



# Use of MEMS Motion Sensors for Embedded Mobile Applications

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## Introduction

There is a strong trend in consumer electronics which shows a growing interest for “motion enabled” products. This trend for “more motion” is characterized by increasing quantity and complexity that not only relies on scaling sensors but also on satisfying the increasing demand for more complex features. Furthermore, there is a higher than ever market demand for lower prices and ever-shorter design cycles for these motion enabled products. The market is pulling hard.

MEMS and silicon manufacturers play a significant role by providing multiple axis sensors, powerful microcontrollers, and now sensor clusters that offer the possibility of creating systems of unprecedented complexity and power. But these technological solutions introduce new challenges in sensor selection, management and signal processing. Product Developers and System Integrators have to manage the impact of the market requirements but struggle with the complexities of this new and fast evolving MEMS machinery.

In this paper, we want to describe the three main components of this fast evolving MEMS toolbox and provide a short review of their capabilities, and limitations. As we will conclude, the trend for high level motion features is therefore to combine these three sensors so that these MEMS can be put at the service of markets needs.

Among the different types MEMS motion sensors on the market, there are three which are most useful for building mobile motion applications: gyroscopes, accelerometers and magnetometers.

These sensors can be used in conjunction with other position related devices that rely on fixed instrumentation. For instance, optic, acoustic, mechanical or electromagnetic systems take advantage of using both mobile and fixed instrumentation, thus giving access to absolute parameters (position or orientation). However, for greatest flexibility and ease-of-use, it is often preferable to use only mobile sensors in a product development effort. In fact, sometimes there is no choice because appropriate fixed instrumentation is not available or such equipment does not support the product requirements. In these situations, we often find that only mobile sensors fixed to the body can be used. This last case is the one considered in this paper.

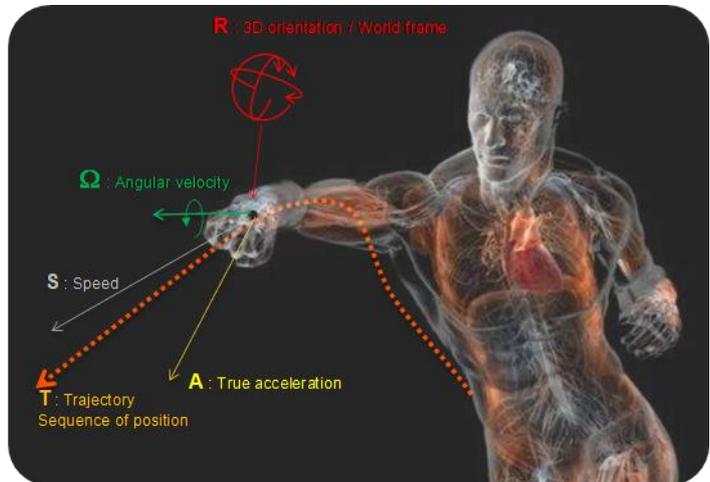
So what can be accomplished with embedded gyroscopes, accelerometers and magnetometers? As individual sensors, they can be quite useful on their own if the objective is a simple motion feature. However, individual MEMS sensor types by themselves are often not sufficient when one’s goal is a more complex motion feature, like the computation of attitude or trajectory estimation. In the text which follows, we’ll present a short review of these three sensors, their capabilities and strengths, and how they can be combined.

## The Objectives of MEMS-based Motion Sensing Systems

One of the primary objectives of MEMS-based motion sensing systems is to define position and orientation of some object or person in a real world frame of reference. Achieving this objective enables a wide range of interesting applications in sports, gaming, health and other areas of interest.

Determining position and orientation in a real world frame of reference requires accurate measurement and tracking in 6 Degrees of Freedom (DOF) in a frame of reference or, simply, frame. Those 6 DOF include three translation and three rotational (see Figure 1). Let's name the three angles Roll, Pitch and Yaw.

In most applications, the frame in which we wish to measure and track these six parameters is fixed to the Earth. Is this possible?

