Orientation Performance Test of Xsens MTi-G AHRS for Automotive Applications

Xsens Technologies (www.xsens.com)

Abstract— **Orientation performance of the MTi-G, a low-cost miniature MEMS Attitude and Heading Reference System (AHRS), was tested in a car on a test track. Two tests were performed; a high-speed test on an oval banked track and a high-dynamic maneuvering test on a track with many corners.**

I. Introduction

The MTi-G is a low-cost miniature MEMS AHRS which can be easily mounted on a vehicle to monitor and analyze its dynamics. The sensor provides, in real-time, the vehicle position, velocity, acceleration, angular velocity, and orientation from which vehicle dynamics parameters such as slip-angle, roll-compensated lateral velocity, and etc. can be derived. Automotive engineers often use high-end systems to test and improve their designs. On the contrary, the MTi-G is about an order of magnitude less in terms of size, power consumption, and cost. As a result, it opens the door for new applications; amateur racing enthusiasts and game developers now have access to obtaining realistic vehicle dynamics data. Since the achievable measurement accuracy of vehicle dynamics depends largely on the accuracy of the orientation, we will focus on the orientation accuracy (roll, pitch, and heading) of the MTi-G

In this article, we discuss, in particular, the orientation performance of the MTi-G onboard Jaguar X-type driven at high speeds (~200 km/h) on a banked oval track and also on a test circuit with tight corners as shown in Fig. 1.

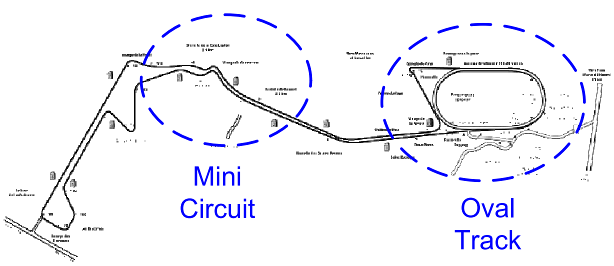

Figure 1: Autodrome de Linas-Montlhery Test Track (Latitude = 48.623577 N, Longitude = 2.245170 E)

II. Methods

A. System Description Overview

The sensor data from MTi-G's internal sensors (calibrated 3D accelerometer, 3D rate gyroscope, 3D magnetometer, L1 GPS receiver, and barometric altimeter) are fused in an onboard Kalman filter to give real-time output of vehicle dynamics. The user can choose from a set of predefined Kalman filter parameters (user scenarios) to meet the motion requirements for a wide range of applications; from human motion, automobiles, boats, to airplanes. The match box-sized sensor (see Fig. 2) weighs 70 grams and consumes approximately 0.5 Watts. The user can provide GPS lever-arm if the GPS antenna is not very close to the MTi-G itself. It is also possible to output the 3D inertial data (acceleration and rate of turn) in the vehicle frame by providing the sensor with the knowledge of sensor alignment with respect to the vehicle.

Figure 2: MEMS-based MTi-G Miniature AHRS

In order to test the orientation performance of the MTi-G, two tests were designed which are described below.

B. Test 1: High-Speed Test on an Oval Circuit with Banked Curve

The test was conducted on January 22, 2008, 12:30 UTC. A test vehicle, a Jaguar X-type, circled around the oval track at fairly constant but high speeds (~200 km/h) to evaluate the orientation performance under high-velocity. Significant roll angles were observed on the banked sections of the test track. The maximum banking at Montlhery track is about 40 degrees.

Figure 3: Onboard View of Autodrome de Linas-Montlhery Test Track during Test 1 (Banked Oval Track)

C. Test 2: High-Dynamics Test on a Mini-Circuit

This test was designed to evaluate the orientation performance of the MTi-G subjected to high dynamic maneuvers. As the Jaguar X-type was nearly pushed to its limits the test contained the elements of rapid acceleration, breaking, and fast cornering. During this test the sensor experienced significant variations in G-forces as well as angular rates (see Fig. 8 for inertial sensor readings).

Figure 4: High-Speed Cornering during Test 2

III. Results

The orientation errors are summarized in Table 1 in terms of RMS and maximum error during about 150 seconds of driving. Note that those figures represent the error after the orientation filter has been given sufficient time to observe the heading from accelerations and estimate the gyroscope bias. The magnetometers were not used here because the heading can be observed as long as the vehicle accelerated often enough. A reference orientation was obtained from a tactical-grade fiber optic gyroscope (FOG).

Table 1: RMS Error in Degrees (Max. error)

	Test 1	Test 2
Roll	0.66 (1.87)	0.59 (1.48)
Pitch	0.98 (2.04)	0.39 (0.99)
Heading	0.45 (1.09)	0.99 (2.09)

A typical startup behavior is shown in Fig. 5. Because the vehicle was initially at rest, the heading was not observable at the beginning. At t = 10 seconds, the vehicle accelerated rapidly and started going around the oval track. The plot demonstrates the initial "warm-up period" required for the orientation algorithm to observe heading through acceleration and reach stable operation.

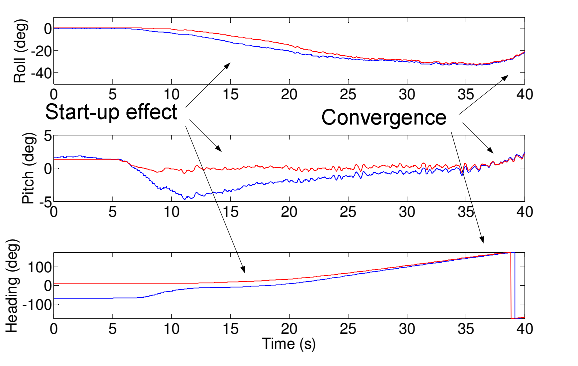

Figure 5: Typical Warm-up Effect of Orientation Algorithm (MTi-G in blue and reference indicated in red)

A. Oval Track Results

On the oval track, the maximum observed roll was in excess of 40 degrees and the vehicle speed was held quite constant between 180 and 190 km/h. The first 1½ laps were made high on the banked curve (steeper band angle) and the last 1½ laps on the flatter section, which can be clearly seen on the roll plot (Fig. 6).

