ACCURATE AND ROBUST ATTITUDE ESTIMATION OF A MOVING VEHICLE USING MEMS GYROSCOPES AND A MONOCULAR CAMERA

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ABSTRACT

In order to estimate accurate attitude of mobile robots and vehicles, we propose a hybrid system which combines a low-cost monocular camera with a gyro sensor. A gyro sensor has drift errors that accumulate over time. On the other hand, a camera cannot obtain the rotation continuously in the case where feature points cannot be extracted from images, although the accuracy is better than a gyro sensor. To solve these problems, we propose a method for combining these sensors based on an Extended Kalman Filter. The errors of the gyro sensors are corrected by referring to the rotations obtained from the camera. In addition, by using the reliability judgment of camera rotations and devising the state value of the Extended Kalman Filter, even when the rotation is not continuously observable from the camera, the proposed method shows a good performance.

1. INTRODUCTION

For attitude measurement, an approach for combining the gyro sensor with a camera has been proposed [1]. In this approach, first of all, a rotation of the camera is calculated by the geometric relation between the camera and feature points that are landmarks in the scene. Then an attitude is obtained using Extended Kalman Filter between the rotations calculated from the camera and the gyro sensor. However, there are some limitations for practical application. Most previous researches experimented only on an artificial texture pattert. However, feature points are usually not available in a natural scene. Moreover, the accuracy of attitude decreases due to mis-matching of feature points when using a camera for estimating rotations. In this paper, we solve the following two practical problems by combing a camera with a gyro sensor.

A: Gyro sensor has drift errors.
B: A rotation may not be obtained continuously from a camera.

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Table 1. Complementary relation between sensors.

	Camera	Gyro sensor
Strong	High accuracy	Continuous output
Weak	Discontinuous output	Low accuracy

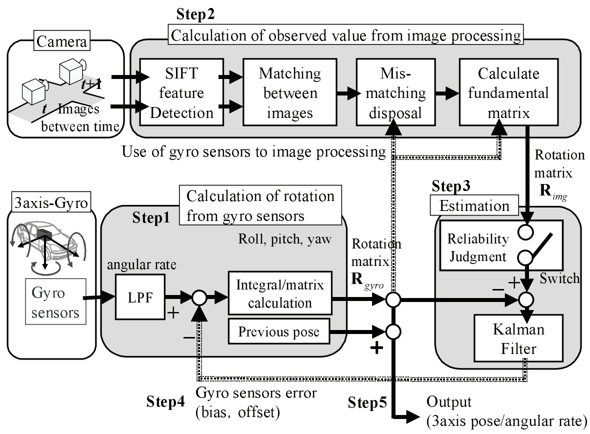

Fig. 1. System architecture of the proposed method.

2. PROPOSED METHOD

Table 1 summarizes strong points and weak points of a camera and a gyro sensor. The accuracy of the gyro sensor is low because of the drift error, but the outputs can be obtained continuously. On the other hand, the accuracy of the camera is high if feature points are correctly associated, but the outputs cannot be obtained continuously when the feature points cannot be extracted. This relation indicates that both weak points can be solved by combining each good point.

A Kalman filter can decrease the errors from the gyro sensor with the help of the camera. On the other hand, the operation from the gyro sensor to the camera, which is the focus on the a slow change of gyro sensor's error under the reliability judgment of a camera rotaion makes it possible to continue estimating an accurate attitude even when feature points cannot be extracted. The entire system architecture is shown in

Figure 1. The procedures is detailed as follows:

Step 1: Calculate a rotation matrix $\boldsymbol{R}_{gyro}$ after reducing white-noise by a low-pass filter.

Step 2: Calculate a rotation matrix $\boldsymbol{R}_{img}$ with a motion stereo method using SIFT feature points of camera images. Here, the $\boldsymbol{R}_{gyro}$ is used for reducing mis-matching of the feature points. The feature points are projected to the next image using the $\boldsymbol{R}_{gyro}$ and then are compared the distance between feature points at time *t* and *t*+1.

