# User Manual

## TRAX

Attitude & Heading Reference System (AHRS)

**PNI**
SENSOR CORPORATION

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# 1    Copyright & Warranty Information

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If any Product furnished hereunder fails to conform to the above warranty, OEM's sole and exclusive remedy and PNI's sole and exclusive liability will be, at PNI's option, to repair, replace, or credit OEM's account with an amount equal to the price paid for any such Product which fails during the applicable warranty period provided that (i) OEM promptly notifies PNI in writing that such Product is defective and furnishes an explanation of the deficiency; (ii) such Product is returned to PNI's service facility at OEM's risk and expense; and (iii) PNI is satisfied that claimed deficiencies exist and were not caused by accident, misuse, neglect, alteration, repair, improper installation, or improper testing.  If a Product is defective, transportation charges for the return of the Product to OEM within the United States and Canada will be paid by PNI.  For all other locations, the warranty excludes all costs of shipping, customs clearance, and other related charges.  PNI will have a reasonable time to make repairs or to replace the Product or to credit OEM's account.  PNI warrants any such repaired or replacement Product to be free from defects in material and workmanship on the same terms as the Product originally purchased.

Except for the breach of warranty remedies set forth herein, or for personal injury, PNI shall have no liability for any indirect or speculative damages (including, but not limited to, consequential, incidental, punitive and special damages) relating to the use of or inability to use this Product, whether arising out of contract, negligence, tort, or under any warranty theory, or for infringement of any other party's intellectual property rights, irrespective of whether PNI had advance notice of the possibility of any such damages, including, but not limited to, loss of use, revenue or profit.  In no event shall PNI's total liability for all claims regarding a Product exceed the price paid for the Product.  PNI neither assumes nor authorizes any person to assume for it any other liabilities.

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# 2 Introduction

Thank you for purchasing PNI Sensor Corporation's TRAX attitude & heading reference system (AHRS). The TRAX employs a proprietary Kalman filtering algorithm that intelligently fuses PNI's patented Reference Magnetic Sensors with a 3-axis gyroscope and 3-axis accelerometer. The result is an orientation device that provides accurate heading information under a wide variety of conditions, including its ability to overcome errors normally caused by erratic motion and/or changes in the local magnetic field. The advanced features of the TRAX make it ideal for a variety of applications, including:

- Unmanned Ground Vehicles (UGV) – Robots and Unmanned Conversions
- Unmanned Underwater Vehicles (UUV) – Autonomous Gliders and ROV's

We're sure the TRAX will help you to achieve the greatest performance from your system. Thank you for selecting the TRAX.

# 3   Specifications

## 3.1   Characteristics & Requirements

**Table 3-1:  Performance Specifications[1]**

| Parameter | | | | Value |
|---|---|---|---|---|
| AHRS Mode | Heading | Accuracy[2] | | 2.0° rms |
| | | Resolution | | 0.1° |
| | Attitude | Range | Pitch | ± 90° |
| | | | Roll | ± 180° |
| | | Accuracy | | 2.0° rms |
| | | Resolution | | 0.01° |
| Compass Mode | Heading | Static Accuracy[3] | | 0.3° rms |
| | | Resolution | | 0.1° |
| | | Repeatability | | 0.05° rms |
| | Attitude | Range | Pitch | ± 90° |
| | | | Roll | ± 180° |
| | | Static Accuracy | | 0.2° rms |
| | | Resolution | | 0.01° |
| | | Repeatability | | 0.05° rms |

**Footnotes:**
1. Specifications are typical unless otherwise noted, and subject to change.
2. Assumes heading status is "1".  See Section 6.6 or Section 7.5.3 for a discussion on heading status.
3. Assumes TRAX is motionless, the local magnetic field is clean relative to user calibration, ≤65° of pitch, and after a Full-Range calibration has been performed.

### Table 3-2: Absolute Maximum Ratings

| Parameter | Minimum | Maximum | Units |
|---|---|---|---|
| Supply Voltage | -0.3 | +10 | VDC |
| Storage Temperature | -40 | +85 | °C |

**CAUTION:**

Stresses beyond those listed above may cause permanent damage to the device. These are stress ratings only. Operation of the device at these or other conditions beyond those indicated in the operational sections of the specifications is not implied.

### Table 3-3: Electrical Requirements

| Parameter | | Value |
|---|---|---|
| Supply Voltage | | 3.8 to 9 VDC |
| Communication Lines | High Level Input | 2.4 V minimum |
| | Low Level Input | 0.6 V maximum |
| | Output Voltage Swing | ±5.2 V typ., ±5.0 V min. |
| | Tx Output Resistance | 300 Ω |
| Current Draw | AHRS Mode@ max. sample rate | 55 mA typical |
| | Compass Mode @ max. sample rate | 28 mA typical |
| | During application of external power | See Figure 3-1 |
| | Sleep Mode | 0.5 mA typical |
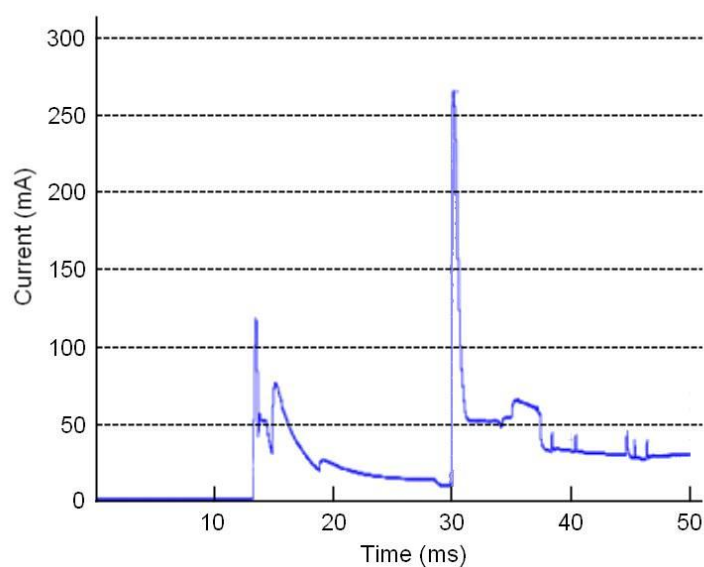


*Figure 3-1: Typical Current Drawing During Application of External Power*

**Table 3-4: I/O Characteristics**

| Parameter | Value |
|---|---|
| Communication Interface | RS232 UART & USB |
| Communication Protocol | PNI Binary |
| Communication Rate[1] | 2400 to 921,600 baud |
| Maximum Data Output Rate | ≈30 samples/sec |

**Footnote:**
1. The TRAX can operate up to 921,600 baud, but native RS232 is limited to 115,200 baud.

**Table 3-5: Environmental Requirements**

| Parameter | Value |
|---|---|
| Operating Temperature[1] | -40C to +85C |
| Storage Temperature | -40C to +85C |

**Footnote:**
1. To meet performance specifications across this range, recalibration will be necessary as the temperature varies.

**Table 3-6: Mechanical Characteristics**

| Parameter | Value |
|---|---|
| Dimensions (l x w x h) | 3.5 x 4.3 x 1.0 cm |
| Weight | 7 gm |
| Connector | 9-pin Molex, pn 53780-0970 |

## 3.2   Mechanical Drawings

DIMENSIONS ARE MILLIMETERS
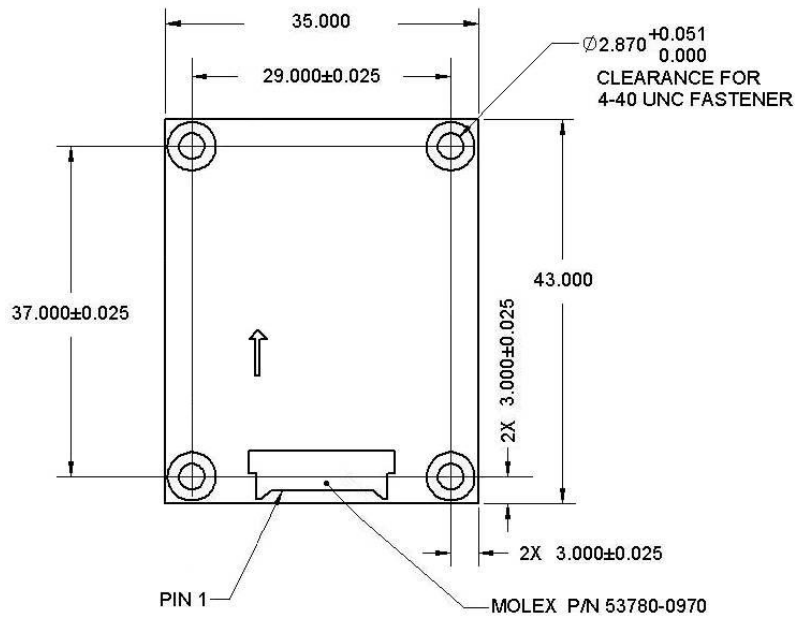


*Figure 3-2:  TRAX PCA Mechanical Drawing*
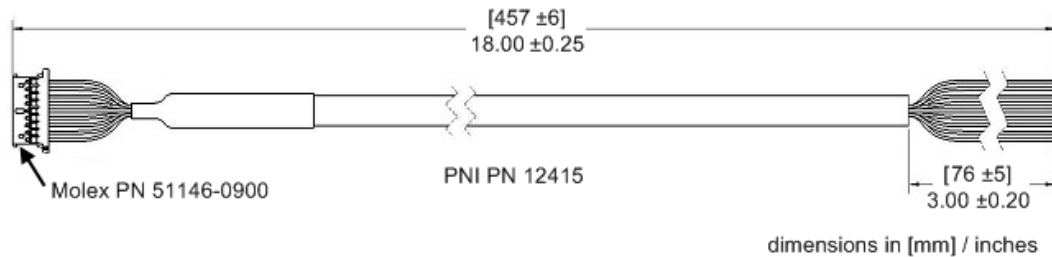


Figure 3-3:  Molex-to-Pigtail Cable Drawing, pn 12415
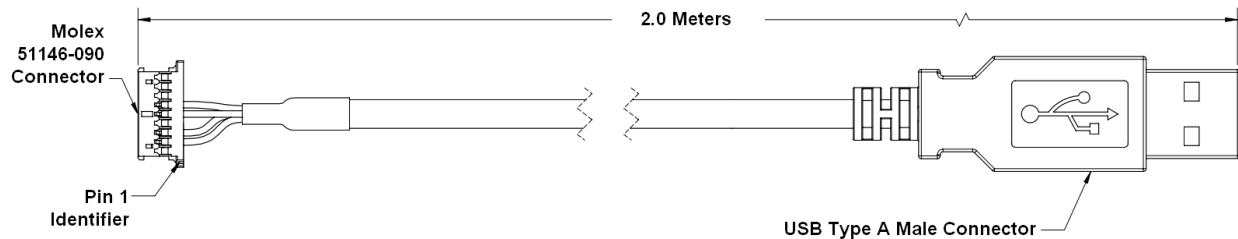


Figure 3-4:  Molex-to-USB Cable Drawing, pn 13119

# 4    Set-Up

This section describes how to configure the TRAX in your host system.  To install the TRAX into your system, follow these steps:

- Make electrical connections to the TRAX.
- Evaluate the TRAX using the TRAX Studio program, or a binary terminal emulation program, such as RealTerm or Tera Term, to ensure the TRAX is working properly.
- Choose a mounting location.
- Mechanically mount the TRAX in the host system.
- Perform a user calibration.

## 4.1   Electrical Connections

The TRAX PCA incorporates a 9 pin Molex connector, part number 53780-0970, which mates with Molex part 51146-0900 or equivalent.  The pin-out for both is given below in Table 4-1.

**Table 4-1:  TRAX Pin Descriptions**

| Pin #[1] | TRAX PCA | |
|---|---|---|
| | 9 Pin Molex Connector | Pigtailed Cable Wire Color |
| 1 | Ground | Black |
| 2 | USB +5 VDC | Gray |
| 3 | Ground | Green |
| 4 | Not Connected | Orange |
| 5 | USB D– | Violet |
| 6 | USB D+ | Brown |
| 7 | RS232 Tx | Yellow |
| 8 | RS232 Rx | Blue |
| 9 | RS232 +5 VDC | Red |

**Footnote:**

1.  Pin #1 is indicated on Figure 3-2.

After making the electrical connections, it is a good idea to perform some simple tests to ensure the TRAX is working as expected.  See Section 6 for how to operate the TRAX with TRAX Studio or Section 7 for how to operate the TRAX using PNI's binary protocol.

## 4.2   Installation Location

The TRAX's wide dynamic range and sophisticated algorithms allow it to operate in many environments. For optimal performance however, you should mount the TRAX with the following considerations in mind:

### 4.2.1   Operate within the TRAX's dynamic range

The TRAX can be user calibrated to correct for static magnetic fields created by the host system. However, each axis of the TRAX has a calibrated dynamic range of $\pm125$ µT. If the total field exceeds this value for any axis, the TRAX may not perform to specification. When mounting the TRAX, consider the effect of any sources of magnetic fields in the host environment that, when added to Earth's field, may take the TRAX out of its dynamic range. For example, large masses of ferrous metals such as transformers and vehicle chassis, large electric currents, permanent magnets such as electric motors, and so on.

### 4.2.2   Locate away from changing magnetic fields

While the TRAX can compensate for transient changes in the local magnetic field, it is good design practice to keep the TRAX away from sources of local magnetic distortion that knowingly will change with time; such as electrical equipment that will be turned on and off, or ferrous bodies that will move.

### 4.2.3   Mount in a physically stable location

Choose a location that is isolated from persistent vibration or other dynamic motion. The TRAX can provide accurate headings while experiencing intermittent dynamic motion, such as vibration or quick heading changes. But if this is persistent the TRAX will have difficulty holding an accurate heading over extended periods of time.

## 4.3   Mechanical Mounting

The TRAX is factory calibrated with respect to its mounting holes. It must be aligned within the host system with respect to these mounting holes. Ensure any stand-offs or screws used to mount the TRAX are non-magnetic. Refer to Section 3.2 for dimensions, hole locations, and the reference frame orientation.

### 4.3.1   Pitch and Roll Convention

The TRAX utilizes Euler angles as the primary method for providing orientation data, although quaternions outputs also are available. The Euler angles are the common

method used for aircraft orientation, where the outputs are heading, pitch and roll. When using Euler angles in aviation, roll is defined as the angle rotated around an axis through the center of the fuselage, while pitch is rotation around an axis through the center of the wings. These rotations are dependent on each other since the axes of rotation move with the plane.

As shown in Figure 4-1, for the TRAX a positive pitch is when the front edge of the board is rotated upward and a positive roll is when the right edge of the board is rotated downward. The order of rotation is given as heading, pitch, and then roll.
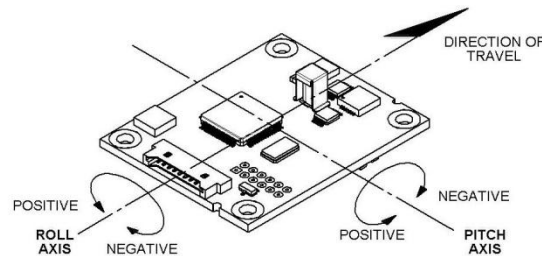


