Yost Labs QGRAD2 Sensor Fusion Performance Analysis

Background

Inertial sensor systems use multiple sensors of different types along with sensor fusion algorithms to compute useful output data. Sensor fusion algorithms utilize the data that comes from sensing elements such as gyroscopic sensors, acceleration sensors, and magnetometer sensors which are each sensitive to different sources of and types of error. Sensor fusion is a process of combining sensory data derived from disparate sources, such as those described above, so that the resulting output information has greater accuracy, less uncertainty, and less sensitivity to error sources than would be possible if the sensors were used individually.

Since sensor fusion is an algorithmic process that combines the component sensor data, different algorithmic approaches may exhibit different performance characteristics. The main performance characteristics of interest are computational complexity and accuracy of the sensor-fused output. Algorithms with higher computational complexity require the execution of more computations to arrive at a sensor-fused output, which, in turn, can result in slower update-rates, higher latency, and more energy usage. Algorithms with higher accuracy will produce a sensor-fused output that more closely approximates the real-world condition of the sensed object. It is often considered that selecting a sensor fusion algorithm involves a set of possible trade-offs; high-accuracy requires high-complexity and, thus lower update rates, high-speed requires reduced complexity resulting in reduced accuracy, but, as described in this paper, this need not be the case.

Yost Labs, Inc. has developed the QGRAD family of sensor fusion algorithms, along with a suite of related methods, that allow sensor fused outputs to be produced using a method that exhibits both high-speed performance and high-accuracy results.

Abstract

This paper illustrates the performance of Yost Labs QGRAD2 sensor fusion algorithm relative to a traditional Kalman filter algorithm, as implemented by ST Micro. To isolate only the performance of the sensor-fusion, both algorithms are implemented upon and tested upon an identical hardware platform, the ST Sensor Tile, with the only difference being the sensor fusion algorithm used.

Test methodology is described for each test performed and test results are presented that characterize speed and accuracy of both systems.

Results show that the Yost Labs QGRAD2 filter is both significantly faster and more accurate than ST Kalman filter.

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Filter Speed Tests

Overview

In order to test the speed of the STM Kalman sensor fusion filter versus the Yost Labs QGRAD2 sensor fusion filter, tests were performed on identical hardware, with the only difference being the sensor fusion algorithm used. The selected hardware platform was the STM SensorTile module (STEVAL-STLCS01V1) which is included with the STM SensorTile Evaluation Kit (ST STEVAL-STLKT01V1).

The tests were conducted using a slightly modified firmware that allowed the measurement of the computation time of the sensor fusion algorithm. This was done by placing a line of code before entering the sensor fusion algorithm that turned on the LED of the STM SensorTile Evaluation Kit and subsequently turned off the LED upon return from the sensor fusion algorithm's update step.

Methodology

Hardware tested:

Two sensor tiles containing custom firmware were used. Both sensors were programed with the firmware that added code to turn on the LED of the STM SensorTile Evaluation Kit board upon entering the sensor fusion algorithm's update function, and then turned off the LED upon exiting the sensor fusion algorithm's update function. Both sensors are identical in hardware and firmware with the exception of running different sensor fusion filters.

Calibration:

Before testing, the sensor tiles were calibrated using the ST BlueMS phone application.

Testing Process:

To measure the time spent in the each of the respective senor fusion algorithms, a digital oscilloscope was connected to the LED pin and the high-period of the pulse-width was measured. Since the LED is set high upon entry into the sensor fusion algorithm and low upon exit, the length of the high-period of the pulse acts as a direct measurement of the computation time of the sensor fusion algorithm itself. Note that all the reading of the sensor component data is done before the sensor fusion algorithm is called, which means that the only thing being measured is the computational complexity of the sensor fusion algorithm. Both the filter duration and the overall update rate were measured.

Results

Summary:

