

3-SPACE
SENSOR

3-SPACE



3-Space Sensor Embedded

Ultra-Miniature Attitude & Heading
Reference System

User's Manual

Yost Labs

630 Second Street
Portsmouth, Ohio 45662

www.YostLabs.com

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1. Usage/Safety Considerations

1.1 Usage Conditions

- Do not use the 3-Space Sensor in any system on which people's lives depend (life support, weapons, etc.)
- Because of its reliance on a compass, the 3-Space Sensor will not work properly near the earth's north or south pole.
- Because of its reliance on a compass and accelerometer, the 3-Space Sensor will not work properly in outer space or on planets with no magnetic field.
- Care should be taken when using the 3-Space Sensor in a car or other moving vehicle, as the disturbances caused by the vehicle's acceleration may cause the sensor to give inaccurate readings.
- Because of its reliance on a compass, care should be taken when using the 3-Space Sensor near ferrous metal structures, magnetic fields, current carrying conductors, and should be kept about 6 inches away from any computer screens or towers.
- The 3-Space Embedded module contains components that are sensitive to electro-static-discharge. Care should be taken when handling the module.
- PCB layout can affect the performance of the 3-Space Embedded module. Placing magnetic components, ferrous metal containing components, high-current conductors, and high-frequency digital signal lines should be avoided during PCB layout.

1.2 Technical Support and Repairs

Standard Limited Product Warranty: Yost Labs warrants the media and hardware on which products are furnished to be free from defects in materials and workmanship under normal use for sixty (60) days from the date of delivery except for OEM warranty items (see below). Yost Labs will repair or replace any defective product which is returned within this time period. Returned items will be tested in order to confirm a manufacturing defect is present. No warranties exist for any misuse.

OEM Limited Product Warranty: The following OEM products are subject to additional return limitations beyond the Standard Limited Product Warranty: surface-mount modules, integrated circuits, bare PCB modules, and other electronic components. Because of the risk of damage or malfunction due to user testing and handling problems, returns will be granted only upon evidence and/or inspection conclusively demonstrating manufacturing defect. All OEM products are individually tested prior to shipment for quality control.

Product Support: Yost Labs provides technical and user support via our number (740-876-4936) and via email (support@yostlabs.com). Support is provided for the lifetime of the equipment. Requests for repairs should be made through the Support department. For damage occurring outside of the warranty period or provisions, customers will be provided with cost estimates prior to repairs being performed.

2. Overview of the 3-Space Sensor

2.1 Introduction

The 3-Space Sensor™ Embedded is an ultra-miniature, high-precision, high-reliability, low-cost SMT Attitude and Heading Reference System (AHRS) which uses triaxial gyroscope, accelerometer, and compass sensors in conjunction with advanced on-board filtering and processing algorithms to determine orientation relative to an absolute reference orientation in real-time.

Orientation can be returned in absolute terms or relative to a designated reference orientation. The proprietary multi-reference vector mode increases accuracy and greatly reduces and compensates for sensor error. The 3-Space Sensor Embedded system also utilizes a dynamic sensor confidence algorithm that ensures optimal accuracy and precision across a wide range of operating conditions.

The 3-Space Sensor Embedded module features are accessible via a well-documented open communication protocol that allows access to all available sensor data and configuration parameters. Versatile commands allow access to raw sensor data, normalized sensor data, and filtered absolute and relative orientation outputs in multiple formats including: quaternion, Euler angles (pitch/roll/yaw), rotation matrix, axis angle, two vector (forward/up).

The 3-Space Sensor Embedded module also offers a range of communication interface options which include SPI, USB 2.0, and asynchronous serial.