*Figure 4-1:  Positive & Negative Roll and Pitch Definition*

## 4.3.2    Mounting Orientation

The TRAX can be mounted in 16 different orientations, as shown in Figure 4-2. All reference points are based on the silk-screened arrow on the top side of the TRAX PCA board. The orientation should be programmed in the TRAX using the Configuration Tab in TRAX Studio or using the kSetConfig command and the kMountingRef setting in the PNI Protocol, as described in Section 7.4.2. The default orientation is "STD 0°".
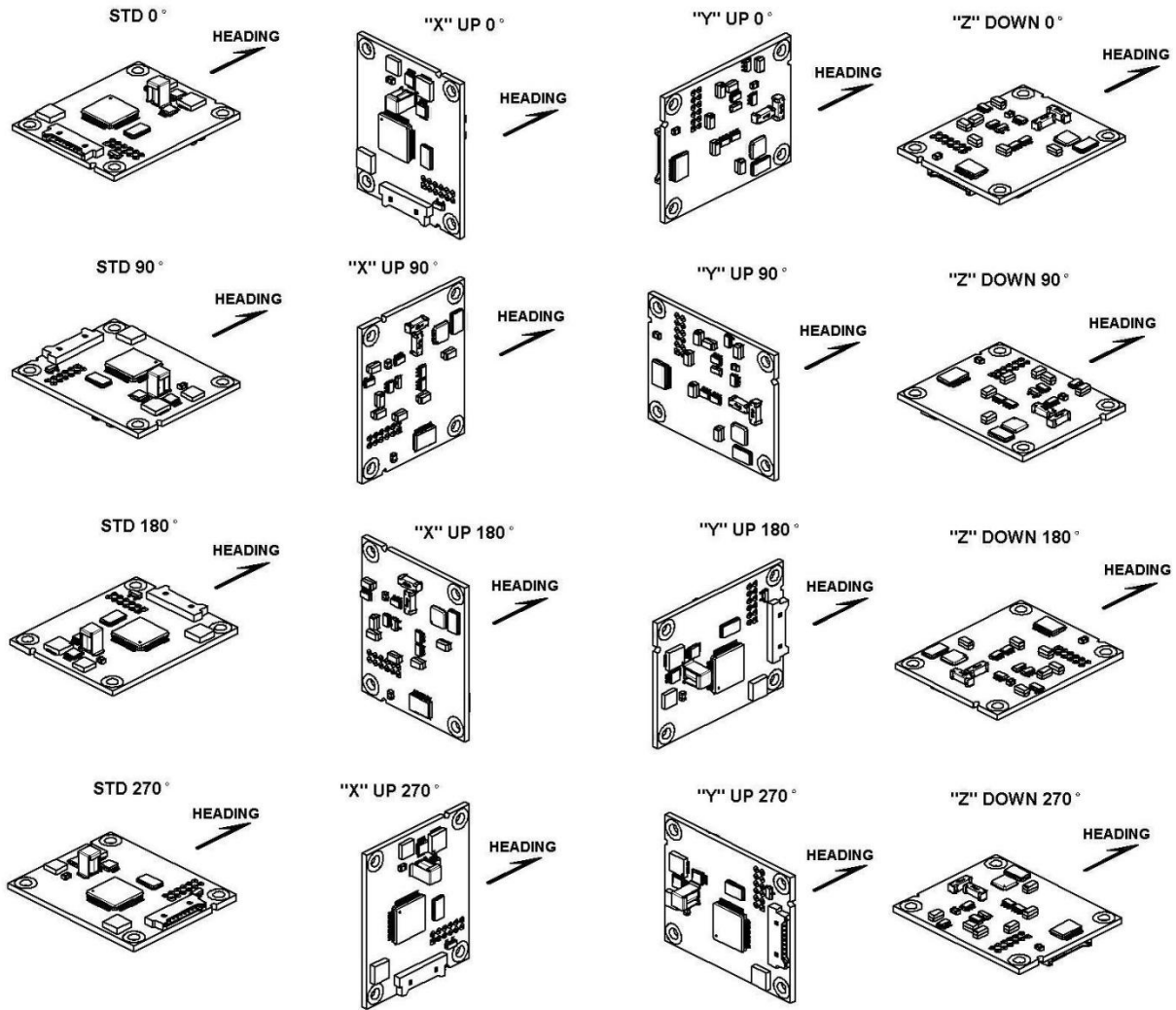
*Figure 4-2: TRAX Enclosed Mounting Orientations*

# 5   User Calibration

The magnetic sensor in the TRAX is calibrated at PNI's factory in a magnetically controlled environment.  However sources of magnetic distortion positioned near the TRAX in the user's system will distort Earth's magnetic field and should be compensated for in the host system with a user calibration.  Examples of such sources include ferrous metals and alloys (ex. iron, nickel, steel, etc.), batteries, audio speakers, current-carrying wires, and electric motors.  Compensation is accomplished by mounting the TRAX in the host system and performing a user calibration.  It is expected the sources of magnetic distortion remain fixed relative to the TRAX's position within the host system.  By performing a calibration, the TRAX identifies the local sources of magnetic distortion and negates their effects from the overall reading to provide an accurate heading.

As with the magnetic sensor, the accelerometer in the TRAX is calibrated at PNI's factory.  But the accelerometer gradually changes over time, and the user either will need to periodically perform a user accelerometer calibration or return the unit to PNI for recalibration.  As a rule-of-thumb, the accelerometer should be recalibrated every 6 to 12 months.  Unlike a magnetic calibration, the accelerometer may be calibrated outside the host system.  Accelerometer calibration is more sensitive to noise or hand jitter than magnetic calibration, especially for subsequent use at high tilt angles.  Because of this, a stabilized fixture is suggested for accelerometer calibration, although resting the unit against a stable surface often is sufficient.

**<u>Key Points:</u>**

- Magnetic calibration:
    - Requires incorporating the TRAX into the user's host system such that the magnetic components of the user's system can be compensated for.
    - Allows for 4 different methods of calibration.  Full-Range Calibration provides the highest heading accuracy, but requires ≥45° of pitch.  2D and Limited-Tilt Calibration allow for good calibration when the range of allowable motion is limited.  Hard-Iron-Only Calibration updates the hard-iron compensation coefficients with a relatively easy procedure.

- Accelerometer calibration requires rotating the TRAX through a full sphere of coverage, but it does not need to be incorporated in the user's system during calibration.

- If the TRAX will experience different states during operation, such as operating with a nearby shutter sometimes closed and sometimes open, or operating over a broad temperature range, then different sets of calibration coefficients can be saved for the various states.  Up to 8 magnetic calibration coefficient sets and 3 accelerometer calibration coefficient sets can be saved.

# 5.1    Magnetic Calibration

Two fundamental types of magnetic distortion exist:  hard-iron and soft-iron.  These are discussed in the following paragraphs, plus a discussion on how temperature also affects magnetic fields and other considerations.  For more information on magnetic distortion and calibration, see PNI's white paper "Local Magnetic Distortion Effects on 3-Axis Compassing" at PNI's website (http://www.pnicorp.com/technology/papers).

## Hard-Iron Effects

Hard-iron distortions are caused by permanent magnets and magnetized objects in close proximity to the sensors.  These distortions add or subtract a fixed component to each axis of the magnetic field reading.  Hard-iron distortions usually are unchanging and in a constant location relative to the sensors, for all heading orientations.

## Soft-Iron Effects

Magnetically "soft" materials effectively bend the magnetic field near them.  These materials have a high magnetic permeability, meaning they easily serve as a path for magnetic field lines.  Unlike hard-iron effects, soft-iron effects do not increase or decrease the total field in the area.  However, the effect of the soft-iron distortion changes as the host system's orientation changes.  Because of this, it is more difficult to compensate for soft-iron materials.

## Temperature Effects

While the hard-iron and soft-iron distortion of a system may remain quite stable over time, normally the distortion signature will change over temperature.  As a general rule, the hard-iron component will change 1% per 10°C temperature change.  Exactly how this affects heading depends on several factors, most notably the hard-iron component of the system and the inclination, or dip angle.

Consider the example of a host system with a 100 µT hard-iron component.  This is a fairly large hard-iron component, but not completely uncommon.  A 10°C temperature change will alter the magnetic field by ~1 µT in the direction of the hard-iron component.  Around San Francisco, with an inclination of ~60°, this results in up to a couple of degrees of heading change over 10°C.

Consequently, no matter how stable a compass is over temperature, it is wise to recalibrate over temperature since the magnetic signature of the host system will change over temperature.  The TRAX helps accommodate this issue by allowing the user to save up to 8 sets of magnetic calibration coefficient sets, so different calibration coefficients can be generated and loaded at different temperatures.

## Other Considerations

Unlike a compass, such as PNI's TCM module, the TRAX is an AHRS and as such it can compensate for transient changes in the local magnetic field. However, the TRAX will work best if it is kept away from dynamic magnetic fields. For example, if there is an electric motor is in the host system that will be turning on and off during TRAX operation, then mount the TRAX far away from the motor such that the motor's state does not affect the heading when TRAX is in Compass Mode. Alternatively, TRAX can store up to 8 different sets of magnetic calibration coefficients, so in the case of the motor, generate and use one set of magnetic calibration coefficients for when the motor is off and another set for when it is on.

The main objective of a magnetic user calibration is to compensate for hard-iron and soft-iron distortions to the magnetic field caused by components within the user's host system. To that end, the TRAX needs to be mounted within the host system and the entire host system needs to be moved as a single unit during a user calibration. The TRAX allows the user to perform a calibration only in a 2D plane or with limited tilt, but provides the greatest accuracy if the user can rotate through 360° of heading and at least ±45°of tilt.

The following subsections provide instructions for performing a magnetic calibration of a TRAX system. Several calibration mode options exist, as summarized in Table 5-1. To meet the accuracy specification, the number of samples should be the "Minimum Recommended" value, or greater. Calibration may be performed using TRAX Studio or using the PNI binary protocol, and up to 8 sets of magnetic calibration coefficients may be saved. The recommended calibration patterns described in the following sub-sections provide a good distribution of sample points. Also, PNI recommends the location of the TRAX remain fairly constant while only the orientation is changed.

**Table 5-1:  Magnetic Calibration Mode Summary**

| Calibration Mode | Static Accuracy in Compass Mode | Tilt Range during Cal | Minimum Recommended # of Samples | Allowable Range of # of Samples |
|---|---|---|---|---|
| Full-Range | 0.3° rms | >±45° | 12 | 10 – 18 |
| 2D Calibration | <2° | <±5° | 12 | 10 – 18 |
| Limited-Tilt | <2° over 2x tilt range | ±5° to ±45° | 12 | 10 – 18 |
| Hard-Iron-Only | Restores prior accuracy | >±3° | 6 | 4 - 18 |

Before proceeding with a calibration, ensure the TRAX is properly installed in the host system. The device should be installed as discussed in Section 4, and the software should be

properly configured with respect to the mounting orientation, Endianness, north reference, etc.

Section 6.5 outlines how to perform a calibration using TRAX Studio, while Section 7.6.2 provides a step-by-step example of how to perform a calibration using the PNI protocol.

## 5.1.1    Full-Range Calibration

- A Full-Range Calibration is appropriate when the TRAX can be tilted ±45° or more.  This method compensates for hard and soft-iron effects in three dimensions, and allows for the highest accuracy readings.  The recommended 12 point calibration pattern is a series of 3 circles of evenly spaced points, as illustrated in

Sample # 1:
Y: 0° P: ± 5°
R: 30° to 40°

Sample # 4:
Y: 270° P: ± 5°
R: -30° to -40°

North/0°

Sample # 2:
Y: 90° P: ± 5°
R: -30° to -40°

Sample # 3:
Y: 180° P: ± 5°
R: 30° to 40°

Sample # 8:
Y: 300° P: > +45°
R: -30° to -40°

Sample # 5:
Y: 30° P: > +45°
R: 30° to 40°

North/0°

Sample # 6:
Y: 120° P: > +45°
R: -30° to -40°

Sample # 7:
Y: 210° P: > +45°
R: 30° to 40°
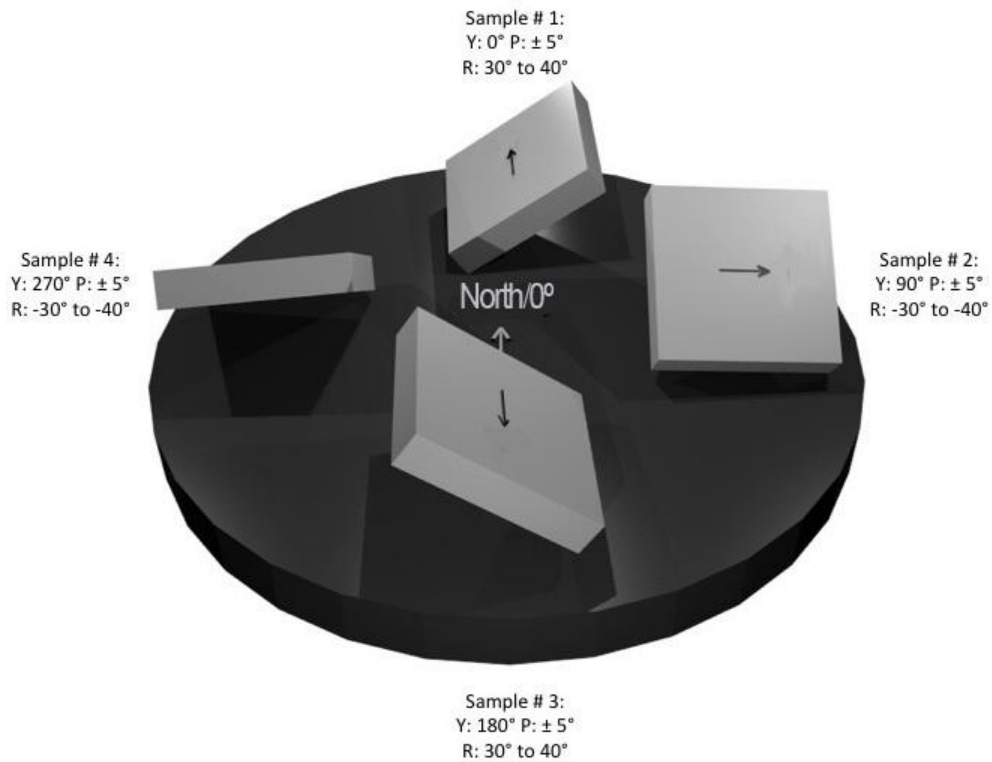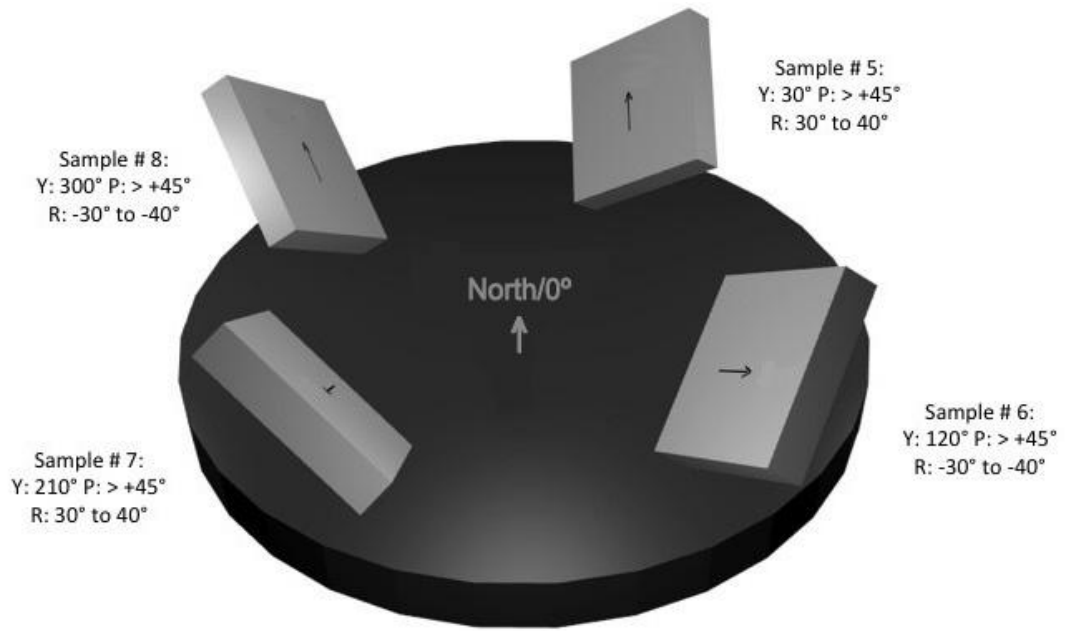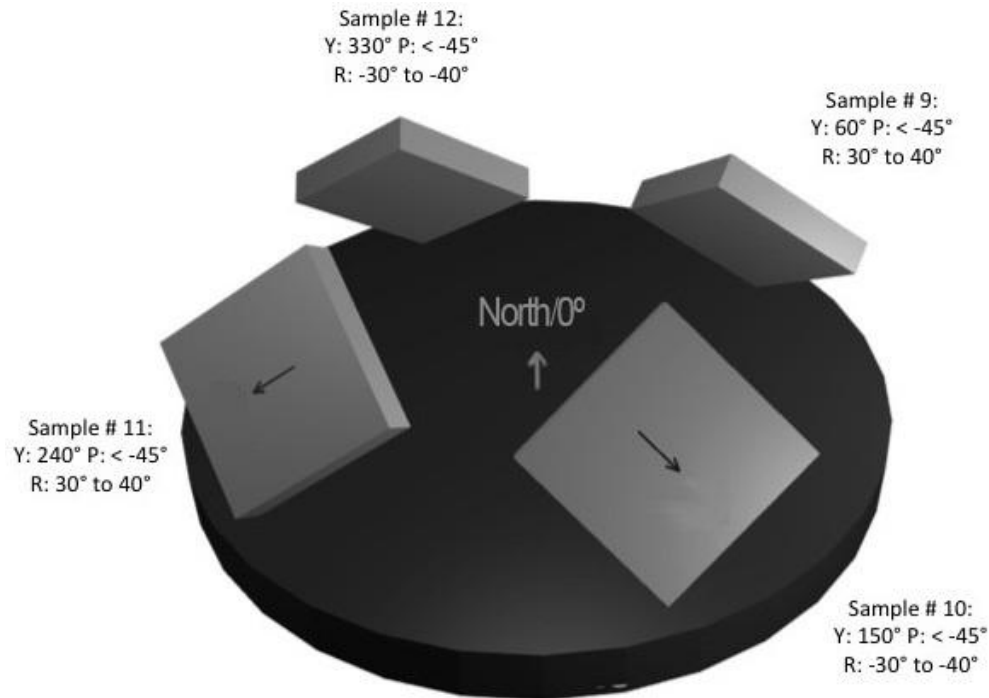
Figure 5-1 and listed in Table 5-2. The pitch used in the second and third circles of the calibration should at least match the maximum and minimum pitch the device is expected to encounter in use.