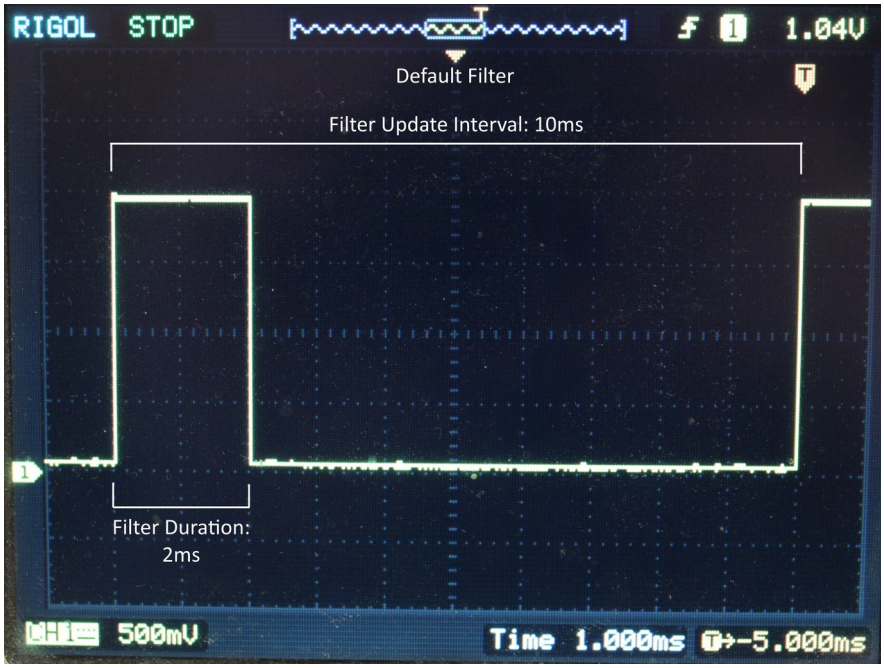
The table below illustrates the actual measured difference in both the filter duration and the update interval of the entire system.

	QGRAD2™ on ST Sensor Tile	Kalman Filter on ST Sensor Tile
Filter Duration	0.2 ms	2 ms
Relative Duration	10x	1x
Update Interval	3.2 ms	10 ms
Relative Update Speed	3x	1x
Update Rate	312 Hz	100 Hz

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These results indicate that the update rate of the QGRAD2 filter, at 0.2ms/update, runs 10x faster than the ST Kalman filter, running at 2ms/update. The results further indicate that on the SensorTile system, the update interval of the entire system when using the QGRAD2 filter firmware, running at 3.2ms is over 3x the update interval of the ST Kalman filter firmware, running at 10ms.

Individual Tests:



ST Kalman Filter



Yost Labs QGRAD2 Filter

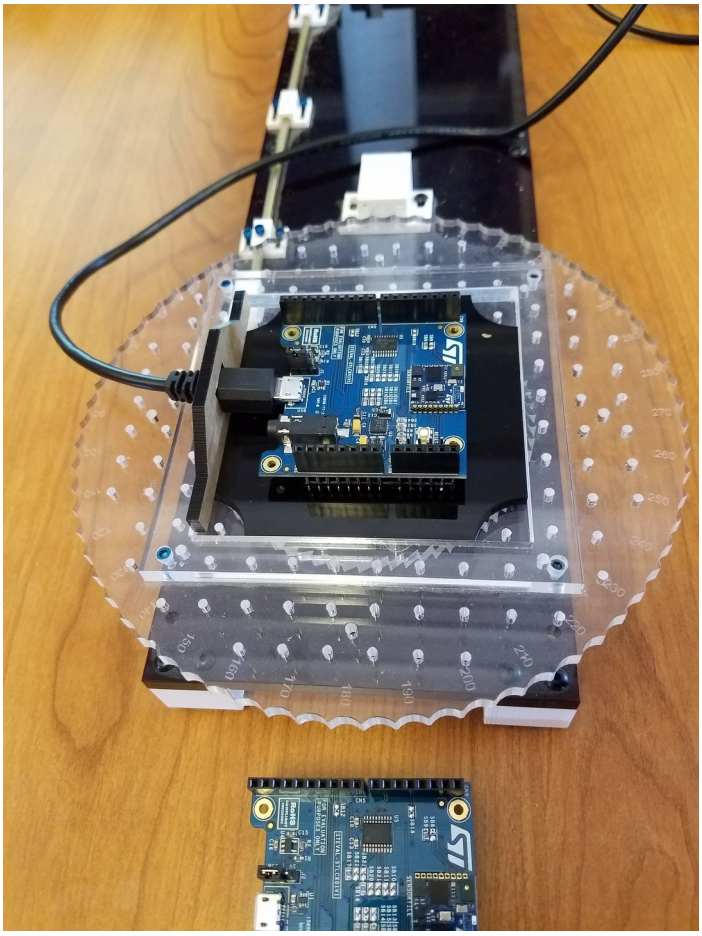
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Filter Accuracy Tests

Overview

In order to test the accuracy of the STM Kalman sensor fusion filter versus the Yost Labs QGRAD2 sensor fusion filter, tests were performed on identical hardware, with the only difference being the sensor fusion algorithm used. The selected hardware platform was the STM SensorTile module (STEVAL-STLCS01V1) which is included with the STM SensorTile Evaluation Kit (ST STEVAL-STLKT01V1).

