A REVIEW ON REAL TIME MEMS SENSOR FUSION

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Abstract -*Low cost systems for navigation make use of advancement in Micro Electro Mechanical Systems (MEMS) for the realization of miniaturized inertial sensors. But the inherent drift in MEMS sensors leads to erroneous navigation data, which can be taken care by incorporating a secondary sensor along with the main sensor by sensor fusion to obtain an optimal output in real time, thereby eliminating the accumulated errors. Data from multiple sensors will provide more reliable and accurate information in addition to redundancy in case of a sensor failure. Sensor fusion algorithm based on Kalman Filter is used for navigation applications, but its accuracy reduces under dynamic conditions. Review on the different sensor fusion algorithms used for navigation applications is done here.*

Key Words: MEMS, IMU, Navigation, Sensor fusion, Kalman filter, Gyroscope, Accelerometer, Magnetometer, Redundancy.

1. INTRODUCTION

Nowadays MEMS sensors are used for motion tracking and navigation applications in many electronic devices such as smart phones, gaming systems, toys, and the next generation wearable devices [1]. These low-cost MEMS inertial sensors suffer from significant run-to-run biases and thermal drifts. To remove these errors lab calibration at room temperature is used [2]. It is a costly process and it is not affordable for the chip manufacturers to conduct thermal calibration of low-cost sensors .In that scenario, real time sensor fusion is necessary by incorporating a secondary sensor[1],[2]. The sensor fusion algorithm improves the estimation accuracy of the fused state and is better than that of individual sensor estimates [3] .Sensor fusion using inertial sensors find applications in robotics, biomedical systems, equipment monitoring, remote sensing, and transportation systems [2].

With the advances in Micro Electro Mechanical Systems (MEMS) technology, inertial sensors are used for navigation in low cost systems [1], [3]. The chips are self-contained because the sensors are not dependent on the transmission or reception of signals from an external source for navigation [4]. The main limitation with these systems is sensor bias which causes increasing drift of the integrated output. [4], [5]. To eliminate the integrated error in real time, it is necessary to use a secondary absolute sensor and provide an appropriate data fusion method based on multiple sensors [6]. Depending on the dynamic properties of the system under study, different types of Kalman filter based sensor fusion algorithms are used [8].Various types of algorithms are being used for sensor fusion, depending on the dynamic properties and computational complexity of the system under study [9], [10], [11].

2. SENSOR FUSION

Sensor fusion is the process of combining the data from separate sources to produce a common data that has improved accuracy and reliability than each of the sources. The commonly used sensor fusion method is to use a Bayesian state estimator like a Kalman filter or a Particle filter to calculate a single fused state from different sensors. The fusion of redundant information reduces the overall uncertainty and thus increases the accuracy of the features perceived by the system [12].

The multi-sensors give complementary, redundant and overlapping information and data fusion is employed to combine the information from various sensors of different types to reduce uncertainty which provide more reliable and accurate information.

3. SENSOR FUSION TECHNIQUE-A COMPARATIVE STUDY

In [4], Li, You, et al proposed a real time calibration method applied for gyro sensors in portable devices. Only biases and scale factor errors are considered and are modeled as first-order Gauss-Markov processes. A Kalman filter system model is used to find the errors of position, velocity, and attitude. The purpose of using accelerometers and magnetometers is providing most accurate gyro bias estimation. The measurement model uses the accelerometer readings directly, instead of deriving roll and pitch from accelerometers. In [4], magnetometer measurements are used to improve the gyro calibration during quasi-static magnetic field (QSMF) periods. The limitation of Kalman filter used with this method for data fusion is low accuracy compared to offline mode.

In [5], Zhang, Zhi-Qiang, and Guang-Zhong Yang used a novel method for inertial sensor calibration. For attitude estimation micro inertial /magnetic sensors has been widely used. The quality of estimation depends on the quality of the inertial sensors used and to ensure the quality, sensor calibration is required. The calibration setup is expensive and impractical for routine applications. Their method requires a simple pan tilt unit. A sensor model is used to convert the sensor reading to physical quantities in metric units. Based on sensor model a cost function is constructed and a two step iterative algorithm is proposed to calibrate the inertial sensors. The misalignment problem for inertial sensors and the methods to minimize the error is addressed in [5]. For sensor fusion, Quarternion based Kalman filtering is used which significantly reduces the root mean square errors (RMS). But the temperature related sensor drift has not been addressed, which is one of the limitations of this work.

In [6], He Zhao and Zheyao Wang uses inertial sensors and ultra sonic sensors for position and orientation determination. Generally Inertial Measurement Units (IMUs) are used for motion determination by measuring acceleration, velocity, displacement, angular rates and rotation angles. When IMUs are used for long term position and orientation estimates, they suffer from serious errors due to drift. For long term measurement, additional secondary sensors are used for drift compensation. The system consists of a magnetometer, a three-axis accelerometer, a three-axis gyroscope, and an ultrasonic sensor. The inclination attitude is determined in static state by measuring the gravity and the earth's magnetic field vectors by using a digital compass constituted by magnetometer and accelerometer. By using gyroscopes, the applicability of the digital compass is extended from static state orientation measurement to dynamic state. For position measurement, accelerometers and ultrasonic sensors are used. The large drift of accelerometer is compensated by the accurate position information from the ultrasonic sensor. The uncertainties in motion are minimized by employing Extended Kalman filter for data fusion which provides a critical function to balance and optimize the redundant information of the multiple sensors.