**Table 5-2: 12 Point Full-Range Calibration Pattern**

| Sample # | Yaw[1] | Pitch | Roll |
|---|---|---|---|
| First Circle | | | |
| 1 | 0° | ±5° | 30° to 40° |
| 2 | 90° | ±5° | -30° to -40° |
| 3 | 180° | ±5° | 30° to 40° |
| 4 | 270° | ±5° | -30° to -40° |
| Second Circle | | | |
| 5 | 30° | > +45° | 30° to 40° |
| 6 | 120° | > +45° | -30° to -40° |
| 7 | 210° | > +45° | 30° to 40° |
| 8 | 300° | > +45° | -30° to -40° |
| Third Circle | | | |
| 9 | 60° | < -45° | 30° to 40° |
| 10 | 150° | < -45° | -30° to -40° |
| 11 | 240° | < -45° | 30° to 40° |
| 12 | 330° | < -45° | -30° to -40° |

**Footnote:**

1. Yaw listings are not absolute heading directions but rather relative heading referenced to the first sample.

*Notes about*

Sample # 8:
Y: 300° P: > +45°
R: -30° to -40°

Sample # 5:
Y: 30° P: > +45°
R: 30° to 40°

North/0°

Sample # 7:
Y: 210° P: > +45°
R: 30° to 40°

Sample # 6:
Y: 120° P: > +45°
R: -30° to -40°

**Sample # 12:**
Y: 330° P: < -45°
R: -30° to -40°

**Sample # 9:**
Y: 60° P: < -45°
R: 30° to 40°

North/0°

**Sample # 11:**
Y: 240° P: < -45°
R: 30° to 40°

**Sample # 10:**
Y: 150° P: < -45°
R: -30° to -40°
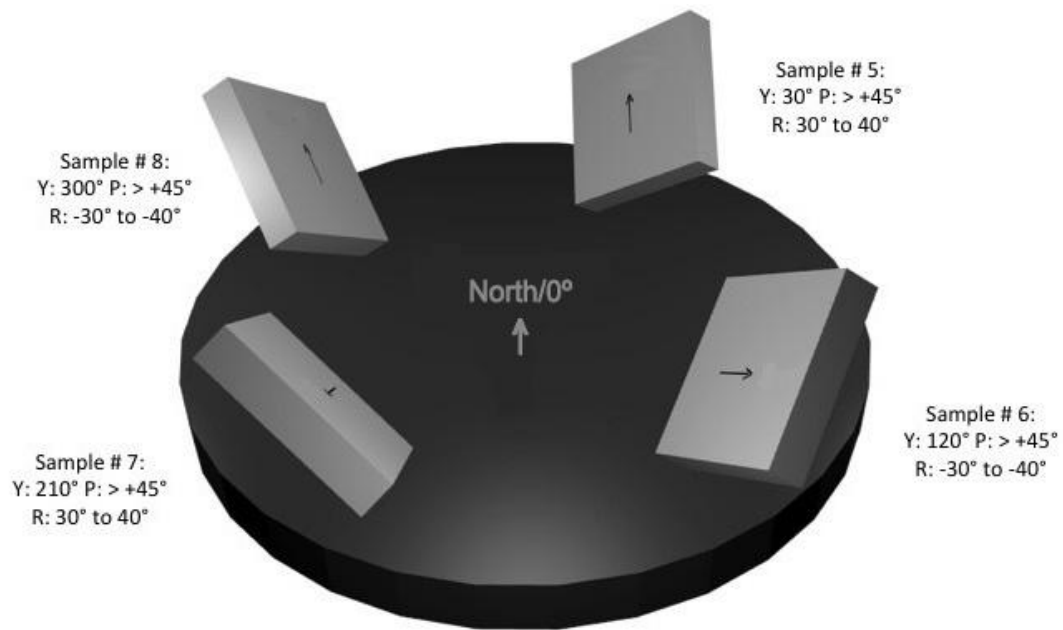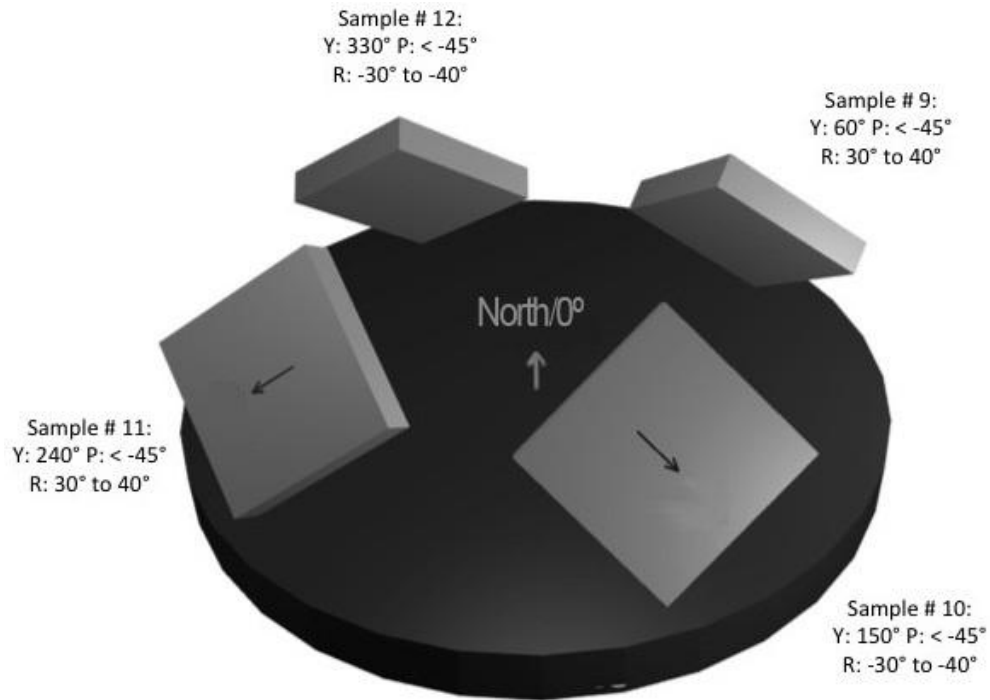
***Figure 5-1: 12*** Point Full-Range Calibration*:*

- *While the figure shows the location of the device changing, this is for illustration purpose and it is best for the location of the device to remain constant.*

- *The arrow on the blocks representing the module correspond to the arrow silkscreened on the board.*
- *It is not necessary for the board to be pointing North, however, it may provide better results, especially in high latitudes.*

Sample # 1:
Y: 0° P: ± 5°
R: 30° to 40°

Sample # 4:
Y: 270° P: ± 5°
R: -30° to -40°

North/0°

Sample # 2:
Y: 90° P: ± 5°
R: -30° to -40°

Sample # 3:
Y: 180° P: ± 5°
R: 30° to 40°

Sample # 5:
Y: 30° P: > +45°
R: 30° to 40°

Sample # 8:
Y: 300° P: > +45°
R: -30° to -40°

North/0°

Sample # 6:
Y: 120° P: > +45°
R: -30° to -40°

Sample # 7:
Y: 210° P: > +45°
R: 30° to 40°

Sample # 12:
Y: 330° P: < -45°
R: -30° to -40°

Sample # 9:
Y: 60° P: < -45°
R: 30° to 40°

North/0°

Sample # 11:
Y: 240° P: < -45°
R: 30° to 40°

Sample # 10:
Y: 150° P: < -45°
R: -30° to -40°
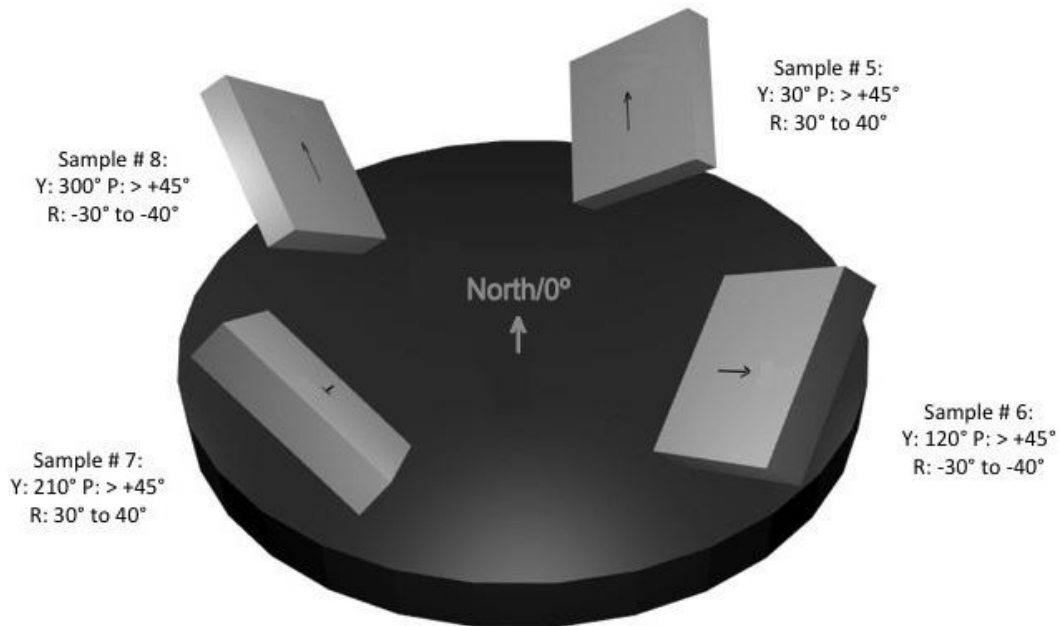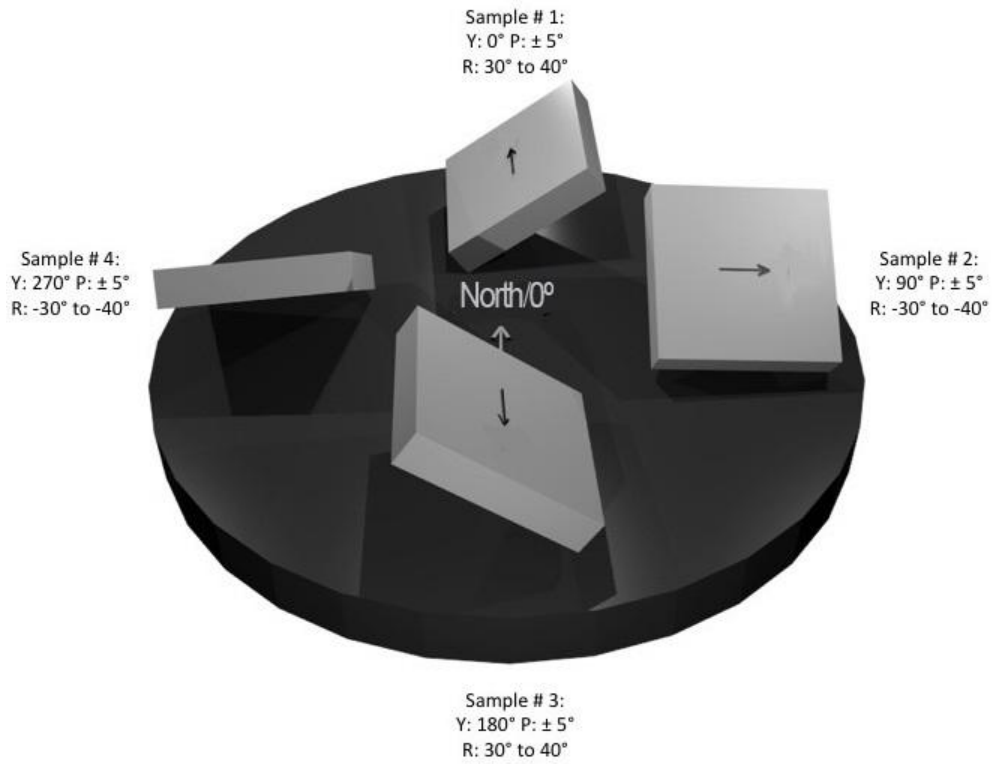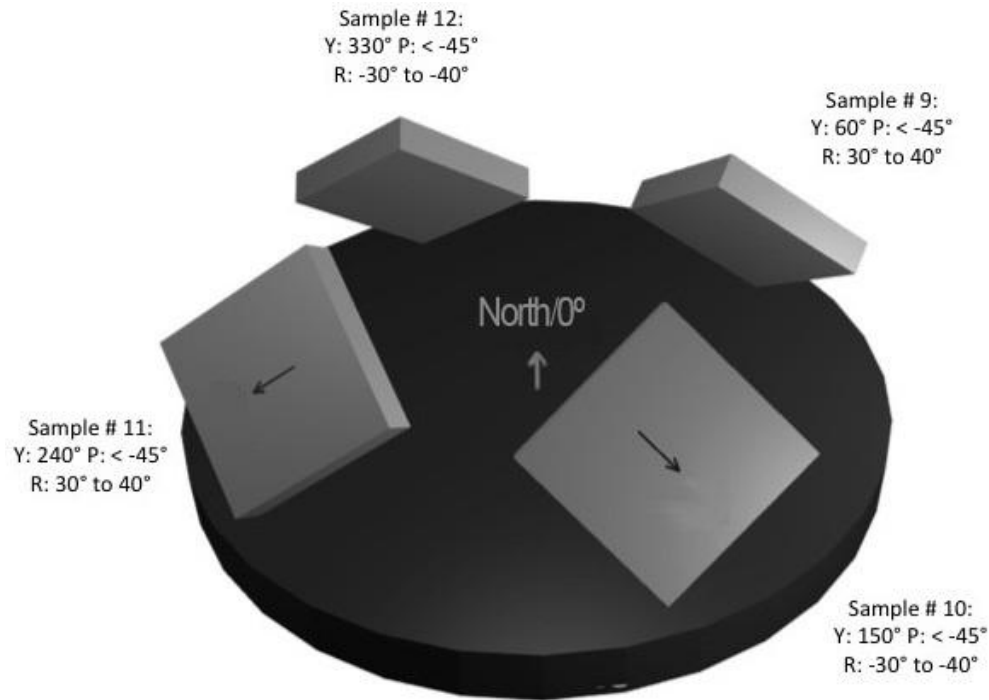
*Figure 5-1:  12 Point Full-Range Calibration*

## 5.1.2    2D Calibration

A 2D Calibration is intended for very low tilt operation (<5°) where calibrating the TRAX with greater tilt is not practical.

This procedure calibrates for hard and soft-iron effects in only two dimensions, and in general is effective for operation and calibration in the tilt range of -5° to +5°.  The recommended 12 point calibration pattern is a circle of evenly spaced points, as given in Table 5-3.

**Table 5-3:  12 Point 2D Calibration Pattern**

| Sample # | Yaw | Pitch[1] | Roll[1] |
|:---:|:---:|:---:|:---:|
| 1 | 0° | 0° | 0° |
| 2 | 30° | max. negative | max. negative |
| 3 | 60° | 0° | 0° |
| 4 | 90° | max. positive | max. positive |
| 5 | 120° | 0° | 0° |
| 6 | 150° | max. negative | max. negative |
| 7 | 180° | 0° | 0° |
| 8 | 210° | max. positive | max. positive |
| 9 | 240° | 0° | 0° |
| 10 | 270° | max. negative | max. negative |
| 11 | 300° | 0° | 0° |
| 12 | 330° | max. positive | max. positive |

<u>Footnote:</u>

1. For best results, the tilt experienced during calibration should match that experienced in service.  For example, if the TRAX is restrained to a level plane in service, then calibration should be in a plane, where "max. positive" and "max. negative" are 0°.

## 5.1.3    Limited-Tilt Calibration

A Limited-Tilt Calibration is recommended when 45° of tilt isn't feasible, but >5° of tilt is possible.  It provides both hard-iron and soft-iron distortion correction.  The recommended 12 point calibration pattern given below is a series of 3 circles of evenly spaced points, with as much tilt variation as expected during use.

**Table 5-4:  12 Point Limited-Tilt Calibration Pattern**

| Sample # | Yaw | Pitch | Roll |
|:---:|:---:|:---:|:---:|
| First Circle | | | |
| 1 | 0° | 0° | 0° |
| 2 | 90° | 0° | 0° |
| 3 | 180° | 0° | 0° |
| 6 | 270° | 0° | 0° |
| Second Circle | | | |
| 7 | 45° | > +5° | > +5° |
| 8 | 135° | > +5° | > +5° |
| 11 | 225° | > +5° | > +5° |
| 12 | 315° | > +5° | > +5° |
| Third Circle | | | |
| 13 | 45° | < -5° | < -5° |
| 14 | 135° | < -5° | < -5° |
| 17 | 225° | < -5° | < -5° |
| 18 | 315° | < -5° | < -5° |

Note that a similar and acceptable alternative pattern would be to follow the recommended 12 point Full-Range Calibration pattern, but substituting the >±45° of pitch with whatever pitch can be achieved and the ±10° to ±20° of roll with whatever roll can be achieved up to these limits. See Section 5.1.1 for more information.