Step 3: Applies $\boldsymbol{R}_{img}$ to the Kalman Filter as an observation value only when a high reliability is obtained for $\boldsymbol{R}_{img}$. The Kalman filter estimates the error of the gyro sensors $\boldsymbol{X}$ as a state value under the constraint that $\boldsymbol{R}_{img}$ is equal to $\boldsymbol{R}_{gyro}$. State value $\boldsymbol{X}$ is as follows.

$$\omega_i = (1 + b_i)\hat{\omega}_i + \delta\omega_i, \quad (1)$$

$$\boldsymbol{X} = [b_r, b_p, b_y, \delta\omega_r, \delta\omega_p, \delta\omega_y]^T, \quad (2)$$

where ω_i is a measurement value, $\hat{\omega}_i$ is the true value, b_i is a bias error, $\delta\omega_i$ is an offset error. $i \in \{r, p, y\}$ represent each of the three axes (roll, pitch, and yaw).

Step 4: Setting a feedback loop, the estimated error is subtracted from the value from gyro sensors per iteration. When it is judged that there is not enough reliability in $\boldsymbol{R}_{img}$, the Kalman filter is not applied and the estimated error which is calculated at the previous iteration is subtracted from the value of gyro sensors.

Step 5: The attitude and the angle rate for each of the three axes are calculated as the output of the system.

3. EXPERIMENTAL RESULT

MEMS gyro sensors (BOSCH: SMG074) and a camera were mounted on a vehicle (MobileRobot: Pioneer3DX), which ran at a passing speed of 1,500 mm/s or less in an outdoor environment and measured with 10Hz cycle. Besides these sensors, an optical fiber gyro sensor (Japan Aviation Electronics Industry Ltd： JM3403) was mounted on the same vehicle. This was used to obtain the ground-truth because its accuracy is high (3 deg/hour). Table 2 compares the estimation accuracy of the proposed method with the gyro sensor. To perform this comparison, we calculated the average error of 900 frames for each axis. The proposed method improved 3-6 degs of the accuracy compared with the gyro sensors.

Table 2. Attitude accuracy [deg] through 900 frames.

	Roll	Pitch	Yaw
Gyro sensor	5.53	7.94	3.94
Proposed method	2.73	1.99	0.84

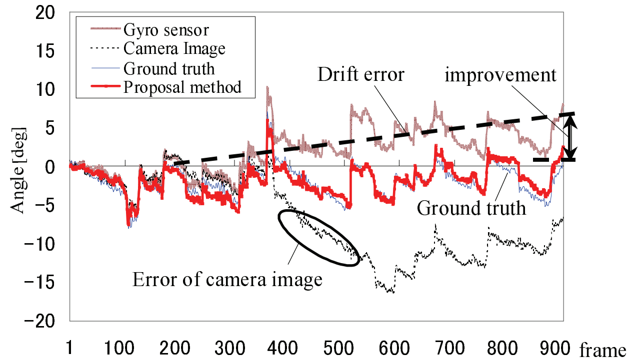

Fig. 2. Attitude in the direction of yaw.

Table 3. The number of mis-matched feature points through 900 frames.

Image processing ＋ Gyro	126
Image processing only	2,740

4. DISCUSSION AND CONCLUSION

Figure 2 shows the estimation results of the yaw axis. The gyro sensor's output departed gradually from the ground-truth, then the error became about 8 deg after 900 frames. The error occurred where the attitude was estimated only from a camera. We consider that this is because a sufficient number of feature points were not obtained from the image. In a real environment, it was confirmed that the proposed method kept high accuracy whereas the estimation using only a camera was difficult. When the rotation is not obtained from the camera the proposed method does not refer to the information obtained from the camera by the reliability judgment and also does not apply the Kalman filter. The error of gyro sensors does not change significantly in a short time, but increases gradually according to the substrate temperature. The reliability judgment and the state value defined as the error of a gyro sensor, makes the proposed system robust in a scene where the number of feature points obtained from the image. Table 3 shows the number of mis-matched feature points. Use of the gyro sensors to select the features points could reduce the mis-matching and improve the reference for the Kalman filter. The experimental results confirmed that accurate and continuous outputs are achieved using the proposed method in a real environment with the complementary use of a gyro sensor and a camera.

5. REFERENCES

[1] Min-geun Song, Jinseong Park, Youngjin Park, and Youn-sik Park, "Fusion Filter for Orientation Estimation of Biped Robot," Motion and Vibration Control, pp.285–294, Springer Netherlands, 2009.