Xtrinsic Sensor Fusion

Software for Tilt-Compensated eCompass with Magnetic Calibration

Xtrinsic sensor fusion of accelerometer and magnetometer data

Overview

Freescale eCompass software performs sensor fusion of accelerometer and magnetometer data to implement a self-calibrating tilt-compensated e-compass. The ANSI C source code and full technical documentation are provided under a simple click-through license without licensing fees for use with Freescale accelerometers and magnetometers. The software is processor agnostic, allowing Freescale customers to retain their existing architecture.

The software is highly optimized to minimize use of program memory, RAM and floating point calculations. The code typically compiles into 10 KB of object code and uses less than 4 KB of RAM. A dedicated floating point unit (FPU) is not required and the software can run on typical 32-bit integer processors with software floating point emulation.

Target Products

- Smartphones
- Tablet PCs
- Digital cameras
- GPS navigation modules

Target Applications

- Tilt-compensated e-compass
- Camera tilt
- Map orientation

Licensing Details

- Immediate download via click-through license
- New optimized version 3 released
- No licensing fees when used with Freescale accelerometers and magnetometers
- Visit freescale.com/ecompass

Xtrinsic eCompass Software Architecture Block Diagram

300 FPU ops total for all steps in 20 to 50 Hz eCompass loop

- Aerospace
  - Sensor Fusion Matrix R (20 to 50 Hz)
- Android™
  - Sensor Fusion Matrix R (20 Hz)
- Windows 8
  - Sensor Fusion for Orientation Matrix R and Low Pass R_p (20 to 50 Hz)
- Aircraft
  - Magnetometer Measurement Buffer Update (20 to 50 Hz)
  - Remove Hard and Soft Iron Distortion B_p = W^(-1)B_p - V (20 to 50 Hz)
  - Compute Hard and Soft Iron Magnetic Calibration V, W High FPU Background Task (3 to 60 K FPU ops) Completing Every 100 s but with Very Low (1 to 10 FPU ops) Overhead per 20 to 50 Hz eCompass Iteration
  - Quaternion from R_p Euler Angles from R_p (20 to 50 Hz)
  - Quaternion q

Roll φ, Pitch θ, Yaw ψ, Compass p

Quaternion q

Euler Angles from R_p (20 to 50 Hz)

Quaternion from R_p

Ongoing

Windows 8

Sensor Fusion for Orientation Matrix R and Low Pass R_p (20 to 50 Hz)

Remove Hard and Soft Iron Distortion B_p = W^(-1)B_p - V (20 to 50 Hz)

Computer Hard and Soft Iron Magnetic Calibration V, W High FPU Background Task (3 to 60 K FPU ops) Completing Every 100 s but with Very Low (1 to 10 FPU ops) Overhead per 20 to 50 Hz eCompass Iteration

Quaternion q

Euler Angles from R_p (20 to 50 Hz)

Quaternion from R_p

Ongoing
Nine new application notes are provided as part of the licensed download and contain detailed and rigorous derivations of the mathematics underlying the software. A simulated sensor driver is provided to allow licensees to immediately evaluate and run the software on any processor platform. When physical sensors are interfaced to the processor, the simulated sensor driver is simply replaced with the real sensor drivers.

Orientation is provided in Euler angle (roll, pitch, yaw and compass heading), rotation matrix and quaternion formats. The Aerospace, Android™ and Windows® 8 coordinate systems are all supported.

Three levels of hard and soft iron magnetic calibration are provided at increasing levels of performance and computational complexity. The simplest four element calibration solver computes the hard iron correction vector and geomagnetic field strength and therefore removes the largest component of the magnetic interference caused by ferromagnetic components on the circuit board. The seven element calibration solver corrects for differing magnetic permeability along the three Cartesian axes and is suitable for the more complex calibration environments found in the dense circuit board layouts of mobile phones and tablets. The highest performing 10 element calibration solver is only provided on request in object code format for ARM® Thumb2 processors. It computes an exact least squares solution to the 10 dimensional magnetic optimization problem including off-diagonal elements of the soft iron matrix.

Software Summary (eCompass and Magnetic Calibration)
- Fully documented ANSI C source code
- Under 10 KB total code size (measured on ARM Thumb2 processors)
- 4 KB RAM requirement
- Suitable for use on integer processors with floating point software emulation
- Processor agnostic software
- Simulated accelerometer and magnetometer driver provided for immediate verification on target processor before interfacing to real sensors
- Compatible with all Freescale accelerometers and magnetometers
- Compass heading accuracy is within five degrees on a correctly laid out circuit board