## 5.1.4 Hard-Iron-Only Calibration

It is not uncommon for the hard-iron magnetic distortions around the TRAX to change. Some reasons for this include significant temperature change or temperature shock to a system, as well as gradual aging of components. A Hard-Iron-Only Calibration allows for quick recalibration of the TRAX for hard-iron effects, and generally is effective for operation and calibration in the tilt range of 3° or more (≥45° is preferred). The recommended 6 point calibration pattern given below is a circle of alternately tilted, evenly spaced points, with as much tilt as expected during use.

**Table 5-5: 6 Point Hard-Iron-Only Calibration Pattern**

| Sample # | Yaw | Pitch[1] | Roll[1] |
|----------|------|--------------|--------------|
| 1 | 0° | max. negative | max. negative |
| 2 | 60° | max. positive | max. positive |
| 3 | 120° | max. negative | max. negative |
| 4 | 180° | max. positive | max. positive |
| 5 | 240° | max. negative | max. negative |
| 6 | 300° | max. positive | max. positive |

**Footnote:**

1. For best results, the tilt experienced during calibration should match that experienced in service. For example, if the TRAX will be subject to ±45° of pitch and roll when in service, then "max negative" should be -45° and "max positive" should be +45°.

## 5.2 Accelerometer Calibration

The TRAX uses a MEMS accelerometer to measure attitude. This data is output as pitch and roll data. Additionally, the accelerometer data is critical for establishing an accurate heading reading when the TRAX is tilted, as discussed in the PNI white paper "Tilt-Induced Heading Error in a 2-Axis Compass", which can be found on PNI's web site (http://www.pnicorp.com/technology/papers).

The TRAX algorithms assume the accelerometer only measures the gravitational field. If the TRAX is accelerating, this will result in the TRAX calculating an inaccurate gravitational

vector, which in turn will result in an inaccurate heading reading. For this reason, the TRAX should be stationary when taking a measurement.
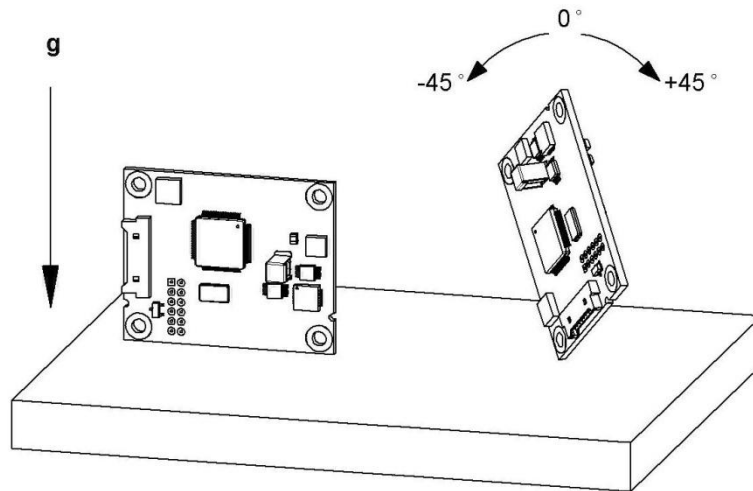
As previously mentioned, PNI calibrates the accelerometer in its factory prior to shipment. But over time the bias and offset of the accelerometer will drift. For this reason PNI recommends the accelerometer be recalibrated every 6 to 12 months. The user may return the TRAX to PNI for accelerometer calibration, or the user may perform a user accelerometer calibration. The remainder of this section covers the user accelerometer calibration.

## 5.2.1 Accel-Only Calibration

The requirements for a good user accelerometer calibration differ significantly from the requirements for a good magnetic calibration. Specifically, a good accelerometer calibration involves the TRAX experiencing a wide range of pitch and roll values, preferably seeing both ±180° of pitch and ±180° of roll. Also, it is necessary for the TRAX to be very still during an accelerometer calibration. If possible, PNI recommends using a fixture to hold the device during calibration, although resting the TRAX on a hard surface normally is sufficient.

The accelerometer either can be calibrated while mounted in the host system or it may be removed and calibrated outside the system. The advantage of performing the calibration while mounted in the host system is the user does not need to remove the TRAX from the system, which can be burdensome, and a simultaneous Mag-and-Accel Calibration may be appropriate. The advantage of performing the calibration outside of the system is it may be much simpler to obtain the desired range of pitch and roll.

Figure 5-2 shows the two basic starting positions for the recommended 18-point calibration pattern. Starting with the TRAX as shown on the left in Figure 5-2, rotate the device about its z axis such that it sits on each of its 4 edges, taking one calibration sample on each edge. Then place the TRAX flat on the surface and take a calibration sample, then flip it over (roll it 180°) and take another sample. Next, starting with the TRAX as shown on the right, take a calibration point with it being vertical (0°). Now tilt the TRAX back 45° and take another calibration point (+45°), then tilt the device forward 45° and take another calibration point (-45°). Repeat this 3-point calibration process for the TRAX with it resting on each of its 4 corners. Note that it is possible to perform an Accel-Only Calibration with as few as 12 sample points, although it generally is more difficult to obtain a good calibration with just 12 sample points. Also, the maximum number of calibration points is 18.

*Figure 5-2: Accelerometer Calibration Starting Orientations*

## 5.2.2    Mag-and-Accel Calibration

The TRAX allows for a simultaneous magnetometer and accelerometer calibration. This requires a good calibration pattern, stable measurements (not handheld), and installation in the user's system such that the appropriate local magnetic environment is present. PNI recommends 18 to 32 calibration points for a Mag-and-Accel Calibration. The Accel-Only Calibration pattern discussed in Section 5.2.1 also will work for a Mag-and-Accel Calibration. Optimal performance is obtained when all rotations of the cube are performed towards magnetic north to achieve the widest possible magnetic field distribution.

Note that combining calibrations only makes sense if all the host system's magnetic distortions (steel structures or batteries, for instance) are present and fixed relative to the module when calibrating. If the Accel-Only Calibration is performed, the user's system distortions are not relevant, which allows the TRAX to be removed from the host system in order to perform the Accel-Only Calibration.

*Note:  Mag-and-Accel Calibration is not available through the Trax Studio*

# 6　Operation with TRAX Studio

The TRAX Studio program puts an easy-to-use, graphical-user interface (GUI) onto the binary command language used by the TRAX. TRAX Studio is intended for evaluating, demonstrating, and calibrating the TRAX. Among other features, the program can log and save the outputs from the TRAX to a file for off-line evaluation. Anything that can be done using TRAX Studio also can be done using PNI's binary protocol, as discussed in Section 7.

*NOTE: TRAX Studio works with the TRAX module configured to Big Endian. This is the default setting, but if the module was set to Little Endian, reset to Big Endian per section 7.4.2*

## 6.1　Installation

TRAX Studio is provided as an executable program which can be downloaded from PNI's website. It will work with Windows XP, Windows Vista, and Windows 7 operating systems. Check the PNI web page at www.pnicorp.com for the latest version.

Copy the "TRAXStudio.msi" file onto your computer. Double-click on the icon and step through the Setup Wizard. The program will be installed into the following directory unless you direct it otherwise: Program Files\PNI Sensor Corporation\TRAX Studio\. A "TRAX Studio" shortcut icon will be placed on your computer's desktop.

Now plug the TRAX into the USB or RS232 port of your computer. **Ensure the TRAX is completely still when plugging it into the USB port, as the gyros initialize during the first five seconds after being plugged in.**

If you are using the Windows XP operating system, then the first time you plug in the TRAX device it will launch the Found New Hardware Wizard. Select a "Yes…" button, then click on <Next> and proceed with the installation. The computer should find the required virtual communications port (VCP) driver by searching the internet, which may take a minute or two. If you are using Windows 7 the computer automatically searches for and installs the driver. If there is a problem with this, download the driver from FTDI's website at http://www.ftdichip.com/Drivers/VCP.htm.

You have now completed the installation of TRAX Studio.

## 6.2　TRAX Studio Header and Connecting to TRAX Studio

If the TRAX is not already plugged into the computer, then do so. Note that the module must be motionless when being plugged in and for 5 seconds afterwards, as this is when the gyros initialize.

Double-click on the TRAX Studio icon to launch TRAX Studio. Below is a picture of the TRAX Studio header. The header includes "Module Information" and "Connection Settings", and under the header are the various TRAX Studio tabs, which are discussed in the subsequent sections. The header is the same regardless of which tab is selected.
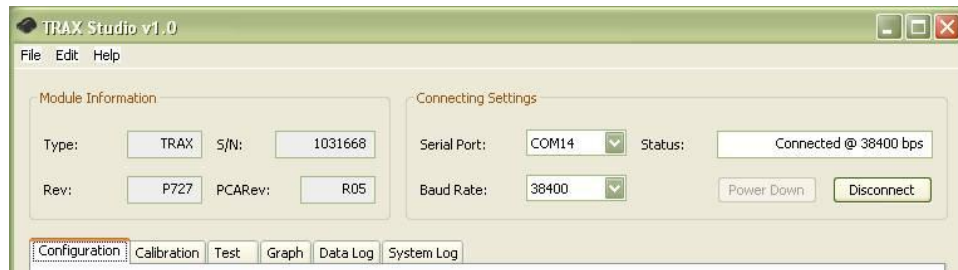


To connect, set the "Serial" field to the appropriate COM port. To determine this, in Windows right click on "My Computer", select "Manage", then select "Device Manager". Expand "Ports" and note the port for "USB Serial Port". This should be the assigned COM port for the TRAX.

Set the baud rate. The default is 38400, and this should be the setting the first time the TRAX is used. Once a connection has been established, the desired baud rate can be changed on the Configuration Tab, as discussed in Section 6.4.1.

Click the <Connect> button. When the connection is established, the light to the left of "Status" will turn green, "Status" will change to "Connected @ [the baud rate]", the <Connect> button will now say <Disconnect>, the <Power Down> button will be live, and the "Device Information" section of the header will populate.

## 6.3  TRAX Studio Footer and Saving/Applying Settings

Below is a picture of the TRAX Studio footer. The footer includes 4 buttons which are discussed below. The footer is the same regardless of which tab is selected. Note that if a field is changed on any of the TRAX Studio tabs, then either <Apply> or <Save> must be selected for the change to take effect.

**Save**

Clicking the <Save> button will save any changes made in TRAX Studio to the TRAX's onboard non-volatile and volatile memory.

**Apply**

Selecting the <Apply> button will apply any changes to the TRAX's volatile memory, but not to the non-volatile memory. If the TRAX is powered off/on, the settings will revert to whatever was last saved in the non-volatile memory.

**Read**

Clicking the <Read> button will read the current settings in the TRAX's volatile memory and display them. This will change any item in bold, which indicates a setting was changed in TRAX Studio but not applied to the TRAX's volatile memory, back to regular type and the setting change will not be applied to the TRAX's memory.

**Default**

Selecting the <Default> button will display the default settings, which are stored in TRAX Studio. Selecting this button will not automatically apply these values, and either <Apply> or <Save> must be selected for the read values to be applied.

## 6.4   Configuration Tab

The Configuration Tab is shown below and its contents discussed in the following subsections. For any changes to take effect, the <Save> button must be selected. Clicking on the <Default> button will load the factory default values, although these must be saved to take effect. Clicking the <Retrieve> button will show the current settings of the device.

## 6.4.1    General Settings

### Baud Rate

The baud rate can be altered by selecting the desired baud rate from the pull down menu, clicking on "Save", and then powering the device off and back on.  The new baud rate will not take effect until the device has been powered off/on.  The default baud rate is 38400.

### Mounting

TRAX Studio supports 16 mounting orientations, as previously illustrated in Figure 4-2.  The default is "Standard".

### Output Units

The TRAX can output heading, pitch, and roll in either degrees or mils.  The default is "Degrees".  (There are 6400 mils in a circle, such that 1 degree = 17.7778 mils and 1 mil = 0.05625 degree.)

### North Reference

When "Magnetic" is selected, the heading output will be relative to magnetic north.  When "True" is selected, heading will be relative to true north, and the declination value should be entered in the next field.  The default is "Magnetic".

### Declination

The declination represents the heading difference between magnetic north and true north, and needs to be entered if "True" is selected as the "North Reference". Declination varies primarily with location, although it also gradually changes over time (years) for a given location. To find the declination for where the TRAX will be used, go to `http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp`.

### Filter Taps

When operating the TRAX in Compass Mode, the TRAX will use a finite impulse response (FIR) filter to effectively provide a stable heading reading. When operating in AHRS Mode a completely different filtering method is used and the number of FIR Taps is not relevant.

The number of taps (or samples) represents the amount of filtering to be performed. Either 0, 4, 8, 16, or 32 taps may be selected, with zero taps representing no filtering. Note that selecting a larger number of taps can significantly slow the time for the initial sample reading and, if "Flush Filters" is selected, the rate at which data is output. The default setting is 32.

The FIR filtering operates on a first-in, first-out (FIFO) basis. For example, with FIR Taps set to 32, once the initial 32 samples are taken the next sample (#33) is included in the filtering and the initial sample (#1) is dropped from the filtering.

### Flush Filter

The Flush Filter setting is only relevant when in Compass Mode, as it affects how the FIR filters are implemented. Flushing the FIR filter clears all the filter values so it is necessary to fully repopulate the filter before a good reading can be given. For example, if 32 FIR taps is set, then 32 new samples must be taken to provide a good reading. It is particularly prudent to flush the filter if the Sampling Delay is set to a non-zero value as this will purge old data. Note that flushing the filters increases the delay until data is output, with the length of the delay being directly correlated to the number of FIR taps. The default is not to Flush Filters.

## 6.4.2    Acquisition Settings

### Acquisition Mode

When operating in Continuous Acquisition Mode, the TRAX continuously outputs data to the host system. The rate is set by the Sample Delay. When operating in Polled Mode, TRAX Studio simulates a host system and polls the TRAX for a single measurement; but TRAX Studio makes this request at a fixed rate which is set by the Polling Delay. In both cases data is continuously output, but in Continuous

Acquisition Mode the TRAX controls the data rate while in Polled Mode the TRAX Studio program controls the data rate. Polled Mode is the default.

## Sample Delay

The Sample Delay is relevant when Continuous Mode is selected. It is the time delay, in seconds, between completion of TRAX sending one set of data and the start of sending the next sample set. If the delay is set to 0, then TRAX will begin sending new data as soon as the previous data set has been sent. Note that the inverse of the Sample Delay is greater than the sample rate, since the Sample Delay does not include the actual measurement acquisition time. The default is 0.

## Polling Delay

The Polling Delay is relevant when Polled Mode is selected. It represents the time delay, in seconds, between the completion of TRAX Studio receiving one set of sampled data and requesting the next sample set. If the delay is set to 0, then TRAX Studio requests new data as soon as the previous request is fulfilled. Note that the inverse of the Polling Delay is greater than the sample rate, since the Polling Delay does not include the actual measurement acquisition time. The default is 0.

# 6.5   Calibration and the Calibration Tab

As discussed in Section 5, a user calibration should be performed to optimize TRAX performance. The Calibration Tab is shown below, and following this are discussions of how to set the calibration settings, how to perform a calibration, and how to interpret the results.

## 6.5.1    Calibration Settings

### Calibration Type

The "Calibration Type" pull down menu establishes the type of calibration to be performed.    The options are Full, 2D, Hard-Iron-Only, Limited-Tilt, and Accelerometer.  These are briefly discussed below and in more detail in Section 5.

**Full Range** – recommended calibration method when ≥45° of tilt is possible.

**2D** – recommended when the available tilt range is limited to ≤5°.

**Hard Iron Only** – serves as a hard-iron recalibration to a prior calibration.  If the hard-iron distortion around the device changes, this procedure can bring the device back into specification more quickly than other methods.

**Limited Tilt Range** – recommended calibration method when >5° of tilt calibration is available, but tilt is restricted to <45°.  (i.e. full range calibration is not possible.)

**Accelerometer** – The user should select this when accelerometer calibration will be performed.  Accelerometer calibration is recommended every 6 to 12 months to compensate for bias drift in the accelerometer. The TRAX can also be returned to PNI for accelerometer calibration.

### Number of Points

This establishes how many samples will be taken during the calibration.  The minimum and recommended number of samples depends on the calibration method, and is summarized in The following subsections provide instructions for performing a magnetic calibration of a TRAX system.  Several calibration mode options exist, as summarized in Table 5-1.  To meet the accuracy specification, the number of samples should be the "Minimum Recommended" value, or greater.  Calibration may be performed using TRAX Studio or using the PNI binary protocol, and up to 8 sets of magnetic calibration coefficients may be saved.   The recommended calibration patterns described in the following sub-sections provide a good distribution of sample points.  Also, PNI recommends the location of the TRAX remain fairly constant while only the orientation is changed.

Table 5-1.  The maximum number of samples is 18.

### Mag Coefficient Set & Accel Coefficient Set

At any one time, the TRAX will use one set of magnetic calibration coefficients and one set of accelerometer calibration coefficients.   The magnetic coefficients compensate for measured magnetic distortions in the host system as determined during a magnetic calibration.  The accelerometer coefficients compensate for bias and offset of the accelerometers, as determined during an accelerometer calibration.