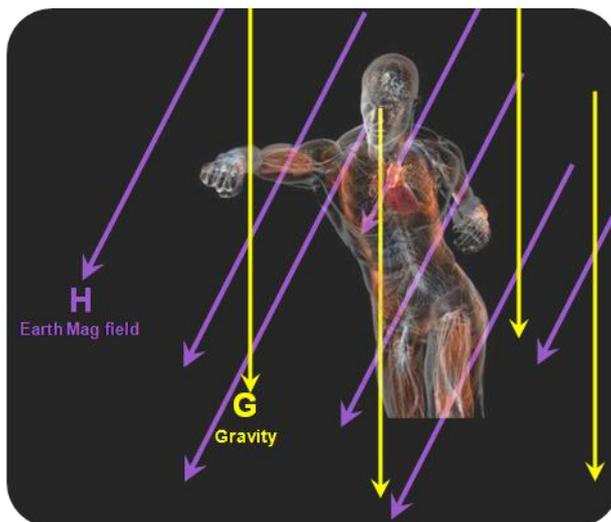


**Figure 1:** 6 Degrees of Freedom (DOF) include 3 translation parameters and 3 orientation parameters. True Acceleration (A) equals the second derivative of position over time.

## What can we sense?

If we were in an inertial frame (i.e. a frame in which no force is applied and we are stationary or moving at a constant speed), we could only sense both our angular acceleration and linear acceleration. For the purposes of our paper, a frame fixed to the earth is considered as an inertial frame.

Moreover, on the earth, we are given two natural and very useful vector fields that surround us all the time: the earth's gravitational and magnetic fields (see figure 2). If we can sense these from the mobile device, we can use them to determine information about our six DOF. This will give us some very valuable information.



**Figure 2:** On Earth, we are moving in 2 natural vector fields that can be considered steady over time in the earth's reference frame.

The gyroscope is the first sensor that we'll consider which contributes to our complete six DOF knowledge. It measures the rotation speed of the mobile device in the earth's frame of reference but expressed in the mobile device's frame. Rotation speed, however, is not yet the orientation that we're looking for. It is first derivative of orientation. This is a good start, but to truly solve the orientation problem over time, we therefore need to know our initial orientation at time zero ( $T_0$ ), and we need be aware of the drift in our calculations over time due to inherent stability characteristics of our gyroscope bias (or offset).

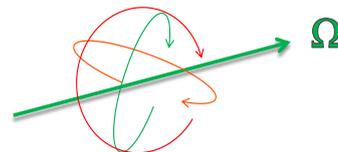
If we know the initial orientation, then a first order integration computation will give us the orientation of the device through time. This is what we can achieve from very accurate gyroscopes with no bias.

All real world gyroscopes do have bias, however. If our gyroscope has a  $1^\circ/\text{sec}$  bias, for example, then after 60 seconds our orientation calculations will have an error of as much as  $60^\circ$ .

Next, we consider the accelerometer. At first glance, the accelerometer will give access to the direction of the local gravitational field and can thus provide information about the tilt (Pitch and Roll) of the mobile device relative to the that field. This would complement the information from our gyroscope and we would now be able to compute two of the three angles we need.

It turns out that this is only true if the accelerometer is attached to a steady state device. If the device is not in a steady state, then the accelerometer is also measuring the True Acceleration of the device (acceleration from its trajectory in space) together with gravitational acceleration. With no additional information, there is no way to separate these two contributing sources of acceleration from our sensor reading. So, we either need to know the True Acceleration from which we can compute the Roll and Pitch, or we need to know the Roll and Pitch from which we can compute the True Acceleration.

The third and final sensor we'll consider is the magnetometer. It has also its pros and cons, but provides very valuable information. As seen in Figure 2 and Figure 4, the magnetometer is able to give orientation relative to a vector field which is constant in time. Unfortunately, over large areas, the magnetic vector



**Figure 3:** Gyroscopes give access to the instantaneous rotation speed. Through a first order integration, we can compute the orientation.



field cannot be considered constant in space. So we'd have to know additional information about variations in the magnetic field over the area relevant to our application.

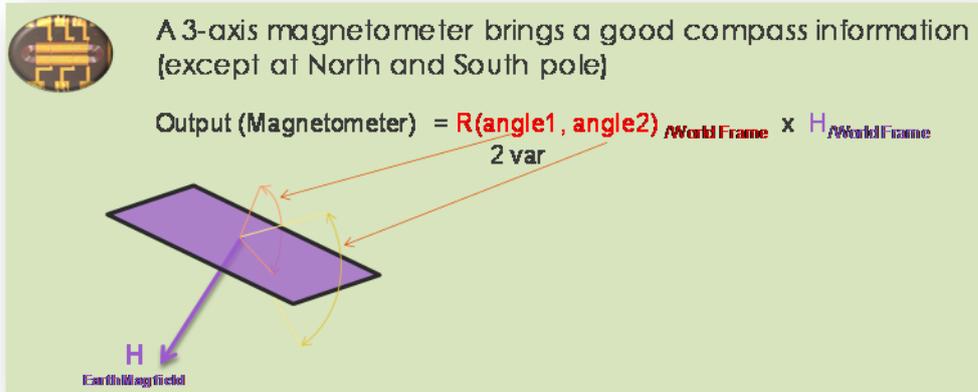


Figure 4: A magnetometer is reading the magnetic vector field at its position, therefore providing absolute information about the Yaw angle.

