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Attitude estimation methods using low-cost GNSS and MEMS MARG sensors and their integration

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Abstract

For low-cost magnetic, angular rate, and gravity (MARG) sensors based on the microelectromechanical system (MEMS) technology, the sensor errors and measurement noises are significantly large. Attitude errors by integrating gyro data accumulate rapidly. When the vehicle is quasi-static, the roll and pitch angles can be determined by accelerometer measurements which use the local gravity as the reference. The magnetometer is resorted to generate heading information by measuring the geomagnetic field. However, the accelerometer and magnetometer measurements can be deteriorated by the vehicle maneuver and ambient artificial magnetic disturbances, respectively.

Thereby a quaternion-based error state Kalman filter (ESKF) is developed to fuse the MEMS MARG sensor measurements for accuracy improved attitude estimation. The error state vector constitutes attitude error and gyro bias variation. the gyro-measured angular rates are used to continuously propagate the vehicle's three-dimensional attitude quaternion in its sampling rate, whilst accelerometer and magnetometer measurements are employed for the state correction. Disturbances such as external accelerations and magnetic anomalies are excluded, and the measurement noise covariance matrix is adaptively adjusted according to the innovations.

Global navigation satellite system (GNSS) based attitude estimation shows time-independent error characteristics. The pitch and heading angles can be determined using a single GNSS antenna based on the time differenced carrier phase (TDCP) observations or derived from a moving baseline formed between two firmly mounted GNSS antennas. The major challenges of the former include cycle slips, carrier phase discontinuity, and slow vehicular velocity which should be excluded from attitude estimation. Whereas the integer ambiguity resolution is indispensable for the latter, the baseline length constrained least-squares ambiguity decorrelation adjustment (C-LAMBDA) method can be applied.

The GNSS/MARG sensors integrated attitude estimation methods are investigated to exploit the complementary merits of the high precision of MARG sensor during the short period and the performance stability of GNSS over the long term. The ESKF developed for the MARG sensor is extended to utilize the GNSS-derived heading and pitch angles for additional measurement updates. The solution continuity is guaranteed by the MARG sensor alone during the periods when the GNSS-derived attitude angles are unavailable.

Key words: Attitude estimation; MARG sensor; GNSS; C-LAMBDA; Data fusion; Error state Kalman filter