However, the TRAX can store eight (8) sets of magnetic calibration coefficients and eight (8) sets of accelerometer calibration coefficients. This feature is useful if the compass will be placed in multiple locations that have different local magnetic field properties. The default is index number 0 and initially this is populated at PNI with factory-generated coefficients for the device itself. The other sets initially are unpopulated.

To store a coefficient set, first select the index number (0 to 7), then perform a calibration. The coefficient values will be stored in the defined index number, assuming the <Save> is selected after the calibration. To recall and use a different set of coefficients, change the "Mag Coefficient Set" and/or "Accel Coefficient Set" number, then click the <Save> button.

### Automatic Sampling

If selected, the TRAX will take a sample point once predefined minimum change and stability requirements have been satisfied. If the user wants to have more control over when the point will be taken then Auto Sampling should be deselected.

### H/P/R Output During Cal

When selected, the heading, pitch, and roll of the device will be output below the sample number during a calibration. Using this feature, the user can monitor the device's orientation to easily follow the appropriate recommended calibration pattern. Since a calibration is being performed, these values are relative and should not be considered accurate.

### Audible Feedback

If selected, TRAX Studio will give an audible signal when a calibration sample is taken.

## 6.5.2 Performing a Calibration

Before proceeding, ensure you are familiar with the recommended calibration pattern corresponding to the "Type" selected. These are discussed in Section 5.

To perform a calibration, follow the following steps:

- Click the <Start> button to begin the calibration process.
- If "Automatic Sampling" is not checked the first sample will be taken automatically assuming the TRAX is relatively stationary. After this, it is necessary to click the <Take Sample> button to take a calibration sample point. This should be repeated until the total number of samples is taken, changing the orientation of the device between samples as discussed in Section 0.

- If "Automatic Sampling" is checked the TRAX needs to be held steady for a short time and then a sample automatically will be taken. Once the window indicates the next number, the device's orientation should be changed and held steady for the next sample. Once the pre-set number of samples has been taken (as set on the Configuration tab) the calibration is complete.

Regardless of whether "Automatic Sampling" is selected, two criteria must be met for a calibration sample to be taken. First, the TRAX must be held steady enough to meet PNI-defined stability criteria. Second, the TRAX's orientation must have changed enough to meet PNI-defined orientation change criteria.

If "H/P/R Output During Cal" is selected, then the "Heading", "Pitch", and "Roll" fields will be populated in real-time once the <Start> button is selected. Note that the readings in these fields are relative, since calibration is in process.

## 6.5.3    Calibration Results

Once the calibration is complete the "Calibration Results" section will indicate the quality of the calibration. This may take a few seconds to populate. The primary score of concern is the MagCalScore or AccelCalScore, depending on whether a magnetic or accelerometer calibration was performed. The other parameters provide information that may assist in improving the MagCalScore should it be unacceptably high. If a calibration is acceptable, then click the <Save> button to save the calibration coefficients to the coefficient set defined on the Configuration Tab.

*Note:  If a calibration is aborted, all the score's will read "179.80", and the calibration coefficients will not be changed.  (Clicking the <Save> button will not change the calibration coefficients.)*

### Mag Cal

Represents the over-riding indicator of the quality of a magnetic calibration. Acceptable scores are <1 for Full-Range Calibration and <2 for other methods. Note that it is possible to obtain acceptable Distribution Error and Tilt Error scores and still have a rather high Mag Cal value. The most likely reason for this is the TRAX is close to a source of magnetic distortion that is not fixed with respect to the device.

### Accel Cal

Represents the quality of an Accelerometer Calibration. The score should be <1.

### Distribution Error

Indicates if the distribution of sample points is good, with an emphasis on the heading distribution. The score should be 0. Significant clumping or a lack of sample points

in a particular section can result in a poor score. Distribution is not calculated for an Accelerometer Calibration.

**Tilt Error**

Indicates if the TRAX experienced sufficient tilt during the calibration, taking into account the calibration method. The score should be 0. Tilt Error is not calculated for an Accelerometer Calibration.

**Tilt Range**

This reports the larger of either half the full pitch range or half the full roll range of all sample points. For example, if the TRAX is pitched +10° to -20°, and rolled +25° to -15°, the Tilt Range value would be 20°, as derived from [+25° - {-15°}]/2. For Full-Range Calibration and Hard-Iron-Only Calibration, this should be ≥45°. For 2D Calibration, this ideally would be ~2°. For Limited-Tilt Calibration the value should be as large as possible given the user's constraints. Tilt Range is not calculated for an Accelerometer Calibration.

**Mag Factory Reset & Accel Factory Reset**

Clicking the Mag Factory Reset and/or Accel Factory Reset will reset the calibration coefficients to those established at PNI. Note that the mag factory coefficients will not take into account magnetic influences inherent in the host system, which could result in very large heading errors. And the accel factory coefficients will not correct for accelerometer drift, which may become significant over an extended period (6 – 12 months, typically). If either of these Reset buttons are selected, it is necessary to click <Save> or <Apply> to have the factory coefficients take effect.

## 6.6    Test Tab

The Test Tab is used to demonstrate and evaluate the performance of the TRAX. The Heading, Pitch, and Roll are output during testing, as well as the Heading Status.

The **Heading Status** provides an indication of the accuracy of the heading. A green box represents a heading accuracy of <2°, a yellow box means the heading uncertainty is approximately 2° to 10°, and a red box means the uncertainty is >10°. These heading uncertainties assume the TRAX was properly calibrated in a clean magnetic environment.
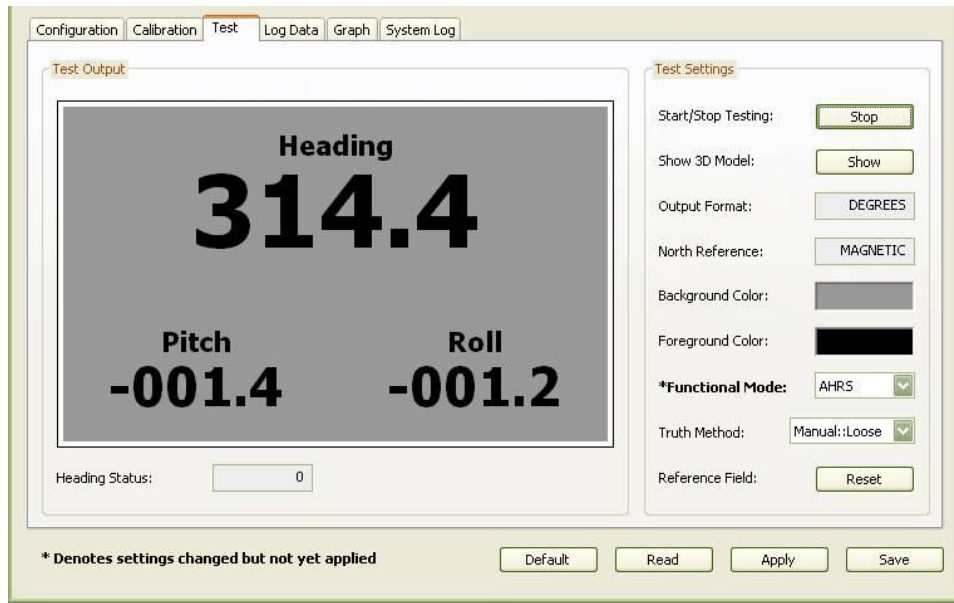
## Start/Stop Testing

Clicking the <Start> button results in the Heading, Pitch, and Roll values being updated on the Test Tab screen, as well as the Heading Status.

If the Acquisition Mode is set to "Continuous", then the data will be continuously updated. The button will change to read <Stop>, such that clicking it again will stop the screen from updating.

If the Acquisition Mode is set to "Single", then only one measurement will be displayed on the screen. The button will briefly gray out while the data is being output to the screen, then return to reading <Start>.

## Show 3D Model

Selecting the <Show> button launches the 3D Model window, as shown below.



Clicking the <Start> button begins continuous updating of the orientation of the rendered model, and of the heading, pitch, and roll output fields. The <Start> button on the Test Tab screen and on the 3D Model screen are linked such that selecting either of them will stop or start both screens.

Clicking on <Fullscreen> will expand the window to the full computer screen, and the button will now read <Windowed>. Clicking <Windowed> will shrink the window back down.

## Output Format & North Reference

The "Output Format" and "North Reference" fields mimic the settings on the Configuration Tab. To change these, return to the Configuration Tab, make the change, then <Apply> or <Save> the change.

## Background & Foreground Color

The foreground and background colors of the screen can be changed by the user. Simply click on the color square and select the new desired color. The change in color automatically is saved. The default is black lettering on a grey background.

## Functional Mode

The TRAX can operate either in AHRS Mode or Compass Mode. While the TRAX is intended to be used as an AHRS, there are times when it is necessary or beneficial

to place it in Compass Mode. Specifically, it is necessary to calibrate the TRAX in Compass Mode. (This is handled automatically in TRAX Studio, so it is not necessary for the user to place the TRAX in Compass Mode when doing a calibration in TRAX Studio.) Also, it may be beneficial to operate in Compass Mode to conserve battery life, since in Compass Mode the TRAX turns off the gyros, generally uses less CPU power, and can be placed in Sleep Mode to significantly reduce current consumption.

## Truth Method

This field allows the user to have control over the breadth of criteria used to establish if the local magnetic field conforms to the reference magnetic field criteria. "Auto" is the default.

## Reference Field Reset

Clicking the Reference Field <Reset> button re-establishes the criteria for a clean magnetic field. After clicking this button the Heading Status box will go green. Assuming an accurate heading reading is desired, this should be done only when the user is confident the local magnetic field is free from distortions. For the purpose of demonstrating the general capabilities of the TRAX a distortion-free local magnetic field may not be required, but the user should realize the heading reading likely will not meet the accuracy specification.

## 6.7    Log Data Tab

TRAX Studio can capture measurement data and then export it to a text file.
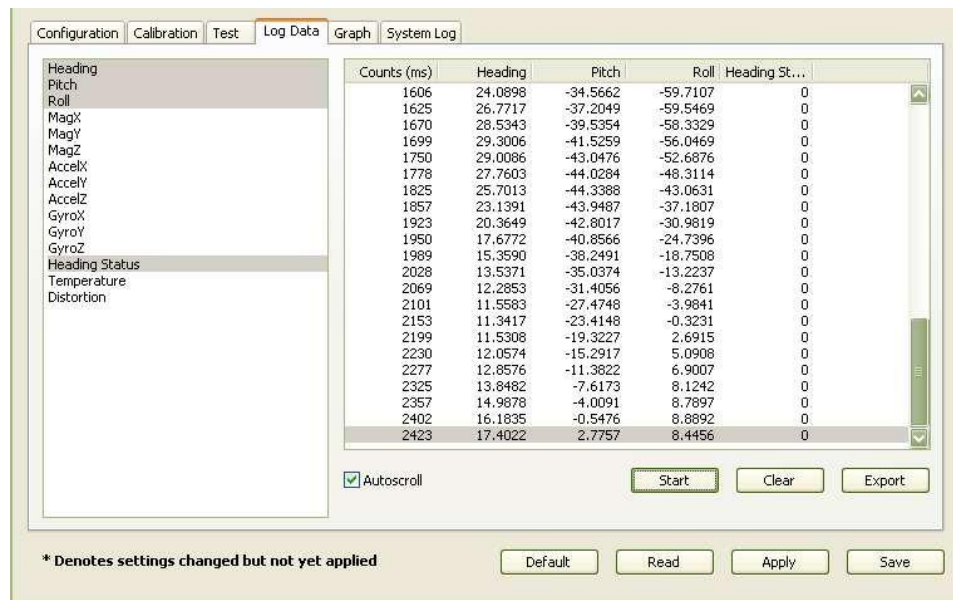
To acquire data and export it, follow the procedure below:

- Select the parameters you wish to log in the window on the left. Use Shift -Click and Ctrl-Click to select multiple items. In the screen shot above, "Heading", "Pitch", "Roll", and "Heading Status" were selected. Note that Heading Status can be 0, 1, or 2, corresponding to "green", "yellow", or "red".
- Click the <Start> button to start logging. The <Start> button changes to a <Stop> button after data logging begins.
- Click the <Stop> button to stop logging data.
- Click the <Export> button to save the data to a file.
- Click the <Clear> button to clear the data from the window.

Note that the "Distortion" log indicates if the magnetic field is >|±125 µT| for any of the magnetic sensors. It is only applicable in Compass Mode, and will always read "FALSE" in AHRS Mode.

## 6.8    Graph Tab

The Graph Tab provides a plot of the measured field strength on the x-axis and y-axis magnetic sensors.
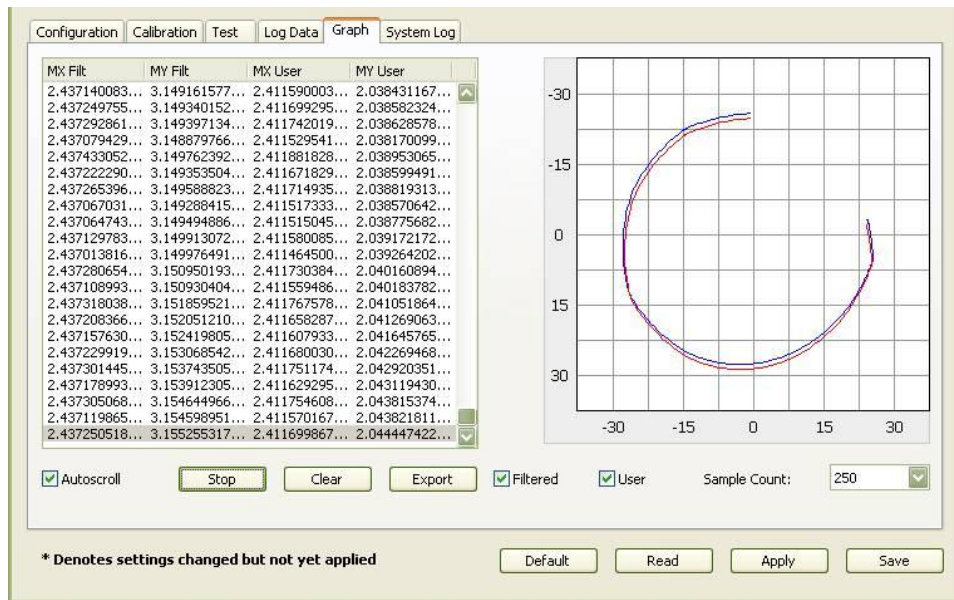


The "Filt" data and plot (blue) provides magnetic field strength measurements after the FIR filter taps are applied, but prior to applying the user calibration coefficients. The "User" data and plot (red) provides data after applying the user calibration coefficients. In AHRS Mode the data and plots are identical, while in Compass Mode there is an offset which represents

the effect of the calibration coefficients. The Graph Tab normally would be used in Compass Mode because of this. The graph can be used to visually see hard and soft-iron effects within the environment measured by the TRAX, as well as corrected output after a user calibration has been performed.

The data can be saved to a .txt log file by clicking <Export>. To clear the data, select <Clear>. To clear both the data and the plot, select <Apply>.

## 6.9    System Log Tab

The System Log tab shows all communication between TRAX Studio and TRAX. Closing TRAX Studio will erase the system log. Select the <Export> button, at the bottom right of the screen, to save the system log to a text file.
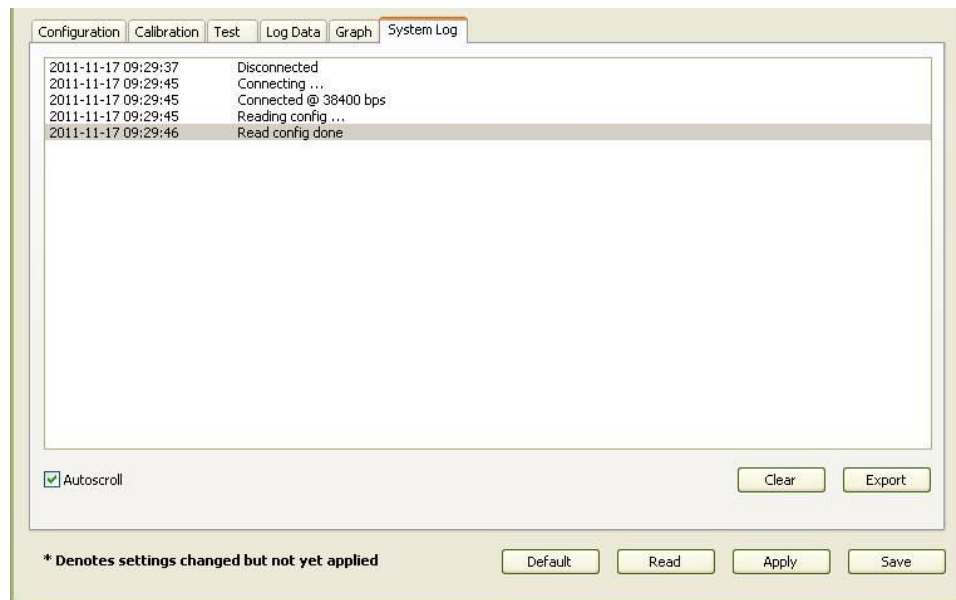
# 7    Operation with PNI Binary Protocol

The TRAX utilizes a binary communication protocol, where the communication parameters should be configured as follows:

**Table 7-1:  Port Configuration**

| Parameter | Value |
|---|---|
| Number of Data Bits | 8 |
| Start Bits | 1 |
| Stop Bits | 1 |
| Parity | none |

## 7.1    Datagram Structure

The data structure is shown below:
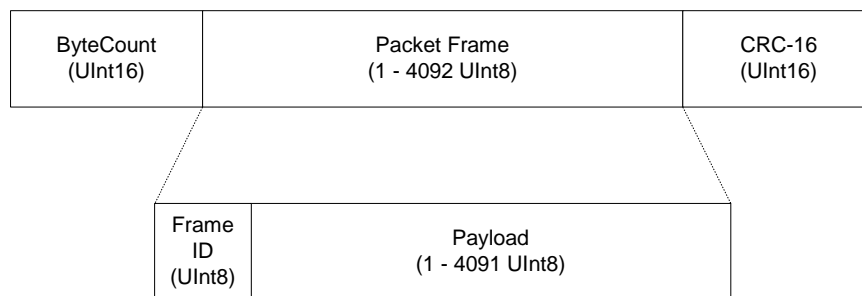


*Figure 7-1:  Datagram Structure*

The ByteCount is the total number of bytes in the packet including the CRC-16 (checksum). The CRC-16 is calculated starting from the ByteCount to the last byte of the Packet Frame. The ByteCount and CRC-16 are always transmitted in big Endian.  Two examples follow.