### Recommended Sensors

<table>
<thead>
<tr>
<th>Accelerometer</th>
<th>Package</th>
<th>Range and Resolution</th>
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</thead>
<tbody>
<tr>
<td>MMA8451Q</td>
<td>3 x 3 x 1 mm 16-pin QFN</td>
<td>±2g, ±4g, ±8g, 14 bits</td>
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<tr>
<td>MMA8452Q</td>
<td>3 x 3 x 1 mm 16-pin QFN</td>
<td>±2g, ±4g, ±8g, 12 bits</td>
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<tr>
<td>MMA8453Q</td>
<td>3 x 3 x 1 mm 16-pin QFN</td>
<td>±2g, ±4g, ±8g, 10 bits</td>
</tr>
<tr>
<td>MMA8652FC</td>
<td>2 x 2 x 1 mm 10-pin DFN</td>
<td>±2g, ±4g, ±8g, 12 bits</td>
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<tr>
<td>MMA8653FC</td>
<td>2 x 2 x 1 mm 10-pin DFN</td>
<td>±2g, ±4g, ±8g, 10 bits</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Magnetometer</th>
<th>Package</th>
<th>Range and Resolution</th>
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</thead>
<tbody>
<tr>
<td>MAG3110FC</td>
<td>2 x 2 x .85 mm 10-pin DFN</td>
<td>±1000 μT, 0.1 μT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Combination Sensor</th>
<th>Package</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FXOS8700CQ</td>
<td>3 x 3 x 1.2 mm 16-pin DFN</td>
<td>±2g, ±4g, ±8g, 14 bits, ±1200 μT, 0.1 μT</td>
</tr>
</tbody>
</table>

### Sensor Toolbox Evaluation Boards

<table>
<thead>
<tr>
<th>Kit Number</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>RD4247MAG3110</td>
<td>The RD4247MAG3110 kit executes the Xtrinsic sensor fusion algorithms on a Windows PC connected via USB to the MMA8451Q accelerometer and MAG3110 magnetometer.</td>
</tr>
<tr>
<td>RD4247FXOS8700</td>
<td>The RD4247FXOS8700 kit executes the Xtrinsic sensor fusion algorithms on a Windows PC connected via USB to the FXOS8700CQ 6-axis sensor which combines a 3-axis accelerometer and 3-axis magnetometer.</td>
</tr>
</tbody>
</table>

### Magnetic Calibration
- Intelligent data buffering reduces or eliminates need for user “figure of eight” handset motion
- Quality of fit metric indicates expected compass heading error
- Exact least squares solution to magnetometer measurements
- Resilient to magnetic jamming corrupting calibration
- Four element magnetic model
  - Three hard iron offsets
  - Geomagnetic field B (μT)
  - Mathematical derivation and ANSI C source code provided
  - 3300 floating point operations per call
- Seven element magnetic model
  - Adds three soft iron gains
  - ANSI C source code provided
  - 20,000 floating point operations per call
- Ten element magnetic model
  - Adds three soft iron cross axis terms
  - 62,000 floating point operations per call
  - ARM Thumb2 object code provided on request

### eCompass
- Aerospace, Android and Windows 8 coordinate systems supported
- Tilt compensation
- Virtual gyro
- Programmable low-pass filter
- Rotation matrix, Quaternion and Euler angle (roll, pitch, yaw) outputs
- 300 floating point operations per call
- Mathematical derivation and ANSI C source code provided

### Sensor Simulation

Xtrinsic eCompass software includes the ability to simulate the accelerometer and magnetometer data at random angles for a user-defined geomagnetic field vector and hard and soft iron magnetic interference. The user can verify that the software can accurately compute the magnetic interference parameters and the e-compass orientation and compass heading information on a processor board before interfacing an actual accelerometer and magnetometer. Once actual sensors are connected to the processor over PC, the sensor simulation driver is simply replaced by the actual sensor driver.
Plot of magnetometer measurements distorted by hard iron interference before (red) and after (blue) correction by the four element Xtrinsic magnetic calibration model

Freescale: A Leader in Sensing Solutions

Expanding on more than 30 years of sensor innovation, our Xtrinsic sensing solutions are designed with the right combination of high-performance sensing capability, processing capacity and customizable software to help deliver smart, differentiated sensing solutions. With Xtrinsic sensors, our vision is to offer a diverse and differentiated product portfolio to meet the expanding needs of the automotive, consumer and industrial segments. Xtrinsic solutions offer ideal blends of functionality and intelligence designed to help our customers differentiate and win in highly competitive markets.

Kinetic MCUs

The Kinetic portfolio of ARM Cortex™ MCUs consists of multiple hardware- and software-compatible ARM Cortex™-M0+ and ARM Cortex™-M4 MCU families with exceptional low-power performance, memory scalability and feature integration. Families range from the entry-level ARM Cortex-M0+ Kinetics L series to the high-performance, feature-rich ARM Cortex-M4 Kinetics K series and include a wide selection of analog, communication, HMI, connectivity and security features.

All Kinetic MCUs are supported by a comprehensive Freescale and third-party hardware and software enablement system which reduces development costs and time to market.

For more information, visit freescale.com/ecompass