The tests were conducted using a motor controlled turntable which was configured to rotate a single ST sensor tile would rotate a full three hundred and sixty degrees while gathering data to be used to calculate the angle at which the sensor is currently facing. The turntable is of a non-ferrous and non-magnetic design eliminating the possibility of magnetic perturbation that could affect the testing results.



Sensor Mounted on Turntable

First the ST implemented Kalman filter programmed sensor would go through the process followed by the Yost Labs' QGRAD2 filter programmed sensor. The data for each test would then be logged before the test was repeated. Four total sets of comparative tests were performed.

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Methodology

Hardware tested:

Two sensor tiles containing custom firmware were used to gather all test data. Both sensors are programed with a USB protocol in order to read/send data to and from the sensor. The firmware includes commands used to read quaternion data, calibrate the gyroscope, and apply a tared position based off of the current orientation. Both sensors are identical in hardware and firmware with the exception of running different sensor fusion filters.

Calibration:

Before testing, the sensor tiles were calibrated using the ST BlueMS phone application. Once the calibration was complete the sensor was secured on the turntable and left untouched and unmoved for ten seconds in order to calibrate the gyroscope.

Testing Process:

To start the test, the sensor was tared (zeroed) in its starting position then the testing process was started. Each step of the testing process involved reading a set of ten samples of quaternion data in the current position, then the table would be indexed 5 degrees ahead and the readings repeated until the sensor was completely rotated through 360 degrees, bringing it back to the starting position. The quaternion samples were averaged for each position to arrive at an average orientation measurement for each of the 72 positions. This average quaternion for each position was then used to calculate the Euler angles for each position and the heading was extracted.

Post Testing:

After completion of the testing process, the Euler angle data was saved off into a file and subsequently loaded into a spreadsheet for further analysis. Within the spreadsheet, the error was calculated by finding the difference between the truth position of the turntable and the position calculated by the samples taken for each of the 72 positions on the turntable. The average error, and maximum error were also calculated.

Results

Summary:

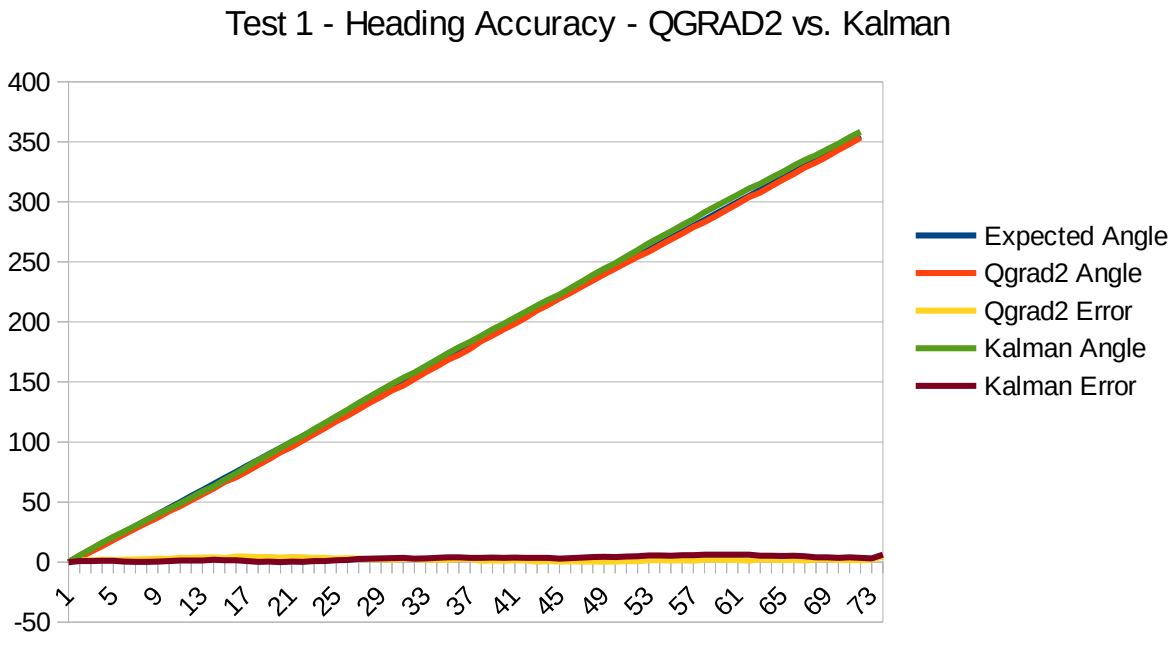
The table below illustrates the average error and maximum error as measured in degrees, as well as the averages across all four tests.

