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Bias Compensation of Gyroscopes in Mobiles with Optical Flow

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Abstract

In this paper a new technique is introduced for bias compensation of gyroscopes with a focus on mobiles phones. The standard problem of using gyroscopes is that integration of raw angular rates with non-zero bias will lead to continuous drift of the estimated orientation. To examine the nature of this bias, a simple error model was constructed for the whole device in terms of inertial sensing. For eliminating the bias, a sensor fusion algorithm was developed using the benefits of optical flow from the camera of the device. Our orientation estimator and bias removal method is based on complementary filters, in combination with an adaptive reliability filter for the optical flow features. The feedback of the fused result is combined with the raw gyroscope angular rates to compensate the bias. Various measurements were recorded on a real device running the demanding optical flow onboard. This way a robust and reliable fusion was constructed, which matched our expectations, and has been validated with simulations and real world measurements.

Keywords: optical flow; sensor fusion, orientation estimation, gyroscope bias; mobile

1. Introduction

Orientation estimation is a significant and desired feature to be implemented in more and more reliable and robust way. Pedestrian tracking, controlling unmanned aerial vehicles (UAV), professional cinematography with post-processing, and many other fields may take advantage of these techniques. Unfortunately available sensors on the market are not capable of producing stable and reliable output on the long-term. For this

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situation, many methods have been developed using complex algorithms like extended Kalman filters [1], combining different sensors (accelerometer, magnetometer), and relying on a custom movement nature of the tracked object. In this paper we propose an algorithm to fuse the benefits of optical flow from the camera of the device with the angular rates of the gyroscope in a reliable way in terms of resulting angle.

For measuring sensor data a Samsung Galaxy S2 mobile phone was used with an unofficial Android 4.4.2 operating system. The device was attached to the arm of an industrial Mitsubishi MELFA RV-3SDB robot to do precise rotations. The rated repeatability of this robot arm is less than 0.05 mm. On the Android side, the methods perform the same way on 2.2+ versions. Although Android KitKat (4.4) has some new methods built-in to fuse raw motion sensor values (built-in virtual sensors and pedometer), our project relies on raw sensor values for better portability. Android reports inertial sensor value changes as events for the developer. Asking the operating system, to provide sensor changes at the fastest possible rate, we could measure an average *20 ms* between samples.

Camera images used for optical flow are rather laggy and imprecise in time, for these are delivered at *30 fps* in best circumstances, but this value tends to fall below *20 fps* caused by external lighting condition changes and demanding system load on the CPU. For this, an interpolation stage was added to the system to match optical flow samples consistently with real gyroscope values. In our measurements we used the iterative Lucas-Kanade method with pyramids by Bouguet, 2000 [2] to track *25 - 225* features on the images. The feature point selection was done by distributing these features equally on the image in that case, when the count of matched features fall below *65%*. From the results of feature displacement of optical flow a vector field was calculated and used for the fusion algorithm. The aggregation of these vectors into a final output vector can be performed in various ways, and is out of the scope of this paper. In case the device has only orientation changes but no physical movement, the output values can reliably be used for absolute, so-called world-frame orientation estimation.

In comparison with others, in [3], authors presents a motion model-based method for robust estimation of orientation via fusing the inertial measurements with the imaging sensor's data. Their method yields a robust recursive estimator of the gyro error parameters, which is independent of the scene's structure. The algorithm's performance is demonstrated using synthetic data as well as visual data extracted from an image stream of high-fidelity computer-generated urban scenes.

The accuracy of optical flow estimation algorithms have been improving steadily as evidenced by results on the Middlebury optical flow benchmark. In [4] the authors attempt to uncover what has made recent advances possible through a thorough analysis of how the objective function, the optimization method, and modern implementation practices influence accuracy. They have found that while median filtering of intermediate flow fields during optimization is a key to recent performance gains, it leads to higher energy solutions. In order to understand the principles behind this phenomenon, they have derived a new objective that formalizes the median filtering heuristic and they have developed a method that ranks at the top of the Middlebury benchmark.

Recently, in paper [5] authors introduce a state estimation framework that allows estimation of the attitude, of an IMU-camera system with respect to a plane. The filter relies only on a single optical flow feature as well as gyroscope and accelerometer measurements. The underlying assumption is that the observed visual feature lies on a static plane. The estimation framework fuses visual and inertial measurements in an Unscented Kalman Filter (UKF). Compared to our work, authors only use one optical feature, and it has to be on a static plane, whereas our approach does not require such limitation.

Simulations were done in MATLAB after all raw data had been recorded on the mobile device. For testing different critical situations, various datasets were generated and also used to measure reliability of the algorithm. In this paper focus is taken on real world measurements.