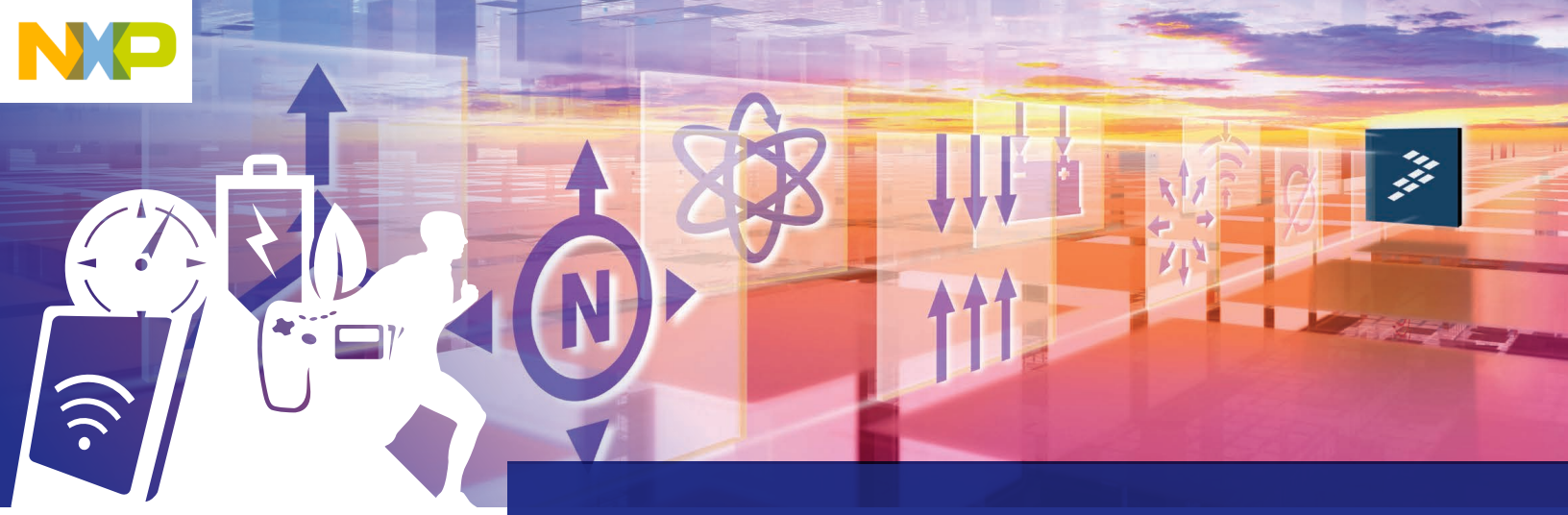


Xtrinsic Sensor Fusion

Software for Tilt-Compensated eCompass with Magnetic Calibration

Xtrinsic sensor fusion of accelerometer and magnetometer data

Target Products

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

Target Applications

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

Licensing Details

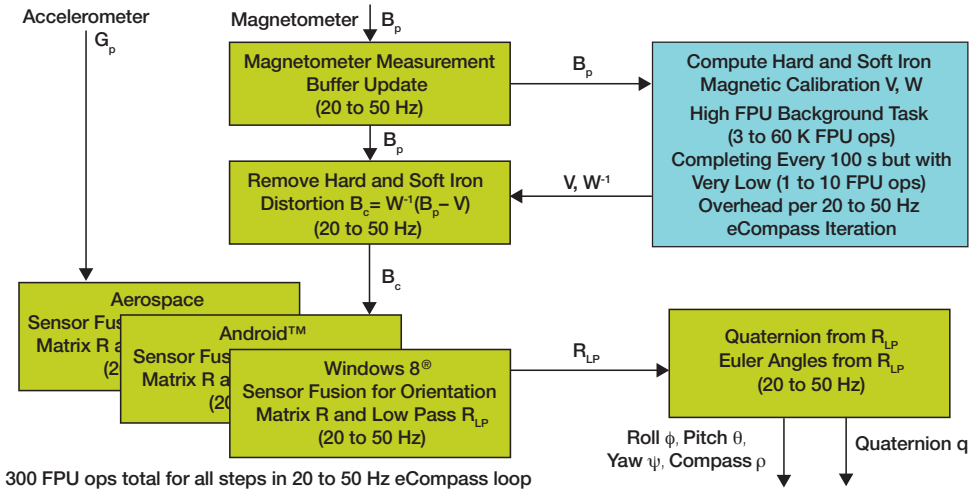
- Immediate download via click-through license
- New optimized version 3 released
- No licensing fees when used with Freescale accelerometers and magnetometers
- Visit **freescale.com/ecompass**

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.

Xtrinsic eCompass Software Architecture Block Diagram



freescale™
Xtrinsic

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

Accelerometer	Package	Range and Resolution
MMA8451Q	3 x 3 x 1 mm 16-pin QFN	±2g, ±4g, ±8g, 14 bits
MMA8452Q	3 x 3 x 1 mm 16-pin QFN	±2g, ±4g, ±8g, 12 bits
MMA8453Q	3 x 3 x 1 mm 16-pin QFN	±2g, ±4g, ±8g, 10 bits
MMA8652FC	2 x 2 x 1 mm 10-pin DFN	±2g, ±4g, ±8g, 12 bits
MMA8653FC	2 x 2 x 1 mm 10-pin DFN	±2g, ±4g, ±8g, 10 bits
Magnetometer	**Package**	**Range and Resolution**
MAG3110FC	2 x 2 x .85 mm 10-pin DFN	±1000 µT, 0.1 µT
Combination Sensor	**Package**	**Range**
FXOS8700CQ	3 x 3 x 1.2 mm 16-pin DFN	±2g, ±4g, ±8g, 14 bits. ±1200 µT, 0.1 µT

Sensor Toolbox Evaluation Boards

Kit Number	Description
RD4247MAG3110	The RD4247MAG3110 kit executes the Xtrinsic sensor fusion algorithms on a Windows PC connected via USB to the MMA8451Q accelerometer and MAG3110 magnetometer.
RD4247FXOS8700	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.

