path at the speed of 0.15m/s. The output frequency of IMU data is 20HZ and the frame rate of camera is 20fps. The east and north velocity errors computed by MV only, INS only and MV/INS are shown in Fig.2. It is easy to see that the east and north velocity errors of the INS drift over time. To the east velocity error, the MV method and the proposed method mainly maintain stable between -0.02m/s and 0.02m/s. To the north velocity error, the MV method and the proposed method mainly stay stable between -0.05m/s and 0.05m/s. Clearly, the proposed method has the lowest error. It reduces the mean east velocity error by about 21.3% and 88.1% compared with MV and INS respectively. And it reduces the mean north velocity error by about 26.5% and 86.1% compared with MV and INS

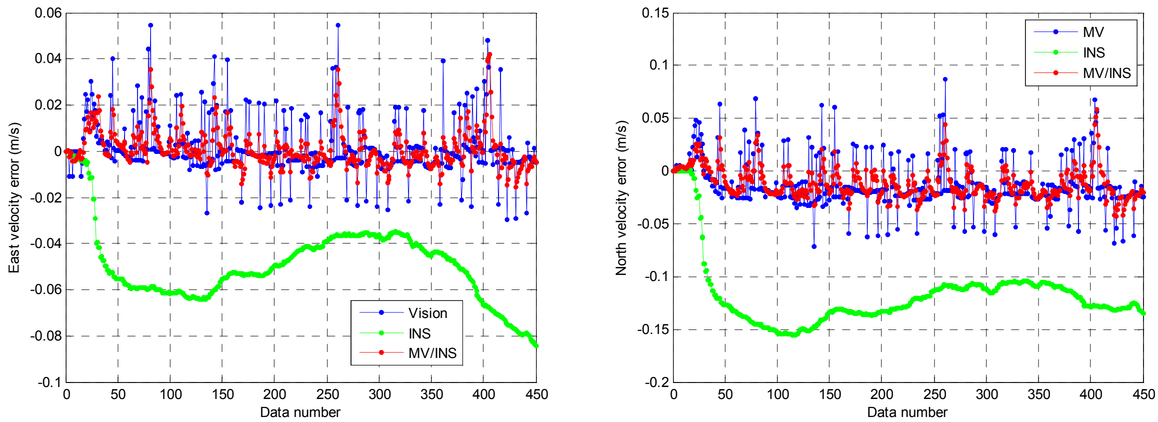

Fig.2 Velocity errors of MV, INS and the proposed method in east and north direction

Table 1 Mean velocity errors in east and north direction

	Mean east velocity error (m/s)	Mean north velocity error (m/s)
MV	0.0075	0.0223
INS	0.0494	0.1183
The proposed method	0.0059	0.0164

Summary

In this work, an optical flow-based MV/INS integrated navigation method for mobile robot indoors is proposed. A real indoor test is done to assess the performance of the proposed method. The test results illustrate that the method rapidly converges and has better accuracy. The proposed algorithm can be applied to the autonomous navigation of mobile robots in case of serious wheel slip and where GPS is fail or unavailable, hence is of great value in practice.

Acknowledgements

This work was supported in part by National Natural Science Foundation of China (No.41204025, 50975049), Ocean Special Funds for Scientific Research on Public Causes (No. 201205035-09), Specialized Research Fund for the Doctoral Program of Higher Education (No. 20110092110039), 973 Program (No.2009CB724002), the 52th China Postdoctoral Science Foundation (No. 2012M520967), and the Program Sponsored for Scientific Innovation Research of College Graduate in Jiangsu Province, China (No.CXLX_0101).

References

[1] Guillaume Blanc, Youcef Mezouar, Philippe Martinet. "Indoor Navigation of a Wheeled Mobile Robot along Visual Routes".Proceedings of the 2005 IEEE International Conference on Robotics and Automation. Barcelona, Spain, April 2005, pp. 3354 – 3359.

[2] W. Wang and D. Wang, "Land vehicle navigation using odometry/ins/vision integrated system," in Proceedings 2008 IEEE Conference on Cybernetics and Intelligent Systems, Chengdu, China, 2008, pp. 754–759.

[3] X. Song, L. Seneviratne, and K. Althoefer, "A kalman filterintegrated optical flow method for velocity sensing of mobile robots," IEEE/ASME Transactions on Mechatronics, vol. 16, pp. 551 –563, Jun 2011.

[4] E. Royer, M. Lhuillier, M. Dhome, and J.-M. Lavest, "Monocular vision for mobile robot localization and autonomous navigation," Int. J. Comput. Vis., vol. 74, no. 3, pp. 237–260, 2007.

[5] J. Shi, C. Tomasi, "Good Features to Track," in IEEE Int. Conf. Computer Vision and Pattern Recognition., 1994, pp. 593-600.

[6] Pyramidal Implementation of the Lucas Kanade Feature Tracker Description of the algorithm Jean-Yves Bouguet. Intel Corporation Microprocessor Research Labs jean-yves.bouguet@intel.com

[7] S.N Tamgade, V.R. Bora, " Motion Vector Estimation of Video Image by Pyramidal Implementation of Lucas Kanade Optical Flow ", Second International Conference on Emerging Trends in Engineering& Technology , 2009.

[8] X. Song, L. D. Seneviratne, K. Althoefer and Z. Song, "Vision-Based Velocity Estimation for Unmanned Ground Vehicles," Int. Journal of Information Acquisition, 2007, vol. 4, no. 4, pp. 303-315.

Mechanical, Electronic and Engineering Technologies (ICMEET 2014)
10.4028/www.scientific.net/AMM.538

Optical Flow-Based Monocular Vision/INS Integrated Navigation for Mobile Robot Indoors
10.4028/www.scientific.net/AMM.538.375