Milad Ghanbari and Mohammad Javad Yazdanpanah [7] presented a sensor fusion method to compensate the constant delay and low bandwidth of tilt sensor for angle measurements. Angle measurements are used in many applications such as navigation systems, robotics, motion analysis, motion control, etc. Typical sensors used for angle measurement are encoders, acceleration sensor, tilt sensor and gyroscope. For high precision applications, the axis of angle measurement is connected to a fixed reference, which can be achieved by means of an encoder. In many applications axis of the angle measurement is not connected to a fixed reference. In [4], gyroscope, tilt sensor or acceleration sensor are used instead of encoder on these types of systems. In the proposed method, the limitation of tilt sensor is compensated by using a gyroscope. The disadvantage of tilt sensor is the delay in its response and high decrement of accuracy at high frequencies. The accuracy of tilt sensor is good at low frequencies only. The gyroscope measures the angular velocity and angle can be achieved by integrating the gyroscope output. Because of the drift phenomenon and the accumulation of numerical integration errors incurred, it is not possible to get accurate angle from angular rate. Therefore a modified Kalman filter is used to solve the delay problem of tilt sensor, but it cannot increase the bandwidth of the tilt sensor. So a complementary filter is formed by combining the data of the tilt sensor and gyroscope, which increases the bandwidth of the measured angle to provide high bandwidth estimation of the angle . From the experiments conducted, they got a no-delay and high bandwidth estimation of the angle by using these two filters.

In [8], A. Assa and F.Janabi-Sharifi proposed a method to overcome the poor performance of Kalman filter under dynamic environment or for non linear systems. Methods based on iterative and adaptive scheme is proposed to overcome the systems instability under dynamic environment. These methods compensate for system noise variations via an efficient adaptation technique, while fast dynamics of the system is accounted through the iterative scheme. The proposed method in [8], is a general scheme and can be employed for various applications. It requires higher computational time.

A new approach to overcome the limitation of Kalman filter under dynamic environment is presented in [9] by Zhao, Yingwei. They proposed a Hybrid Kalman filtering method combines Cubature Kalman filtering (CKF) and Extended Kalman filter (EKF).Cubature Kalman filtering is used for nonlinear systems and Extended Kalman filter (EKF) is used for linear systems . Hybrid method results in a balance between computational load and estimation accuracy .The proposed scheme used a Kalman filter to improve the position accuracy of a GPS/inertial measurement unit (IMU) tightly coupled navigation system to the sub-meter level. The CKF is a second order approximation to a nonlinear system, the larger the dimensionality of the state vector is, the more Cubature points are required to propagate states and covariance matrix. Thus the direct implementation of the CKF in a Precise Point Positioning (PPP) /IMU tightly-coupled navigation system greatly increases the computational load. Therefore a dual estimation framework CKF+EKF hybrid filtering method is used by applying the CKF to estimate the nonlinear states and the EKF for the linear parameters in parallel.

Plangi, Siim, et al. proposed a work on Kalman filter based sensor fusion aimed for real time vehicle tracking in [10] by combining the Gyroscope, Accelerometer and GPS outputs. Even though real time tracking systems have quick response and depend on quality of the positioning estimation and its parameters, they can be interrupted due to any malfunction of the traditional GPS receiver or the embedded ones. Therefore, the proposed method, takes the advantage of the available sensors within the smart phone in order to refine the tracking using the multi-sensor fusion technique based on Kalman filter and map matching. It is challenging to perform a good positioning and tracking estimation by using GPS based real time tracking systems because of canyon effect and reduction of the satellite visibility in dense urban environments. The proposed method employs sensor fusion of Accelerometer, Gyroscope and GPS outputs. In the proposed method, they concluded that accurate estimation of speed is acquired by fusing the GPS speed and the vehicle acceleration using the Kalman filter. The heading of the vehicle is estimated by fusing the GPS sensor outputs and the angular speed data outputs using the Kalman Filter. To obtain the best location estimation, Kalman Filter is used to fuse the data together with GPS location data acts as measurements and the already fused speed and heading act as control variables. According to their experimental results and comparison with GPS based tracking methods, proposed model in [10] attained high accuracy.

4. CONCLUSION

Sensor fusion finds immense applications in the area of mobile robotics, biomedical systems, transportation systems etc. This paper reviews the different methods and algorithms, presently being used for implementing sensor fusion technique and thereby minimizing the accumulated errors in the MEMS sensors. The real time calibration system requires a secondary sensor with an appropriate data fusion algorithm. The prime factor which determines the accuracy of measurement depends on the quality of the inertial sensors used. Kalman filter can be used for sensor fusion but the computational load will be higher and the output is unstable for dynamic response in case of non linear systems. Hence for the low cost MEMS navigation systems, real time sensor fusion technique is used as an alternative of sensor calibration.

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