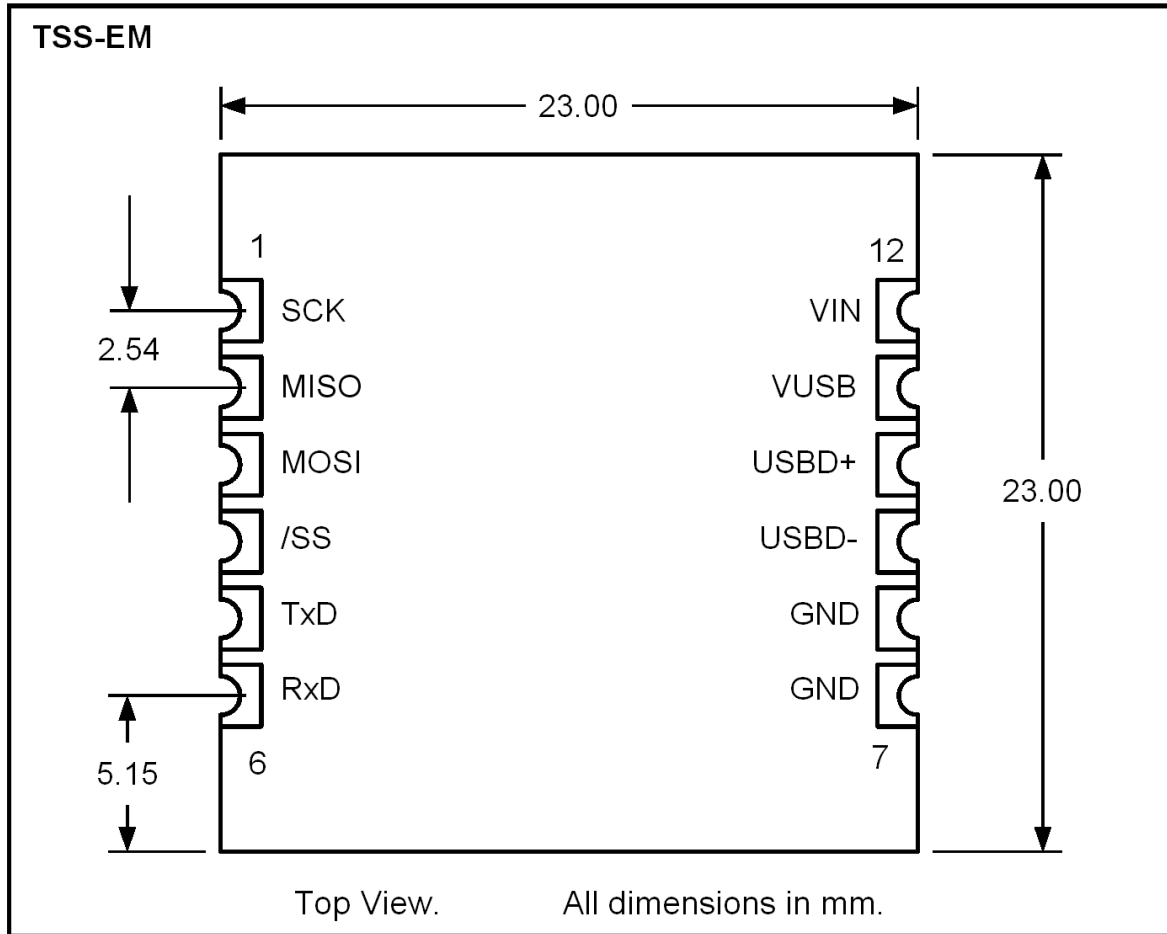
When used as a USB device, the Embedded 3-Space Sensor™ provides mouse emulation and joystick emulation modes that ease integration with existing applications.

2.2 Applications

- Robotics
- Motion capture
- Positioning and stabilization
- Vibration analysis
- Inertial augmented localization
- Personnel / pedestrian navigation and tracking
- Unmanned air/land/water vehicle navigation
- Education and performing arts
- Healthcare monitoring
- Gaming and motion control
- Accessibility interfaces
- Virtual reality and immersive simulation

2.3 Hardware Overview

The 3-Space Embedded is packaged as a 23mmx23mmx2.2mm castellated edge SMT module. Alternatively, the module can be through-hole mounted by adding standard 0.1” header strips to the castellated edge pads.