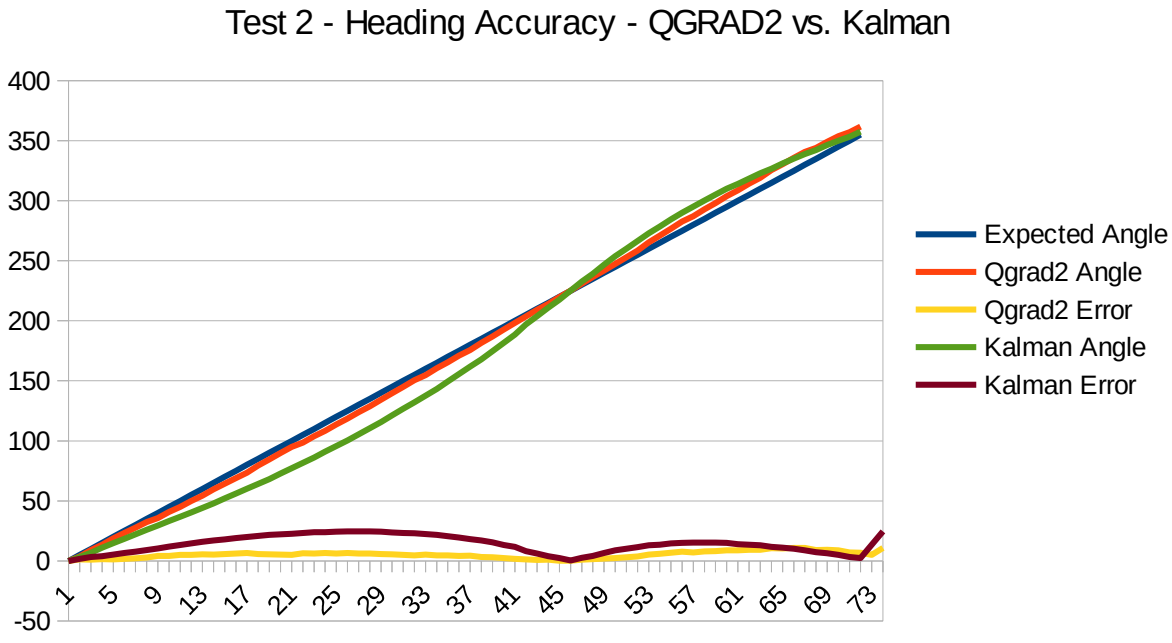
Test	QGRAD2 Average Error	ST Kalman Average Error	QGRAD2 Maximum Error	ST Kalman Maximum Error
1	2.050	2.989	4.514	6.268
2	5.048	13.548	10.869	24.660
3	3.388	6.732	6.708	11.814
4	5.632	7.441	13.025	15.015
Average	**4.029**	**7.677**	**8.779**	**14.439**

These results show an average accuracy improvement of 1.9x favoring QGRAD2 over Kalman and a reduction in the maximum error of 1.6x favoring QGRAD2 over Kalman.