Magnetic Calibration

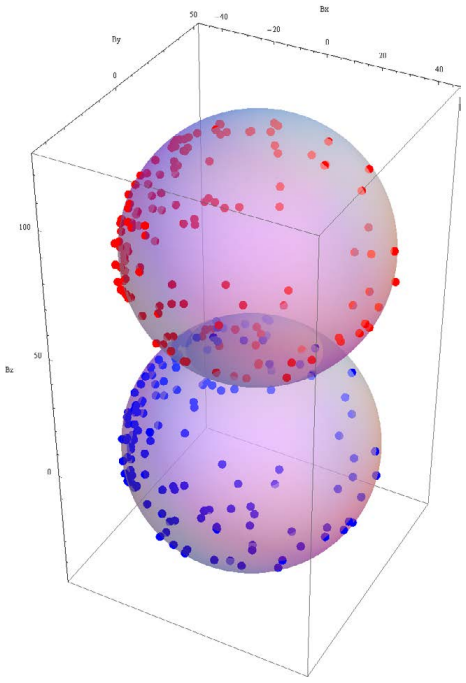
- Intelligent data buffering reduces or eliminates need for user “figure of eight” handset motion
- Quality of fit metric indicates expected compass heading error
- Exact least squares solution to magnetometer measurements
- Resilient to magnetic jamming corrupting calibration
- Four element magnetic 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 I^2C, the sensor simulation driver is simply replaced by the actual sensor driver.



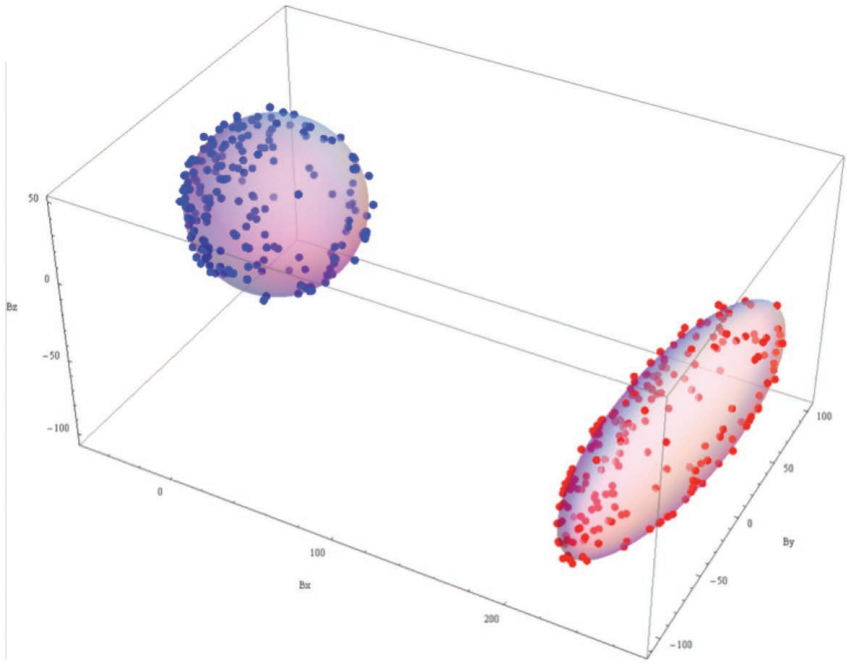
Plot of magnetometer measurements distorted by hard iron interference before (red) and after (blue) correction by the four element Xtrinsic magnetic calibration model

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.

Documentation Provided Under License Agreement

Document	Title
AN4676	Euler Angle, Rotation Matrix and Quaternion Representations of Orientation in Aerospace, Android and Windows 8 Coordinates
AN4681	Implementing a Virtual Gyro Using Accelerometer and Magnetometer Sensors
AN4684	Magnetic Calibration of Hard and Soft Iron Interference
AN4685	Tilt-Compensated eCompass in Aerospace, Android and Windows 8 Coordinate Systems
AN4696	Accelerometer and Magnetometer Sensor Simulation for Tilt-Compensated eCompass
AN4697	Low-Pass Filtering of Orientation Estimates
AN4698	CPU, Flash and RAM Benchmarks
AN4699	Data Structures for Matrix and Vector Algebra
AN4700	Control Loop, Data Structures and Compile Time Constants
AN4706	Accelerometer and Magnetometer Selection and Configuration
AN4709	Tilt Estimation using an Accelerometer in Aerospace, Android and Windows 8 Coordinate Systems



Plot of magnetometer measurements distorted by hard iron and soft iron interference before (red) and after (blue) correction by the ten element Xtrinsic magnetic calibration model

Kinetis MCUs

The Kinetis 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+ Kinetis L series to the high-performance, feature-rich ARM Cortex-M4 Kinetis K series and include a wide selection of analog, communication, HMI, connectivity and security features.

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

freescale.com/Kinetis

For more information, visit freescale.com/ecompass

Document Number: ECOMPASSFS REV 1