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# Improved Attitude Determination by Compensation of Gyroscopic Drift by use of Accelerometers and Magnetometers

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*Abstract*—**This paper presents a self-aiding scheme for improved attitude determination using low-cost MEMS-based inertial measurement unit consisting of three axis accelerometers, gyroscopes and magnetometers. The technique estimates and compensates gyroscope biases by use of sensors fusion mechanism. To achieve this, attitude is computed from gyroscopes through traditional rate integration scheme and the same is achieved from a combination of accelerometers and magnetometers through vector matching. The two attitudes computed are compared to form an attitude error to estimate biases of the gyros which are continuously adjusted through a feedback mechanism. This technique is compared with Kalman filter based data fusion algorithm which uses gyroscopes and a combination of accelerometers and magnetometers to estimates gyro biases. Both algorithms are tested on real data and showed comparable results.**

**keywords**: MEMS, IMU, attitude determination, navigation, Kalman filter, Wahba's problem, vector matching, bias estimation

## I. Introduction

Attitude estimation is an essential requirement in a wide range of applications like vehicle and space navigation, robotics, virtual environment, surveillance, Unmanned Air Vehicle (UAV) and head tracking systems [3], [6], [16]. Attitude and position determination of moving objects by use of gyroscopes and accelerometers have been well established in the field of inertial navigation systems (INS) [19]. In a strapdown INS, the attitude of a body is determined by rate integration of three orthogonal gyros physically attached to the body starting from a known value. To get position and velocity three accelerometers are also attached to the body to measure the acceleration vector. The obtained acceleration in the body frame is converted to the reference frame by use of attitude information. The velocity and position are then computed by single and double integration of acceleration vector after subtracting gravity value.

However, it is well-known fact that gyroscopes suffer from bias error which results in linear attitude drift after numerical integration. In this paper, with gyro bias, we refer to the rate sensed by a gyro when no physical rate is present and with bias drift we refer to the change in gyroscope's output due to its intrinsic behavior, temperature or any other environmental effect. Traditionally, expensive sensors are utilized for inertial navigation purposes. However, in recent times a new class of sensors based on Micro Electromechanical Systems (MEMS) are also being utilized. These provide a significant benefit in cost, but the performance is degraded. An important error in gyros and accelerometers is bias value [4], [19]. A component of bias can be computed in a well arranged inertial navigation laboratory and can be compensated but cannot be removed completely. This determines the performance of an inertial navigation system. Even if the initial bias is measured and compensated to a degree, the in-run bias of MEMS sensors is enough to introduce a significant error in attitude. In static case, accelerometers can be used to measure the gravity vector from which the tilt angles (pitch and roll) can be calculated and magnetometers are used to measure the local magnetic field vector from which the heading angle is calculated [1]. Nevertheless, these sensors are not ideal for dynamic motion as linear acceleration affects the gravity vector and nearby magnetic fields disturb the magnetometer measurements. Therefore in many applications, a triad of gyros together with a triad of accelerometers and magnetometers can be used to provide better attitude information [8].

An alternative approach suitable for many applications is known as an integrated solution. This technique employs additional sources of navigation information external from the inertial system. The outputs of the inertial navigation system are compared with independent measurements from other external sources and the difference between the two measurements is used to correct the inertial system's outputs [19]. Different methods are available to combine the outputs of inertial system with independent measurements for corrections including complementary filtering, Kalman filtering, particle filtering and artificial intelligence [13]. In conventional work, Kalman filter has been studied extensively for sensors integration to estimate and compensate inertial sensors errors [6], [8], [15], [16], [18]. In general Kalman filter is an optimal algorithm for estimating error states of a system from noisy measurements. Kalman filter is used in complementary form in inertial navigation which functions in two steps. In the first step, the error states are estimated by using state space model