September 2003

PNI Corporation

APPLICATION NOTE
Calibration Computations for Practical Compassing using the PNI-11096 Magnetometer ASIC

Introduction

Accurate compass heading information is needed for many applications. A two-axis magnetometer is the minimum sensor configuration required to calculate a magnetic compass heading. Often, the magnetic sensors must be deployed in a system environment that contains interfering magnetic fields. The Earth's magnetic field is a weak field (~0.5Gauss), and nearby magnetic objects can interfere with its accurate measurement. PNI Corp has developed a simple-to-implement algorithm for calibrating a two-axis magnetometer to allow for accurate heading measurements under such circumstances.

The Earth's magnetic field is three-dimensional. In the Northern hemisphere the X-Y component of magnetic field vector lies parallel to the Earth's surface and points towards the magnetic north pole, but the majority of the Earth's field vector lies along the Z axis, which points into the ground. Because of this, compasses need to be held level to the Earth's surface in order to be accurate.

Note 1. The following calculations assume that the compass is level during heading measurement.

Note 2. The following approach is only one of many that can be applied in a two-axis system. There are other approaches that may be equally effective.

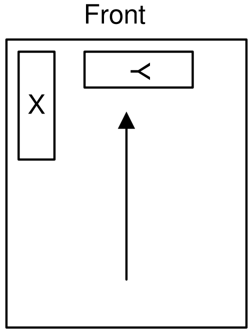

Figure 1. Diagram of a 2-axis magnetometer - based compass.

Calibration Procedure

1) Each heading computation is assumed to be made with a pair of valid X and Y sensor readings which are taken with minimal delay (<100mS) between each other. The sensors are assumed to be at right angles with respect to each other and lie level with respect to the Earth's surface. By convention, the positive end of the X-axis points to the North and the positive end of the Y-axis points East. See Figure 1.

2) The compass should be installed into the host system in its intended operating configuration in as level a position as possible. For example, if the compass is to be used on the dashboard of a car, install the compass into its permanent position on the dashboard while trying to place it as parallel to the Earth's surface as possible. Upon initiation of the calibration sequence take two readings from the compass at 180° apart from each other. In the car example from above, the first reading would be taken upon initiation of calibration and a second point would be taken at the upon conclusion of a U-turn.

   Let these measurement pairs be represented by (X1,Y1) and (X2,Y2).

   - The compass must be installed in the host system in its final configuration. Do not calibrate the compass, and then place it into the host system.
   - For maximum accuracy, the measurements should be as close to 180° apart as possible.

3) Let (Xe,Ye) represent the Earth's magnetic field in any given direction as measured with no interfering magnetic field. The host system will superimpose its additive interfering field, which we can call (X0,Y0), on top of (Xe,Ye). Let (Xn,Yn) represent the field of a given heading as measured by the sensors in the operating environment, such that it contains the interfering fields as generated by the host system.

$$Xn = Xe + X0$$
$$Yn = Ye + Y0 \qquad (1)$$

So:

$$Xe = Xn - X0$$
$$Ye = Yn - Y0 \qquad (2)$$

(Xe,Ye) represents the true Earth's magnetic field – which is the field that the correct heading can be computed from. Therefore, the offset value (X0,Y0) needs to be calculated and subtracted from (Xn,Yn) in order to obtain the correct heading information.

4) Because the compass is fixed with respect to the host system, the readings (X1,Y1) and (X2,Y2) taken during calibration will both contain the same (X0,Y0) values. Since the calibration points are 180° apart, the Earth's magnetic field contained within (X1,Y1) and (X2,Y2) will be equal but opposite in sign. So we can write:

$$X1 = Xe + X0$$
$$Y1 = Ye + Y0 \qquad (3)$$
$$X2 = -Xe + X0$$
$$Y2 = -Ye + Y0 \qquad (4)$$

Thus if we add the appropriate equations above and solve for X0 and Y0 we find

$$X0 = (X1 + X2)/2$$
$$Y0 = (Y1 + Y2)/2 \qquad (5)$$

5) X0 and Y0 are generally constant values that can should be stored and subtracted for each heading computation performed. Their values will change if the magnetic field of the host system either increases through magnetization or decreases through demagnetization.