**Example:**  The complete packet for the kGetModInfo command, which has no payload is:

| 00  05 | 01 | EF  D4 |
|---|---|---|
| ByteCount | Frame ID | Checksum |

**Example:**  Below is a complete sample packet to start a 2D Calibration (kStartCal):

| 00  09 | 0A | 00  00 | 00 14 | 5C  F9 |
|---|---|---|---|---|
| ByteCount | Frame ID | CalOption (MSBs) | CalOption (2D Calibration) | Checksum |

## 7.2　Parameter Formats

### 7.2.1　Endianness

TRAX can treat 32-bit and 16-bit parameters as having big or little Endian formatting. For 32-bit parameters, the big Endian byte order is ABCD EFGH, while the little Endian byte order is DCBA HGFE. For 16-bit parameters the big Endian byte order is ABCD, while the little Endian byte order is DCBA. The Endianness is selectable by the user per Section 7.4.2. The default is big Endian, and this is generally assumed in the manual.

### 7.2.2　Floating Point

Floating-point parameters conform to ANSI/IEEE Std 754-1985. A hex-to-floating-point converter can be found at http://babbage.cs.qc.cuny.edu/IEEE-754.old/32bit.html. Note that for this converter, little Endian values must be manually converted to big Endian.

Please refer to the Standard for more information. PNI also recommends referencing the user's compiler instructions to understand how the compiler implements floating-point.

#### 64-Bit Floating Point (Float64)

Below is the 64-bit float format in big Endian. In little Endian the bytes are in reverse order in 4-byte groups (e.g. DCBA HGFE).

| 63 | 62 | 5251 | 0 |
|----|----|------|---|
| S | Exponent | | Mantissa |

The value (v) is determined as:

$$v = (-1)S * 2(Exponent-1023) * 1.Mantissa,\ if\ and\ only\ if\ 0 < Exponent < 2047$$

#### 32-Bit Floating Point (Float32)

Shown below is the 32-bit float format in big Endian. In little Endian, the 4 bytes are in reverse order (e.g. DCBA).

| 31 | 30 | 2322 | 0 |
|----|----|------|---|
| S | Exponent | | Mantissa |

The value (v) is determined as:

$$v = (-1)S * 2(Exponent-127) * 1.Mantissa,\ if\ and\ only\ if\ 0 < Exponent < 255$$

## 7.2.3 Signed Integer

For signed integers, the most significant bit (msb) represents the sign of the value, where 0=positive and 1=negative.  Signed integers are represents in 2's compliment.

### Signed 32-Bit Integer (SInt32)

SInt32-based parameters are signed 32-bit numbers (2's compliment).  Bit 31 represents the sign of the value, where 0=positive and 1=negative.

| 31 | 24 23 | 16 15 | 8 7 | 0 |
|---|---|---|---|---|
| msb | | | lsb | |

Big Endian

| 7 | 0 15 | 8 23 | 16 31 | 24 |
|---|---|---|---|---|
| lsb | | | msb | |
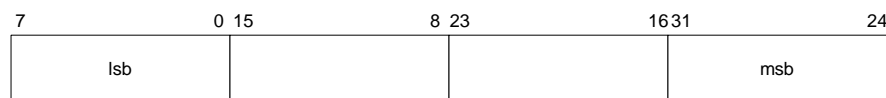
Little Endian

### Signed 16-Bit Integer (SInt16)

SInt16-based parameters are signed 16-bit numbers (2's compliment).  Bit 15 represents the sign of the value, where 0=positive and 1=negative.

| 15 | 8 7 | 0 |
|---|---|---|
| msb | lsb | |

Big Endian

| 7 | 0 15 | 8 |
|---|---|---|
| lsb | msb | |
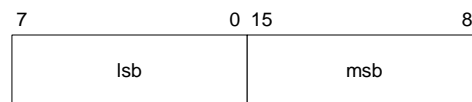
Little Endian

### Signed 8-Bit Integer (SInt8)

UInt8-based parameters are unsigned 8-bit numbers.  Bit 7 represents the sign of the value, where 0=positive and 1=negative.

| 7 | 0 |
|---|---|
| byte | |
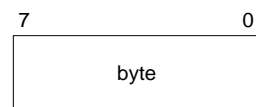
## 7.2.4    Unsigned Integer

### Unsigned 32-Bit Integer (UInt32)

UInt32-based parameters are unsigned 32-bit numbers.

| 31          | 24 23 | 16 15 | 8 7         | 0 |
|-------------|-------|-------|-------------|---|
| msb         |       |       | lsb         |   |

Big Endian

| 7           | 0 15  | 8 23  | 16 31       | 24 |
|-------------|-------|-------|-------------|----|
| lsb         |       |       | msb         |    |
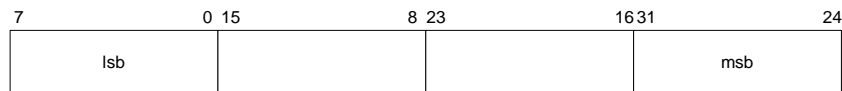
Little Endian

### Unsigned 16-Bit Integer (UInt16)

UInt16-based parameters are unsigned 16-bit numbers.

| 15    | 8 7   | 0 |
|-------|-------|---|
| msb   | lsb   |   |

| 7     | 0 15  | 8 |
|-------|-------|---|
| lsb   | msb   |   |
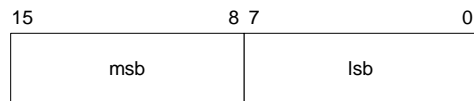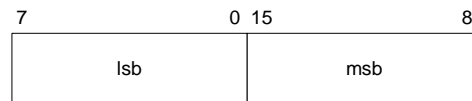
Big Endian                         Little Endian

### Unsigned 8-Bit Integer (UInt8)

UInt8-based parameters are unsigned 8-bit numbers.

| 7        | 0 |
|----------|---|
| byte     |   |
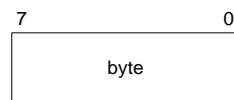
## 7.2.5    Boolean

Boolean is a 1-byte parameter that MUST have the value 0=FALSE or 1=TRUE.

| 7        | 0 |
|----------|---|
| byte     |   |
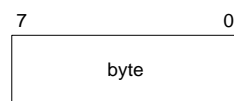
## 7.3 Commands Overview

Table 7-2 provides a summary of the basic commands available with the TRAX.

**Table 7-2: TRAX Command Set**

| Frame ID Dec | Hex | Command | Description |
|---|---|---|---|
| 1 | 0x01 | kGetModInfo | Queries the device's type and firmware revision. |
| 2 | 0x02 | kGetModInfoResp | Response to kGetModInfo |
| 3 | 0x03 | kSetDataComponents | Sets the data components to be output. |
| 4 | 0x04 | kGetData | Queries the TRAX for data |
| 5 | 0x05 | kGetDataResp | Response to kGetData |
| 6 | 0x06 | kSetConfig | Sets internal configurations in TRAX |
| 7 | 0x07 | kGetConfig | Queries TRAX for the current internal configuration |
| 8 | 0x08 | kGetConfigResp | Response to kGetConfig |
| 9 | 0x09 | kSave | Saves the current internal configuration and any new user calibration coefficients to non-volatile memory. |
| 10 | 0x0A | kStartCal | Commands the TRAX to start user calibration |
| 11 | 0x0B | kStopCal | Commands the TRAX to stop user calibration |
| 12 | 0x0C | kSetFIRFilters | Sets the FIR filter settings for the magnetometer & accelerometer sensors. |
| 13 | 0x0D | kGetFIRFilters | Queries for the FIR filter settings for the magnetometer & accelerometer sensors. |
| 14 | 0x0E | kGetFIRFiltersResp | Contains the FIR filter settings for the magnetometer & accelerometer sensors. |
| 15 | 0x0F | kPowerDown | Powers down the module |
| 16 | 0x10 | kSaveDone | Response to kSave |
| 17 | 0x11 | kUserCalSampleCount | Sent from the TRAX after taking a calibration sample point |
| 18 | 0x12 | kUserCalScore | Contains the calibration score |
| 19 | 0x13 | kSetConfigDone | Response to kSetConfig |
| 20 | 0x14 | kSetFIRFiltersDone | Response to kSetFIRFilters |
| 21 | 0x15 | kStartContinuousMode | Commands the TRAX to output data at a fixed interval |
| 22 | 0x16 | kStopContinuousMode | Stops data output when in Continuous Mode |
| 23 | 0x17 | kPowerUpDone | Confirms the TRAX has received a signal to power up |
| 24 | 0x18 | kSetAcqParams | Sets the sensor acquisition parameters |
| 25 | 0x19 | kGetAcqParams | Queries for the sensor acquisition parameters |
| 26 | 0x1A | kSetAcqParamsDone | Response to kSetAcqParams |
| 27 | 0x1B | kGetAcqParamsResp | Response to kGetAcqParams |
| 28 | 0x1C | kPowerDownDone | Response to kPowerDown |
| 29 | 0x1D | kFactoryMagCoeff | Resets magnetometer calibration coefficients to original factory-established values |
| 30 | 0x1E | kFactoryMagCoeffDone | Response to kFactoryMagCoeff |

| 31 | 0x1F | kTakeUserCalSample | Commands the TRAX to take a sample during user calibration |
|----|------|--------------------|----------------------------------------------------------|
| 36 | 0x24 | kFactoryIAccelCoeff | Resets accelerometer calibration coefficients to original factory-established values |
| 37 | 0x25 | kFactoryAccelCoeffDone | Respond to kFactoryAccelCoeff |
| 79 | 0x4F | kSetFunctionalMode | Puts TRAX in Compass Mode or AHRS Mode |
| 80 | 0x50 | kGetFunctionalMode | Queries for Compass Mode or AHRS Mode |
| 81 | 0x51 | kGetFunctionalModeResp | Response to kGetFunctionalMode |
| 110 | 0x6E | kSetResetRef | Establishes criteria for the reference magnetic field. |
| 119 | 0x77 | kSetMagTruthMethod | Sets if dip angle & radius establish mag truth (standard) or additional criteria (tight). |
| 120 | 0x78 | kGetMagTruthMethod | Queries for standard or tight truth method. |
| 121 | 0x79 | kGetMagTruthMethodResp | Response to kGetMagTruthMethod |

## 7.4 Set-Up Commands

### 7.4.1 Module Information

**kGetModInfo (frame ID 1$_d$, 0X01)**

This frame queries the device's type and firmware revision number.  The frame has no payload.

**kGetModInfoResp (frame ID 2$_d$, 0X02)**

The response to kGetModInfo is given below.  The payload contains the device type identifier followed by the firmware revision number.

Payload

| Type | Revision |
|------|----------|
| UInt32 | UInt32 |

Note that the Type and Revision can be decoded from the binary format to character format using the ASCII standard.  For example, the hex string "00 0D 02 54 52 41 58 31 32 30 38 C7 87" can be decoded to read "TRAX 1208".  A Hex-to-ASCII converter can be found at:  http://www.dolcevie.com/js/converter.html

### 7.4.2 Module Configuration

**kSetConfig (frame ID 6$_d$, 0X06)**

This frame sets internal configurations in the TRAX.  The first byte of the payload is the configuration ID followed by a format-specific value.  These configurations can

only be set one at time.  To save these in non-volatile memory, the kSave command must be issued.

Payload

| Config ID | Value |
|-----------|-------|
| UInt8 | ID Specific |

**Example**:  To configure the declination, the payload would look like:

Payload

| 1 | 10.0 |
|---|------|
| Declination ID | Declination Angle (Float32) |

**Table 7-3:  Configuration Identifiers**

| Settings | Config. ID$_d$ | Format | Values / Range | Default |
|----------|---------------|--------|----------------|---------|
| kDeclination | 1 | Float32 | -180˚ to +180˚ | 0 |
| kTrueNorth | 2 | Boolean | True or False | False |
| kBigEndian | 6 | Boolean | True or False | True |
| kMountingRef | 10 | UInt8 | 1 = STD 0°<br>2 = X UP 0°<br>3 = Y UP 0°<br>4 = STD 90°<br>5 = STD 180°<br>6 = STD 270°<br>7 = Z DOWN 0°<br>8 = X UP 90°<br>9 = X UP 180°<br>10 = X UP 270°<br>11 = Y UP 90°<br>12 = Y UP 180°<br>13 = Y UP 270°<br>14 = Z DOWN 90°<br>15 = Z DOWN 180°<br>16 = Z DOWN 270° | 1 |
| kUserCalNumPoints | 12 | UInt32 | 4 – 18 | 12 |
| kUserCalAutoSampling | 13 | Boolean | True or False | True |

| | | | 4 – 2400<br>5 – 3600<br>6 – 4800<br>7 – 7200<br>8 – 9600 | |
|---|---|---|---|---|
| kBaudRate | 14 | UInt8 | 9 – 14400<br>10 – 19200<br>11 – 28800<br>12 – 38400<br>13 – 57600<br>14 - 115200 | 12 |
| kMilOut | 15 | Boolean | True or False | False |
| kHPRDuringCal | 16 | Boolean | True or False | True |
| kMagCoeffSet | 18 | UInt32 | 0 - 7 | 0 |
| kAccelCoeffSet | 19 | UInt32 | 0 - 7 | 0 |

Configuration parameters and settings for kSetConfig:

### kDeclination (Config. ID 1$_d$)

This sets the declination angle to determine True North heading. Positive declination is easterly declination and negative is westerly declination. This is not applied unless kTrueNorth is set to TRUE.

### kTrueNorth (Config. ID 2$_d$)

Flag to set compass heading output to true north heading by adding the declination angle to the magnetic north heading.

### kBigEndian (Config. ID 6$_d$)

Sets the Endianness of packets. TRUE is Big Endian. FALSE is Little Endian.

*Note: TRAX Studio requires Big Endian. Return the module to Big Endian if Little Endian has been set if it will be used with TRAX Studio.*

### kMountingRef (Config. ID 10$_d$)

This sets the reference orientation for the TRAX. Please refer to Figure 4-2 for additional information.

### kUserCalNumPoints (Config. ID 12$_d$)

The user must select the number of points to take during a calibration. Table 7-4 provides the "Minimum Recommended" number of sample points, as well as the full "Allowable Range". The "Minimum Recommended" number of samples normally is sufficient to meet the TRAX's heading accuracy specification, while less than this may make it difficult to meet specification. See Section 5 for additional information.

**Table 7-4: Sample Points**

| Calibration Mode | Number of Samples | |
| --- | --- | --- |
| | Allowable Range | Minimum Recommended |
| Full-Range | 10 to 18 | 12 |
| Limited-Tilt | 10 to 18 | 12 |
| 2D Calibration | 10 to 18 | 12 |
| Hard-Iron-Only | 4 to 18 | 6 |
| Accelerometer-Only | 12 to 32 | 18 |
| Mag-and-Accel | 12 to 32 | 18 |

### kUserCalAutoSampling (Config. ID 13$_d$)

This flag is used during user calibration. If set to TRUE, the TRAX automatically takes calibration sample points once the minimum change and stability requirements are met. If set to FALSE, the device waits for kTakeUserCalSample to take a sample with the condition that a magnetic field vector component delta is greater than 5 µT from the last sample point. If the user wants to have maximum control over when the calibration sample point are taken then this flag should be set to FALSE.

### kBaudRate (Config. ID 14$_d$)

Baud rate index value. A power-down, power-up cycle is required when changing the baud rate.

### kMilOut (Config. ID 15$_d$)

Sets the output units as mils (TRUE) or degrees (FALSE). The default is FALSE.

### kHPRDuringCal (Config. ID 16$_d$)

This flag sets whether or not heading, pitch, and roll data are output simultaneously while the TRAX is being calibrated. The default is TRUE, such that heading, pitch, and roll are output during calibration. FALSE disables simultaneous output.