For many applications, however, we can make the assumption that this vector field has a constant direction in the motion space of our device. The strength of the magnetometer is that the readings are not affected by motion (i.e. there's no magnetic field created by the motion of the device) and it is the only sensor that can provide information related to the absolute third angle that we need (Yaw).

Thus we see that any individual sensor cannot provide enough information to determine the absolute orientation of a mobile device. Depending on the application and its context, merging data from these 3 sensors can allow us to estimate orientation. Additionally, if we know the angles, there is even a way to estimate True Acceleration.

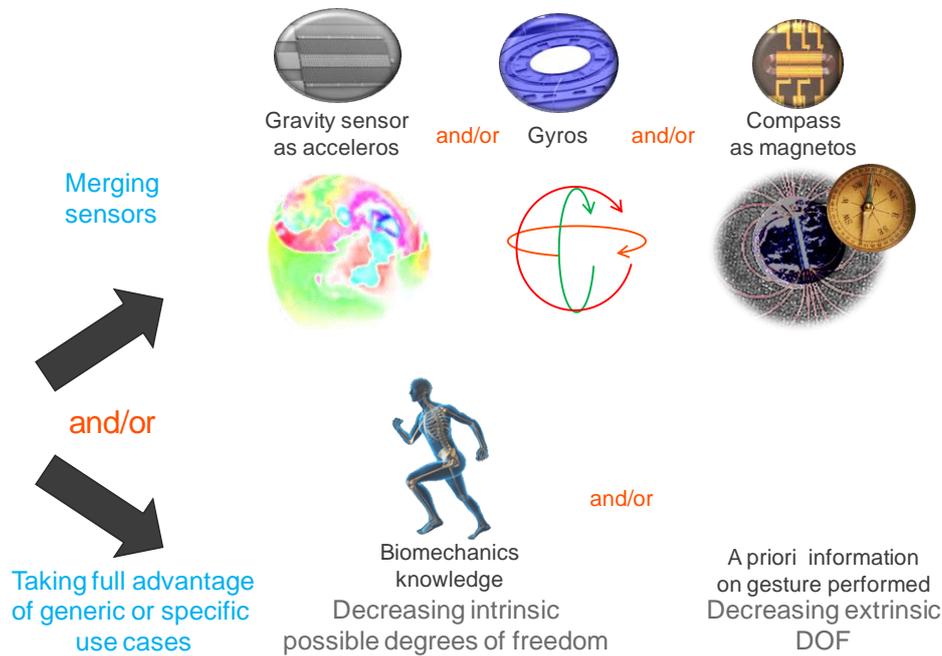
**In conclusion:**

- Gyroscopes allow us to measure Rotation Speed. If the initial orientation at T0 is known, and if we can estimate the sensor bias, then we can calculate true orientation.
- Accelerometers allow us to measure the sum of True Acceleration and the gravitational field (i.e. Pitch and Roll angle). However, these phenomena are inseparable unless we know one of these two.
- Magnetometers gives allow us to measure the final angle, Yaw, and is not subject to distortions from motion. However, the magnetic vector field can vary in space over large areas.

Fusion techniques are a solution to the drawback of individual sensors.

Movea's MotionIC offerings provide innovative data fusion techniques in the form of software, firmware, integrated chips and chipsets to put this MEMS machinery at the service of market needs. Movea's embedded and application specific software derives advanced motion information to enable "motion responsiveness" in any consumer device. System Integrators and OEMs will have "plug & play" solutions that will allow them to focus on user experience and reduce their Time-to-Market.

Figure 5 below summarizes how multiple sensors, initial conditions, and constraints can lead to the solutions we need for our applications.



**Figure 5 : Merging Sensors and A priori information is the best way to get access to True Motion parameters**

### About Movea

Movea is a leading provider of motion processing chips, software, firmware, and IP for the Consumer Electronics industry. Movea's unique motion processing capabilities enable customers and partners to quickly add motion intelligence to their products, meaning reduced risk, cost, and Time-to-Market for delivering compelling new motion-based features that create more end-user value. Movea has a global reach with headquarters in Grenoble, France, a US subsidiary in Silicon Valley, California, as well as technology partners, manufacturing partners and distributors around the world. Further information about Movea can be found at [www.movea.com](http://www.movea.com).

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