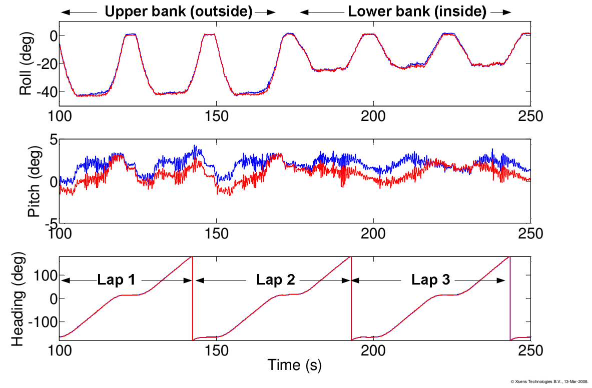

Figure 6: Test 1 Orientation Comparison for MTi-G (blue) and a tactical-grade IMU (red)

The distribution of orientation error, in terms of Euler angles, during the measurement is shown in Fig. 7. The RMS and maximum error are shown in Table 1.

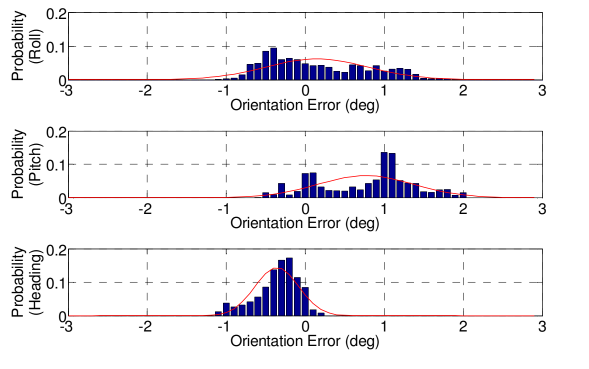

Figure 7: Test 1 Orientation Error Histogram (roll, pitch, and heading from the top)

B. Mini-circuit Results

In the second test, the high dynamics experienced by the MTi-G sensor can be observed from the 3D inertial sensor data shown in Fig. 8. The acceleration varied from about 0 to 2g, angular velocity reached 50 deg/s while cornering, and the vehicle speed ranged from approximately 30 to 120 km/h. Note that the inertial data shown below is expressed in the sensor frame which includes acceleration due to gravity.

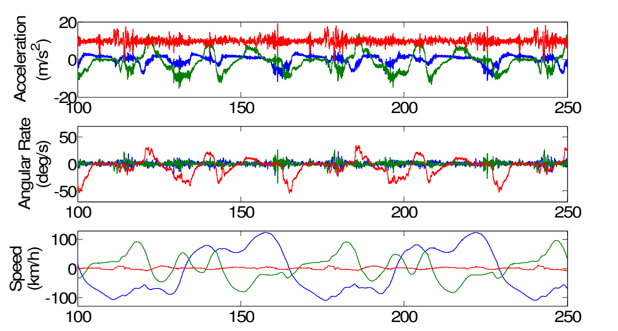

Figure 8: Test 2 3D Inertial Sensor Data (acceleration, angular velocity, and velocity)

The corresponding orientation errors during this test are very similar to Test 1, and the RMS and maximum values are shown in Table 1.

IV. Conclusion

The MTi-G miniature AHRS has been tested in a Jaguar X-type at Autodrome de Linas-Montlhery, France. A high-speed test around a banked oval track and a high-dynamic test were carried out to evaluate its orientation performance for automotive applications. A tactical-grade FOG IMU was used as a reference system. Both tests yielded sub-degree RMS orientation error. About an order of magnitude less in terms of size, power consumption, and cost compared to the high-end measurement systems geared towards the automotive industry, the MTi-G opens the door for many other exciting applications.

V. Discussion

The orientation performance of the MTi-G remained satisfactory even under challenging conditions, in terms of GPS reception quality, considering that the mini-circuit was lined with tall trees which obstructed the view to some GPS satellites. The MTi-G supports SBAS (satellite-based DGPS) and outputs the UTC time and satellite information. With the MTi-G, it is possible to check the quality of GPS fix in real-time by checking how many satellites are being used for a fix, as well as the availability of SBAS correction data.

In this test, the heading was obtained purely from observed acceleration, and we did not use the measured magnetic field. This approach is robust against magnetic disturbances and works very well as long as the vehicle accelerates sufficiently and the orientation algorithm is given enough time to estimate the heading from acceleration. The MTi-G also offers an “automotive” scenario which assumes zero lateral velocity with respect to the vehicle frame. This option, however, requires either the MTi-G to be manually aligned with the vehicle or the sensor-to-vehicle alignment matrix to be known. Under normal driving conditions, this option may provide more stable heading. Since this test included significant amount of drifting (sliding while cornering), in which large lateral velocities were observed, the automotive scenario was not used.

If the orientation of the sensor with respect to the vehicle is known (body alignment), the vehicle dynamics parameters such as slip angle, longitudinal, lateral accelerations, and etc. can be analyzed from the data obtained by MTi-G.

VI. Acknowlegements

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