6) Heading is calculated from Xe and Ye, as follows:

$Ae = \text{arctangent}(Ye / Xe).$

7) Depending upon the arctangent function implemented, Ae will need to be map into the correct quadrant. The (Xe,Ye) values correspond to the following quadrants:

+X, +Y → Ae is between 0° and 90°

-X, +Y → Ae is between 90° and 180°

-X, -Y → Ae is between 180° and 270°

+X, -Y → Ae is between 270° and 360°

Declination

Declination is the difference between magnetic north and true north. There is a difference between the two directions because the earth's magnetic North Pole is not in the same location as the true North Pole. A compass measures earth's magnetic field, so it always points to magnetic North. An additional complexity is that the difference between magnetic North and true North varies from place to place.

Fortunately, there are many ways to obtain declination. Most hiking topographic maps will list your declination. You can also find web pages such as the National Geophysical Data Center's site www.ngdc.noaa.gov/cgi-bin/seg/gmag/fldsnth1.pl .

Declination is defined as "East" if magnetic North falls to the east of true North; and "West" if magnetic North falls to the West of true North. A positive declination is "East", and a negative declination is "West". For instance, the NGDC website listed above shows that for Mountain View, CA (37N, 122W) the declination is "15d 25.7m". First, it is positive, so it is Eastward declination. The "d" stands for degrees; the "m" stands for minutes. 60 minutes = 1 degree, so the declination is 15.4º east.

Once you know your declination, you can correct the compass heading so that you will know your heading relative to true North. Add the declination to your compass measurement to get the true heading. For example, if your declination is 15°E, you will add 15° to your compass measurement. If your declination is 10°W, you add -10° to your compass measurement.

Common Errors

Distortion

Compasses can easily give false readings if you use them near external magnetic objects or if you use them tilted from level. You can easily test for these conditions to warn the user of a problem with the heading. When you calculate your calibration for the compass, you should also store the magnitude of the measured earth's field Me = sqrt(Xe^2 + Ye^2). Then, when making future heading measurements, the stored value Me can be compared with the current corrected measurement values. If they differ, the compass is either tilted or next to a magnetic object. The tolerance can be adjusted to balance between accuracy and usability.

Other Disturbances

EL Backlight Operation and Accuracy Correction

When an EL or other backlight is used in a compass system, it is often observed that turning the backlight on causes a heading change in one or more directions. This is due to the fact that the backlight system often draws enough current during operation to cause the voltage level of a battery based power supply to drop enough to effect the zero offset of the ASIC. In addition, if there is other backlight support circuitry, such as inductors or other current loops, the magnetic fields generated by those components can directly affect the sensor readings to create similar heading changes as well. An algorithmic solution to this problem can be implemented during the user calibration procedure that the user of the compass would normally execute. In addition to obtaining the magnetic offset for each of the X and Y axes (X_{offset} and Y_{offset}), the backlight is turned on for 1/2 second (and then turned off) and an additional reading of the sensors is taken before the user is instructed to start the calibration rotations. The X and Y values taken while the backlight is momentarily on are stored as $X_{backlight\_offset}$ and $Y_{backlight\_offset}$. Then, whenever during normal operation, the backlight is turned on, simple take the raw sensor readings, X_{raw} and Y_{raw}, subtract out X_{offset} and Y_{offset}, and then subtract out $X_{backlight\_offset}$ and $Y_{backlight\_offset}$. So it is $X = X_{raw} - X_{offset} - X_{backlight\_offset}$ and $Y = Y_{raw} - Y_{offset} - Y_{backlight\_offset}$. Whenever the backlight is not on, then do not subtract out $X_{backlight\_offset}$ and $Y_{backlight\_offset}$ for the values to be used in the ArcTan calculations.

PNI-11096 ASIC Part Number Index

Part Number	Description
10174	26 pad Die
10175	28 pin SOIC
11182	28 pad MLF

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