### kMagCoeffSet (Config. ID 18$_d$)

This command provides the flexibility to store up to eight (8) sets of magnetometer calibration coefficients in the TRAX. The default is set number 0. To store a set of coefficients, first establish the set number (number 0 to 7) using kMagCoeffSet, then perform the magnetometer calibration. The coefficient values will be stored in the defined set number. This feature is useful if the compass will be placed in multiple locations that have different local magnetic field properties.

### *kAccelCoeffSet (Config. ID 19$_d$)*

This command provides the flexibility to store up to eight (8) sets of accelerometer calibration coefficients in the TRAX. The default is set number 0. To store a set of coefficients, first establish the set number (number 0 to 7) using kAccelCoeffSet, then perform the accelerometer calibration. The coefficient values will be stored in the defined set number.

## kSetConfigDone (frame ID 19$_d$, 0X13)

This frame is the response to kSetConfig frame. The frame has no payload.

## kGetConfig (frame ID 7$_d$, 0X07)

This frame queries the TRAX for the current internal configuration value. The payload contains the configuration ID requested.

Payload

| Config ID |
|:---:|

UInt8
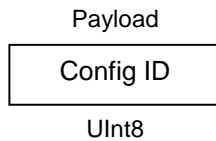
## kGetConfigResp (frame ID 8$_d$, 0X08)

The response to kGetConfig is given below. The payload contains the configuration ID and value.

Payload

| Config ID | Value |
|:---:|:---:|
| UInt8 | ID Specific |
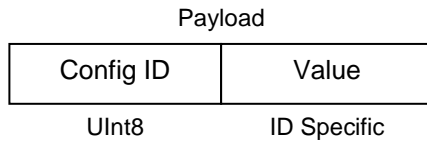
**Example:** If a request to get the set declination angle, the payload would look like:

Payload

| 1 | 10.0 |
|:---:|:---:|
| Declination ID | Declination Angle (Float32) |
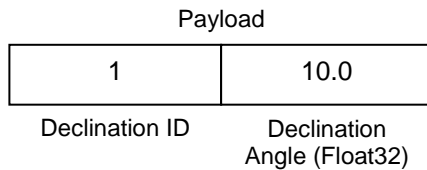
## kSetMagTruthMethod (frame ID 119$_d$, 0X77)

This frame allows the user to have control over the breadth of criteria used to establish if the local magnetic field conforms to the reference magnetic field criteria. The "AutoMerge" criteria is the default. The payload is defined below.

Payload

```
┌─────────────────────┐
│   MagTruthMethod    │
└─────────────────────┘
        UInt8
```

MagTruthMethod Payload Value:
"1": Standard
"2": Tight
"3": AutoMerge
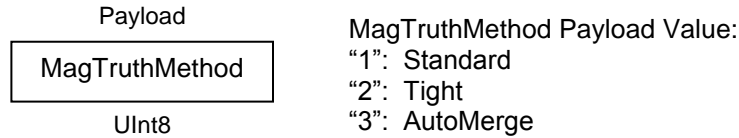
### kGetMagTruthMethod (frame ID 120$_d$, 0X78)

This frame queries the setting of the Mag Truth Method. It has no payload.

### kGetMagTruthMethodResp (frame ID 121$_d$, 0X79)

This frame is the response of kGetMagTruthMethod and the payload is the same as for kSetMagTruthMethod.

## 7.4.3    Saving Settings

### kSave (frame ID 9$_d$, 0X09)

This frame commands the TRAX to save internal configurations and user calibration to non-volatile memory. Internal configurations and user calibration are restored on power up. The frame has no payload. This is the ONLY command that causes the device to save information to non-volatile memory.

### kSaveDone (frame ID 16 $_d$, 0X10)

This frame is the response to kSave frame. The payload contains a UInt16 error code: 0 indicates no error; 1 indicates an error when attempting to save data to memory.

Payload

```
┌─────────────────────┐
│     Error Code      │
└─────────────────────┘
        UInt16
```
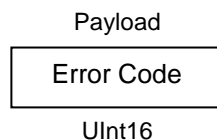
# 7.5  Measurement Commands

## 7.5.1    Setting the Reference Magnetic Field Criteria

Prior to operating the TRAX in AHRS mode it is necessary to establish the criteria for a known distortion-free local field. This should be done with the TRAX installed in the host system, as the distortion presented by the host system is constant and will be compensated for by the TRAX algorithms.

### kSetResetRef (frame ID 110<sub>d</sub>)

**kSetResetRef (frame ID 110$_d$)**

This frame re-aligns the TRAX 9-axis heading to the 6-axis (mag and accel) heading and establishes the criteria for the reference magnetic field. The frame should be sent when the user is confident the local magnetic field is not distorted. It has no payload.

## 7.5.2    Data Acquisition Parameters

**kSetAcqParams (frame ID 24 $_d$)**

This frame sets the sensor acquisition parameters in the TRAX. The payload should contain the following:

Payload

| AcquisitionMode | FlushFilter | PNIReserved | SampleDelay |
|---|---|---|---|
| UInt8 | UInt8 | Float32 | Float32 |

***AcquisitionMode:***
> This flag sets whether output will be presented in Continuous or Polled Acquisition Mode. Poll Mode is TRUE and should be selected when the host system will poll the TRAX for each data set. Continuous Mode is FALSE and should be selected if the user will have the TRAX output data to the host system at a relatively fixed rate. Poll Mode is the default.

***FlushFilter:***
> This is only relevant in Compass Mode. Setting this flag to TRUE results in the FIR filter being flushed (cleared) after every measurement. The default is FALSE.
>
> Flushing the filter clears all tap values, thus purging old data. This can be useful if a significant change in heading has occurred since the last reading, as the old heading data would be in the filter. Once the taps are cleared, it is necessary to fully repopulate the filter before data is output. For example, if 32 FIR taps is set, 32 new samples must be taken before a reading will be output. The length of the delay before outputting data is directly correlated to the number of FIR taps.

***PNIReserved:***
> These 4 bytes serve no function. PNI recommends populating the bytes with 0.

***SampleDelay:***
> The SampleDelay is relevant when the Continuous Acquisition Mode is selected. It is the time delay, in seconds, between completion of TRAX sending one set of data and the start of sending the next data set. The default is 0 seconds, which means TRAX will send new data as soon as the previous data set has been sent.

Note that the inverse of the SampleDelay is somewhat greater than the actual sample rate, since the SampleDelay does not include actual acquisition time.

### kSetAcqParamsDone (frame ID 26 d)

This frame is the response to kSetAcqParams frame. The frame has no payload.

### kGetAcqParams (frame ID 25 d)

This frame queries the unit for acquisition parameters. The frame has no payload.

### kGetAcqParamsResp (frame ID 27 d)

This frame is the response to kGetAcqParams frame. The payload should contain the same payload as the kSetAcqParams frame.

## 7.5.3    Data Components

### kSetDataComponents (frame ID 3d)

This frame defines what data is output when kGetData is sent. Table 7-5 summarizes the various data components and more detail follows this table. Note that this is not a query for the device's model type and software revision (see kGetModInfo). The first byte of the payload indicates the number of data components followed by the data component IDs. Note that the sequence of the data components defined by kSetDataComponents will match the output sequence of kGetDataResp.

Payload

| ID Count | ID 1 | ID 2 | ID 3 | ………. |
|----------|------|------|------|-------|
| UInt8 | UInt8 | UInt8 | UInt8 | |
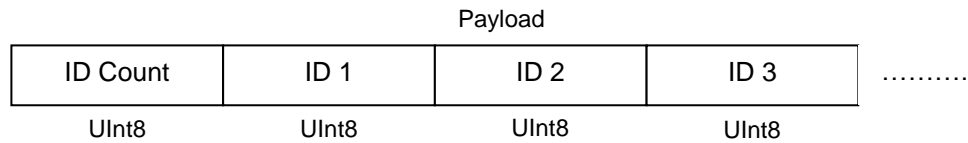
**Example:** To query for heading and heading status, the payload should contain:

Payload

| 02 | 05 | 18 |
|----|----|----|
| ID Count | Heading ID | Pitch ID |
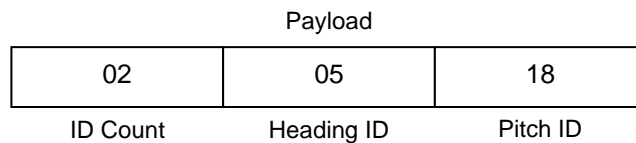
**Table 7-5:  Component Identifiers**

| Component | Component ID | | Format | Units |
|-----------|--------------|-----|--------|-------|
| | Decimal | Hex | | |
| kHeading | 5 | 0x05 | Float32 | degrees |
| kPitch | 24 | 0x18 | Float32 | degrees |
| kRoll | 25 | 0x19 | Float32 | degrees |
| kHeadingStatus | 79 | 0x4F | UInt8 | value |

| kQuaternion | 77 | 0x4D | 4x Float32 | quaternion |
|---|---|---|---|---|
| kTemperature | 7 | 0x07 | Float32 | ° Celsius |
| kDistortion | 8 | 0x08 | Boolean | True or False (Default) |
| kCalStatus | 9 | 0x09 | Boolean | True or False (Default) |
| kAccelX | 21 | 0x15 | Float32 | G |
| kAccelY | 22 | 0x16 | Float32 | G |
| kAccelZ | 23 | 0x17 | Float32 | G |
| kMagX | 27 | 0x1B | Float32 | $\mu$T |
| kMagY | 28 | 0x1C | Float32 | $\mu$T |
| kMagZ | 29 | 0x1D | Float32 | $\mu$T |
| kGyroX | 74 | 0x4A | Float32 | radians/sec |
| kGyroY | 75 | 0x4B | Float32 | radians/sec |
| kGyroZ | 76 | 0x4C | Float32 | radians/sec |

Component types are listed below. All are read-only values.

### kHeading, kPitch, kRoll (Component IDs $5_d$, $24_d$, $25_d$)

Provides compass heading, pitch and roll outputs. The heading range is 0.0° to +359.9°, the pitch range is -90.0° to +90.0°, and the roll range is to -180.0° to +180.0°.

### kHeadingStatus (Component IDs $79_d$)

The heading status provides an indication of the uncertainty of the heading. "1" represents a heading uncertainty of <2°, "2" means the heading uncertainty is approximately 2° to 10°, and "3" means the uncertainty is >10°.

### Quaternion (Component ID $77_d$)

The quaternion values generated by the TRAX algorithm are output in one data package that contains the four quaternions. The quaternions are output as Q0, Q1, Q2, and Q3, where Q3 is the scalar quaternion. When in AHRS Mode, heading, pitch, and roll are subsequently calculated from these quaternions.

### kTemperature (Component ID $7_d$)

This value is provided by the device's internal temperature sensor. Its value is in degrees Celsius and has an accuracy of ±3° C.

### kDistortion (Component ID $8_d$)

This flag indicates at least one magnetometer axis reading is beyond ±125 $\mu$T. It is only applicable in Compass Mode, and will always read "FALSE" in AHRS Mode.

### kCalStatus (Component ID $9_d$)

This flag indicates the user calibration status. False means it is not user calibrated and this is the default value.

### kAccelX, kAccelY & kAccelZ (Component IDs 21$_d$, 22$_d$, 23$_d$)

These values represent the accelerometer sensor data for the x, y, and z axis, respectively. The values are normalized to g (Earth's gravitational force).

### kMagX, kMagY & kMagZ (Component IDs 27$_d$, 28$_d$, 29$_d$)

These values represent the magnetic sensor data for the x, y, and z axis, respectively. The values are given in µT.

### kGyroX, kGyroY, kGyroZ (Component IDs 74$_d$, 75$_d$, 76$_d$)

These values represent the gyroscope sensor data for rotation around the x, y, and z axis, respectively. The values are in radians per second.

## 7.5.4    Making a Measurement

### kGetData (frame ID 4$_d$)

If the TRAX is configured to operate in Polled Acquisition Mode (see kSetAcqParams), then this frame requests a single measurement data set. The frame has no payload.

### kStartContinuousMode (frame ID 21 $_d$)

If the TRAX is configured to operate in Continuous Acquisition Mode (see kSetAcqParams), then this frame initiates the outputting of data at a relatively fixed data rate, where the data rate is established by the SampleDelay parameter. The frame has no payload.

### kStopContinuousMode (frame ID 22 $_d$)

This frame commands the TRAX to stop data output when in Continuous Acquisition Mode. The frame has no payload.

### kGetDataResp (frame ID 5$_d$)

The response to kGetData and kStartContinuousMode is kGetDataResp. The specific data fields that will be output (ID 1, Value ID 1, etc.) should have been previously established by the kSetDataComponents command frame.

Payload

| ID Count | ID 1 | Value ID 1 | ID 2 | Value ID 2 | ID 3 | Value ID 3 |
|----------|------|------------|------|------------|------|------------|
| UInt8 | UInt8 | ID Specific | UInt8 | ID Specific | UInt8 | ID Specific |

**Example:**    If heading and heading status are set to be output per the kSetDataComponents command, the payload would look like:

| Payload | | | | |
|---|---|---|---|---|
| 2 | 5 | 359.9 | 79 | 1 |
| ID Count | Heading ID | Heading (Float32) | Heading Status ID | Heading Status (UInt8) |

## 7.6   Calibration Commands

### 7.6.1   User Calibration Commands

First, note that in order to perform a user calibration, it is necessary to place the TRAX in Compass Mode, as discussed in Section 7.7.  Note that TRAX allows for a maximum of 12 calibration points.

### kStartCal (frame ID 10$_d$)

This frame commands the TRAX to start user calibration with the current sensor acquisition parameters, internal configurations and FIR filter settings.

| Payload |
|---|
| CalOption |

UInt32

CalOption Payload Value:
"10$_d$" or "0A$_h$":  Full-Range Calibration (default)
"20$_d$" or "14$_h$":  2D Calibration
"30$_d$" or "1E$_h$":  Hard-Iron-Only Calibration
"40$_d$" or "28$_h$":  Limited-Tilt Calibration
"100$_d$" or "64$_h$":  Accel-Only Calibration
"110$_d$" or "6E$_h$":  Mag-and-Accel Calibration

*Note:  The payload needs to be 32 bit (4 byte).  If no payload is entered or if less than 4 bytes are entered, the unit will default to the previous calibration method.*

The CalOption values are given below, along with basic descriptions of the options.

***Full-Range Calibration***
Recommended calibration method when >45° of tilt is possible.  Can be used for between 20° and 45° of tilt, but accuracy will not be as good

***2D Calibration***
Recommended when the available tilt range is limited to ≤5°.  Can be used for 5° to 10° of tilt, but accuracy will not be as good.

***Hard-Iron-Only Calibration***
Recalibrates the hard-iron offset for a prior calibration.  If the local field hard-iron distortion has changed, this calibration can bring the TRAX back into specification.

### Limited-Tilt Calibration

Recommended calibration method when >5° of tilt calibration is available, but tilt is restricted to <45°. (i.e. full range calibration is not possible.)

### Accel-Only Calibration

Select this when an accelerometer calibration will be performed.

### Accelerometer and Magnetic Calibration ($110_d = 6E_h$)

Selected when magnetic and accelerometer calibration will be done simultaneously.

Below is a complete sample packet to start a 2D Calibration (kStartCal):

| 00 09 | 0A | 00 00 | 00 14 | 5C F9 |
|---|---|---|---|---|
| ByteCount | Frame ID | CalOption (MSBs) | CalOption (2D Calibration) | Checksum |

Heading, pitch and roll information is output via the kGetDataResp frame during the calibration process. This feature provides guidance during the calibration regarding calibration sample point coverage. During calibration, in the kGetDataResp frame, the number of data components is set to be 3 and then followed by the data component ID-value pairs. The sequence of the component IDs are kHeading, kPitch and kRoll.

## kTakeUserCalSample (frame ID 31 $_d$)

This frame commands the TRAX to take a sample during user calibration. The frame has no payload.

## kUserCalSampleCount (frame ID 17 $_d$)

This frame is sent from the TRAX after taking a calibration sample point. The payload contains the sample count with the range of 1 to 18.

Payload

| SampleCount# |
|---|

UInt32
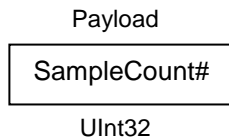
## kStopCal (frame ID 11$_d$)

This command aborts the calibration process. The prior calibration results are retained.

## 7.6.2    Performing a User calibration

The steps below provide an example of the steps to perform a user calibration.

- Using the kSetParam command, set the number of tap filters to 0.
- Using the kSetConfig command, set kUserCalAutoSampling.  "False" is generally recommended, but "True" may be more convenient.
- Using the kSetConfig command, set kMagCoeffSet (magnetometer calibration) and/or kAccelCoeffSet (accelerometer calibration).  These fields allow the user to save multiple sets of calibration coefficients.  "0" is the default.
- Using the kSetConfig command again, set kUserCalNumPoints to the appropriate number of calibration points.
- Initiate a calibration using the kStartCal command.  Note that this command requires indentifying the type of calibration procedure (i.e. Full-Range, 2D, etc.).
- Follow the appropriate calibration procedure, as discussed in Section 5.  If kUserCalAutoSampling was set to "False", then send a kTakeUserCalSample command when ready to take a calibration point.  If kUserCalAutoSampling was set to "True", then look for kUserCalSampCount to confirm when a calibration point has been taken.  During the calibration process, heading, pitch, and roll information will be output from the TRAX, and this can be monitored using kDataResp.
- When the final calibration point is taken, the device will present the calibration score using kUserCalScore.
- If the calibration is acceptable (see Section 7.6.2), save the calibration coefficients using kSave.