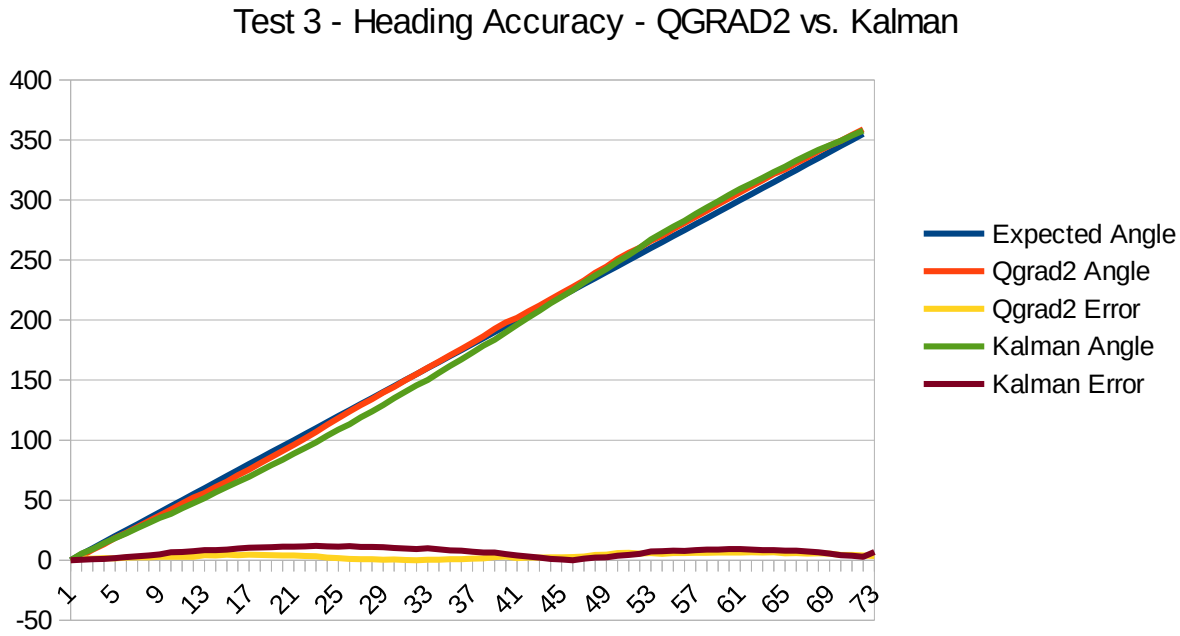
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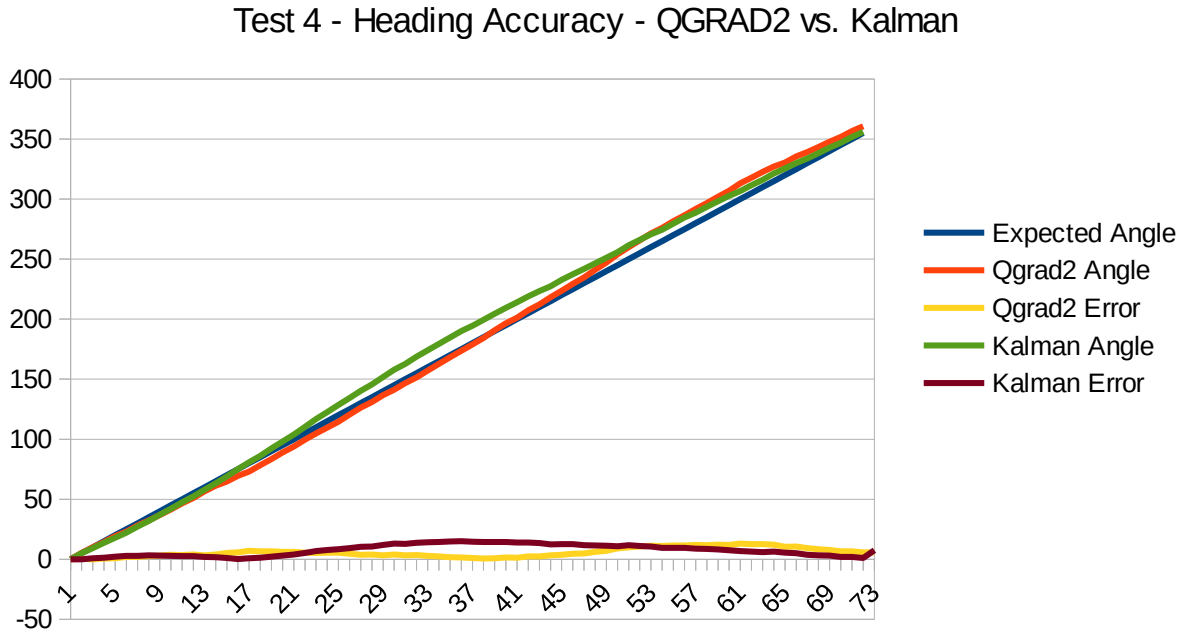
Individual Tests:





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Conclusion

Yost Labs QGRAD2 sensor fusion algorithm outperforms traditional Kalman-filter-based approaches in both accuracy and speed. The algorithmic complexity of the QGRAD2 leads to reduced computational load. This, in turn, allows for an inertial system that has advantages of either increase performance or lower power consumption. The increased performance can be especially advantageous in cases where update rate and reduced latency are important. The reduced computational load can also be especially advantages for systems where reduced power consumption is important, such as wearables or other battery-powered systems.

More Information

For more information, visit us on the web at:

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