## 7.6.3    Calibration Score

**kUserCalScore (frame ID 18 d)**

The calibration score is automatically sent upon taking the final calibration point. The payload is defined below, and the various payload components are discussed after this.

Payload

| MagCalScore | Bytes 5-8 | AccelCalScore | DistributionError | TiltError | TiltRange |
|-------------|-----------|---------------|-------------------|-----------|-----------|
| Float32 | Float32 | Float32 | Float32 | Float32 | Float32 |

*MagCalScore:*
Represents the over-riding indicator of the quality of the magnetometer calibration.  Acceptable scores will be $\leq 1$ for full range calibration, $\leq 2$ for other

methods. Note that it is possible to get acceptable scores for DistributionError and TiltError and still have a rather high MagCalScore value. The most likely reason for this is the TRAX is close to a source of local magnetic distortion that is not fixed with respect to the device.

### Bytes 5-8:
Reserved for PNI use.

### AccelCalScore:
Represents the over-riding indicator of the quality of the accelerometer calibration. An acceptable score is ≤1.

### DistributionError:
Indicates if the distribution of sample points is good, with an emphasis on the heading distribution. The score should be 0. Significant clumping or a lack of sample points in a particular section can result in a poor score.

### TiltError:
Indicates if the TRAX experienced sufficient tilt during the calibration, taking into account the calibration method. The score should be 0.

### TiltRange:
This reports the larger of either half the full pitch range or half the full roll range of sample points. For example, if the device is pitched +10° to -20º, and rolled +25º to -15º, the TiltRange value would be 20º (as derived from [+25º - {-15º}]/2). For Full-Range Calibration and Hard-Iron-Only Calibration, this should be ≥45°. For 2D Calibration, ideally this should be ≈2°. For Limited-Tilt Calibration the value should be as large a possible given the user's constraints.

## 7.6.4    Factory Calibration

### kFactoryMagCoeff (frame ID 29 d)

This frame clears the magnetometer calibration coefficients and loads the original factory-generated coefficients. The frame has no payload. This frame must be followed by the kSave frame to save the change in non-volatile memory.

### kFactoryMagCoeffDone (frame ID 30 d)

This frame is the response to kFactoryMagCoeff frame. The frame has no payload.

### kFactoryAccelCoeff (frame ID 36 d)

This frame clears the accelerometer calibration coefficients and loads the original factory-generated coefficients. The frame has no payload. This frame must be followed by the kSave frame to save the change in non-volatile memory.

**kFactoryAccelCoeffDone (frame ID 37 d)**

This frame is the response to kFactoryAccelCoeff frame. The frame has no payload.

## 7.7 Compass Mode Commands

The TRAX normally operates in AHRS Mode, which uses a proprietary Kalman algorithm to fuse the inputs of its 3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer. However, the user can place the TRAX in Compass Mode, wherein it only uses the inputs from the accelerometer and magnetometer to establish heading, pitch, and roll. In this case the TRAX operates very similarly to PNI's TCM electronic compass.

There are a couple of reasons it may be desirable to place the TRAX in Compass Mode. As previously mentioned, it is necessary to place the TRAX in Compass Mode to perform a calibration. Additionally, if a static measurement is to be made in a known clean local magnetic field, then a somewhat higher level of accuracy is achievable in Compass Mode. Also, by placing the TRAX in Compass Mode it can subsequently be placed into Sleep Mode which will significantly reduce power consumption when not taking measurements.

### 7.7.1 Switching Functional Mode

**kSetFunctionalMode (frame ID 79 d)**

This frame establishes whether the TRAX operates in AHRS Mode or Compass Mode. The frame has a one byte payload. The payload byte is "0" to operate in Compass Mode and "1" to operate in AHRS Mode. The default is "1".

Payload

| FunctionalMode |
|---|

UInt8

FunctionalMode Payload Value:
"0": Compass Mode
"1": AHRS Mode (default)
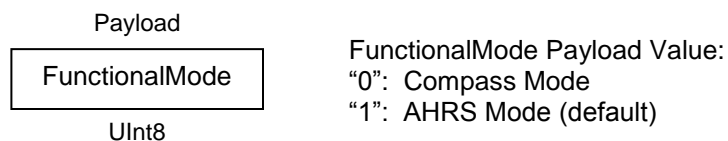
Sending the kSave command after changing the mode will save the new setting in non-volatile memory.

**kGetFunctionalMode (frame ID 80 d)**

This frame queries the TRAX functional mode. The frame has no payload.

**kGetFunctionalModeResp (frame ID 81 d)**

This is the response of kGetFunctionalMode, and it has the same payload definition as kSetFunctionalMode.

## 7.7.2　FIR Filters

When operating in Compass Mode, the TRAX incorporates a finite impulse response (FIR) filter to provide a more stable heading reading.  The number of taps (or samples) represents the amount of filtering to be performed.  The number of taps directly affects the time for the initial sample reading, as all the taps must be populated before data is output.  The FIR filter settings have no affect when operating in AHRS Mode.

The TRAX can be configured to clear, or flush, the filters after each measurement, as discussed in Section 7.5.2.  Flushing the filter clears all tap values, thus purging old data.  This can be useful if a significant change in heading has occurred since the last reading, as the old heading data would be in the filter.  Once the taps are cleared, it is necessary to fully repopulate the filter before data is output.  For example, if 32 FIR taps is set, 32 new samples must be taken before a reading will be output.  The length of the delay before outputting data is directly correlated to the number of FIR taps.

**kSetFIRFilters (frame ID 12$_d$)**

The payload for kSetFIRFilters is given below.

Payload

| Byte 1 | Byte 2 | Count N | Value 1 | Value 2 | Value 3 | Value N |
|--------|--------|---------|---------|---------|---------|---------|
| UInt8 | UInt8 | UInt8 | ID Specific | ID Specific | ID Specific | ID Specific |

Byte 1 should be set to 3 and Byte 2 should be set to 1.  The third payload byte indicates the number of FIR taps to use, which can be 0 (no filtering), 4, 8, 16, or 32.  This is followed by the tap values (0 to 32 total Values can be in the payload), with each Value being a Float64, and suggested values given in Table 7-6.

**Table 7-6:  Recommended FIR Filter Tap Values**

| Count | 4-Tap Filter | 8-Tap Filter | 16-Tap Filter | 32-Tap Filter |
|-------|-------------|-------------|---------------|---------------|
| 1 | 04.6708657655334e-2 | 01.9875512449729e-2 | 07.9724971069144e-3 | 01.4823725958818e-3 |
| 2 | 04.5329134234467e-1 | 06.4500864832660e-2 | 01.2710056429342e-2 | 02.0737124095482e-3 |
| 3 | 04.5329134234467e-1 | 01.6637325898141e-1 | 02.5971390034516e-2 | 03.2757326624196e-3 |
| 4 | 04.6708657655334e-2 | 02.4925036373620e-1 | 04.6451949792704e-2 | 05.3097803863757e-3 |
| 5 | | 02.4925036373620e-1 | 07.1024151197772e-2 | 08.3414139286254e-3 |
| 6 | | 01.6637325898141e-1 | 09.5354386848804e-2 | 01.2456836057785e-2 |
| 7 | | 06.4500864832660e-2 | 01.1484431942626e-1 | 01.7646051430536e-2 |
| 8 | | 01.9875512449729e-2 | 01.2567124916369e-1 | 02.3794805168613e-2 |
| 9 | | | 01.2567124916369e-1 | 03.0686505921968e-2 |

| 10 | | | 01.1484431942626e-1 | 03.8014333463472e-2 |
|---|---|---|---|---|
| 11 | | | 09.5354386848804e-2 | 04.5402682509802e-2 |
| 12 | | | 07.1024151197772e-2 | 05.2436112653103e-2 |
| 13 | | | 04.6451949792704e-2 | 05.8693165018301e-2 |
| 14 | | | 02.5971390034516e-2 | 06.3781858267530e-2 |
| 15 | | | 01.2710056429342e-2 | 06.7373451424187e-2 |
| 16 | | | 07.9724971069144e-3 | 06.9231186101853e-2 |
| 17 | | | | 06.9231186101853e-2 |
| 18 | | | | 06.7373451424187e-2 |
| 19 | | | | 06.3781858267530e-2 |
| 20 | | | | 05.8693165018301e-2 |
| 21 | | | | 05.2436112653103e-2 |
| 22 | | | | 04.5402682509802e-2 |
| 23 | | | | 03.8014333463472e-2 |
| 24 | | | | 03.0686505921968e-2 |
| 25 | | | | 02.3794805168613e-2 |
| 26 | | | | 01.7646051430536e-2 |
| 27 | | | | 01.2456836057785e-2 |
| 28 | | | | 08.3414139286254e-3 |
| 29 | | | | 05.3097803863757e-3 |
| 30 | | | | 03.2757326624196e-3 |
| 31 | | | | 02.0737124095482e-3 |
| 32 | | | | 01.4823725958818e-3 |

### kSetFIRFiltersDone (frame ID 20 $_d$)

This frame is the response to kSetFIRFilters.  The frame has no payload.

### kGetFIRFilters (frame ID 13$_d$)

This frame queries the FIR filter settings for the sensors.  Byte 1 should be set to 3 and Byte 2 should be set to 1.

Payload

| Byte 1 | Byte 2 |
|---|---|
| UInt8 | UInt8 |
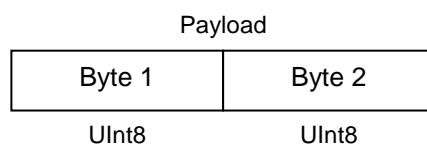
### kGetFIRFiltersResp (frame ID 14$_d$)

This is the response to kGetFIRFilters and it has the same payload definition as kSetFIRFilters.

## 7.7.3    Power Down/Up

For certain applications it is desirable to conserve battery power.  To maintain accurate heading readings in AHRS Mode generally requires continual sensor updates to the Kalman algorithm.  However, this is not the case in Compass Mode wherein readings may be taken only when heading information is desired.  Consequently, when in Compass Mode the TRAX may be powered down when heading data is not required.

### kPowerDown (frame ID 15$_d$)

This frame is used to power-down the module.  The frame has no payload.  The command will power down all peripherals including the sensors, microprocessor, and RS-232 driver.  However, the driver chip has a feature to keep the Rx line enabled.  The TRAX will power up when it receives any signal on the native UART Rx line.

### kPowerDownDone (frame ID 28$_d$)

This frame confirms the TRAX received a command to power down.  The frame has no payload.

### kPowerUpDone (frame ID 23$_d$)

This frame confirms the TRAX received a command to power up.  (The TRAX will power up when it receives any signal on the native UART Rx line.)  The frame has no payload.

## 7.8    Using Multiple Coefficient Sets

The ability to store and access multiple calibration coefficients sets the FieldForce TRAX apart from our Prime or legacy TCM. This section will detail the command list and provide two examples for utilizing this functionality.

# Table 7-7: Multiple Coefficient Command List

| **Magnetometer Calibration** | | | | | |
|---|---|---|---|---|---|
| **kSetConfig (frame ID)** | **kCoeffCopySet (config ID)** | **Value (UInt32)** | **Examples** | **Command Bytes** | **TRAX Response** |
| 0x06 | 0x12 | 0-7 | Set kCoeffCopySet to be copy 0 | 0x00 0x0A 0x06 0x12 0x00 0x00 0x00 0x00 0x3E 0x76 | 0x00 0x05 0x13 0xDD 0xA7 |
| | | | Set kCoeffCopySet to be copy 1 | 0x00 0x0A 0x06 0x12 0x00 0x00 0x00 0x01 0x2E 0x57 | 0x00 0x05 0x13 0xDD 0xA8 |
| | | | Set kCoeffCopySet to be copy 4 | 0x00 0x0A 0x06 0x12 0x00 0x00 0x00 0x04 0x7E 0xF2 | 0x00 0x05 0x13 0xDD 0xA9 |
| **kGetConfig (frame ID)** | **kCoeffCopySet (config ID)** | **Value (UInt32)** | **Examples** | **Command Bytes** | **TRAX Response** |
| 0x07 | 0x12 | | get kCoeffCopySet value which is currently used in TRAX | 0x00 0x06 0x07 0x12 0x19 0x44 | 0x00 0x0A 0x08 0x12 0x00 0x00 0x00 0x?? CRC1 CRC2 |
| **Accelerometer Calibration** | | | | | |
| **kSetConfig (frame ID)** | **AccelCoeffCopySet (config ID)** | **Value (UInt32)** | **Examples** | **Command Bytes** | **TRAX Response** |
| 0x06 | 0x13 | 0 - 2 | Set kAccelCoeffCopySet to be copy 0 | 0x00 0x0A 0x06 0x13 0x00 0x00 0x00 0x00 0x94 0x27 | 0x00 0x05 0x13 0xDD 0xA7 |
| | | | Set kAccelCoeffCopySet to be copy 1 | 0x00 0x0A 0x06 0x13 0x00 0x00 0x00 0x01 0x84 0x06 | 0x00 0x05 0x13 0xDD 0xA8 |
| | | | Set kAccelCoeffCopySet to be copy 2 | 0x00 0x0A 0x06 0x13 0x00 0x00 0x00 0x02 0xB4 0x65 | 0x00 0x05 0x13 0xDD 0xA9 |
| **kGetConfig (frame ID)** | **AccelCoeffCopySet (config ID)** | **Value (UInt32)** | **Examples** | **Command Bytes** | **TRAX Response** |
| 0x07 | 0x13 | | get kAccelCoeffCopySet value which is currently used in TRAX | 0x00 0x06 0x07 0x13 0x09 0x65 | 0x00 0x0A 0x08 0x13 0x00 0x00 0x00 0x?? CRC1 CRC2 |

## Examples

**Example 1:** Save Magnetic Calibration result to Coeff Copy Set 4.

Set the kCoeffCopySet to copy 4 by sending the following command.

0x00 0x0A 0x06 0x12 0x00 0x00 0x00 0x04 0x7E 0xF2

Get the kCoeffCopySet to verify by sending the following command. (Optional)

0x00 0x06 0x07 0x12 0x19 0x44

Send kSave command to save the kCoeffCopySet to flash so that it will be still available after power cycle. The kSave command is as following.

0x00 0x05 0x09 0x6E 0xDC

Start a user calibration, when completes, save calibration coeffs to TCM. The coeffs have been saved into coeff set copy 4.


**Example 2:** Use Magnetic Coeff Copy Set 1 in TCM. (The assumption is user has saved calibration coeffs to set 1 before)

Set the kCoeffCopySet to copy 1 by sending the following command.

0x00 0x0A 0x06 0x12 0x00 0x00 0x00 0x01 0x2E 0x57

Get the kCoeffCopySet to verify by sending the following command. (Optional)

0x00 0x06 0x07 0x12 0x19 0x44

Send kSave command to save the kCoeffCopySet to flash so that it will be still available after power cycle. The kSave command is as following.

0x00 0x05 0x09 0x6E 0xDC

# Revision Control Block

| Revision | Description of Change | Effective Date | Approval |
|----------|----------------------|----------------|----------|
| R06 | Added Revision Control Block. Changed PNI address. Eliminated "FieldForce" reference and capitalized TRAX throughout. Combined Table 3-1 and 3-2. Added Absolute Maximum Ratings and Communication Lines specs. Changed Supply Voltage spec. Added Figure 3-4, Molex-to-USB cable, and rename other cable drawings to be more descriptive. Removed "pigtail" reference except when it applies to Molex-to-pigtail cable. Modified Sections 5.1 and 5.2, including adding Accel and Mag Cal. Rearranged Table 7-2 to be in numerical order, and added hex numbers and added section links. Changed Table 7-4 and preceding paragraph. Renamed "field calibration" to "user calibration", kMagCoeffCopySet to kMagCoeffSet, kAccelCoeffCopySet to kAccelCoeffSet, kSetFactoryMagCoeff to kFactoryMagCoeff, kSetFactoryMagCoeffDone to kFactoryMagCoeffDone, kSetFactoryAccelCoeff to kFactoryAccelCoeff, and kSetFactorAccelCoeffDone to kFactoryAccelCoeffDone. Updated Table 7-5 to include decimal and hex component IDs and corrected the example prior to the table. | Mar. 31, 2014 | A. Leuzinger |
| R07 | Added instructions to insure a TRAX module is set to Big Endian if it will be used with TRAX Studio in sections 6 and 7.4.2. | Sept. 19, 2014 | D. McKenzie |
| R08 | Removed references to and diagrams of the enclosed Trax<br><br>Added section on using multiple calibration coefficients | January 21, 2015 | DMcKenzie |