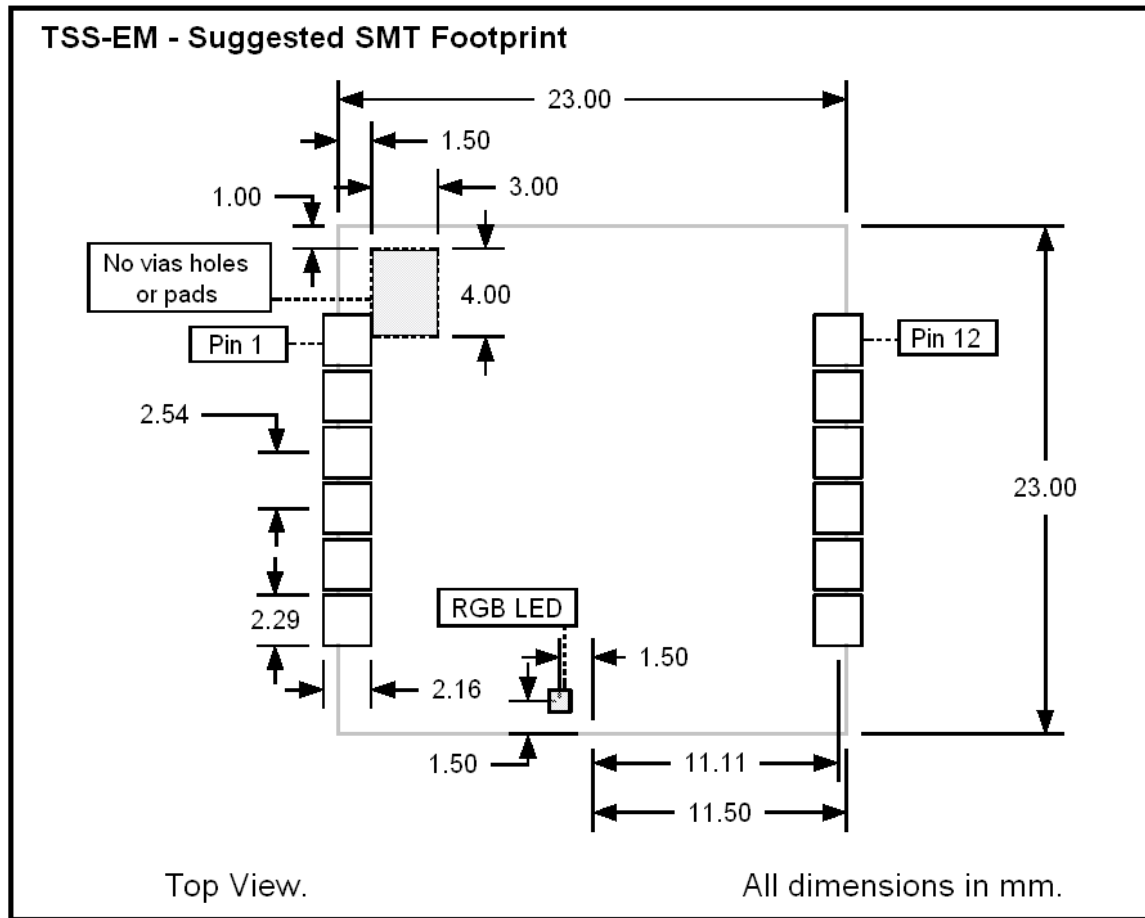


2.3.1 Pin Functions

Pad Number	Signal Name	Description
1	SCK	SPI Serial Clock. Input to Module.
2	MISO / INT	SPI Master In Slave Out. Output from Module. Can be configured to act as filter update Interrupt.
3	MOSI	SPI Master Out Slave In. Input to Module.
4	/SS	SPI Slave Select. Active Low Input to Module.
5	TxD / INT	UART Asynchronous Transmit Data. Output from Module. Can be configured to act as filter update Interrupt.
6	RxD	UART Asynchronous Receive Data. Input to Module.
7	GND	Ground. Only one ground pad must be connected.
8	GND	Ground. Only one ground pad must be connected. Commonly connected to USB supply ground.
9	USB D-	USB Data Minus. Only requires connection during USB mode use.
10	USB D+	USB Data Plus. Only requires connection during USB mode use.
11	VUSB	+5v USB Power Supply Input. Only requires connection during USB mode use.
12	VIN	Voltage Input +3.3v ~ +6.0v. Only required when USB power is not being used.

2.3.2 PCB Layout

PCB layout should follow the suggested SMT footprint below.



Additionally, since PCB layout can affect the performance of the 3-Space Embedded module observe the following layout guidelines:

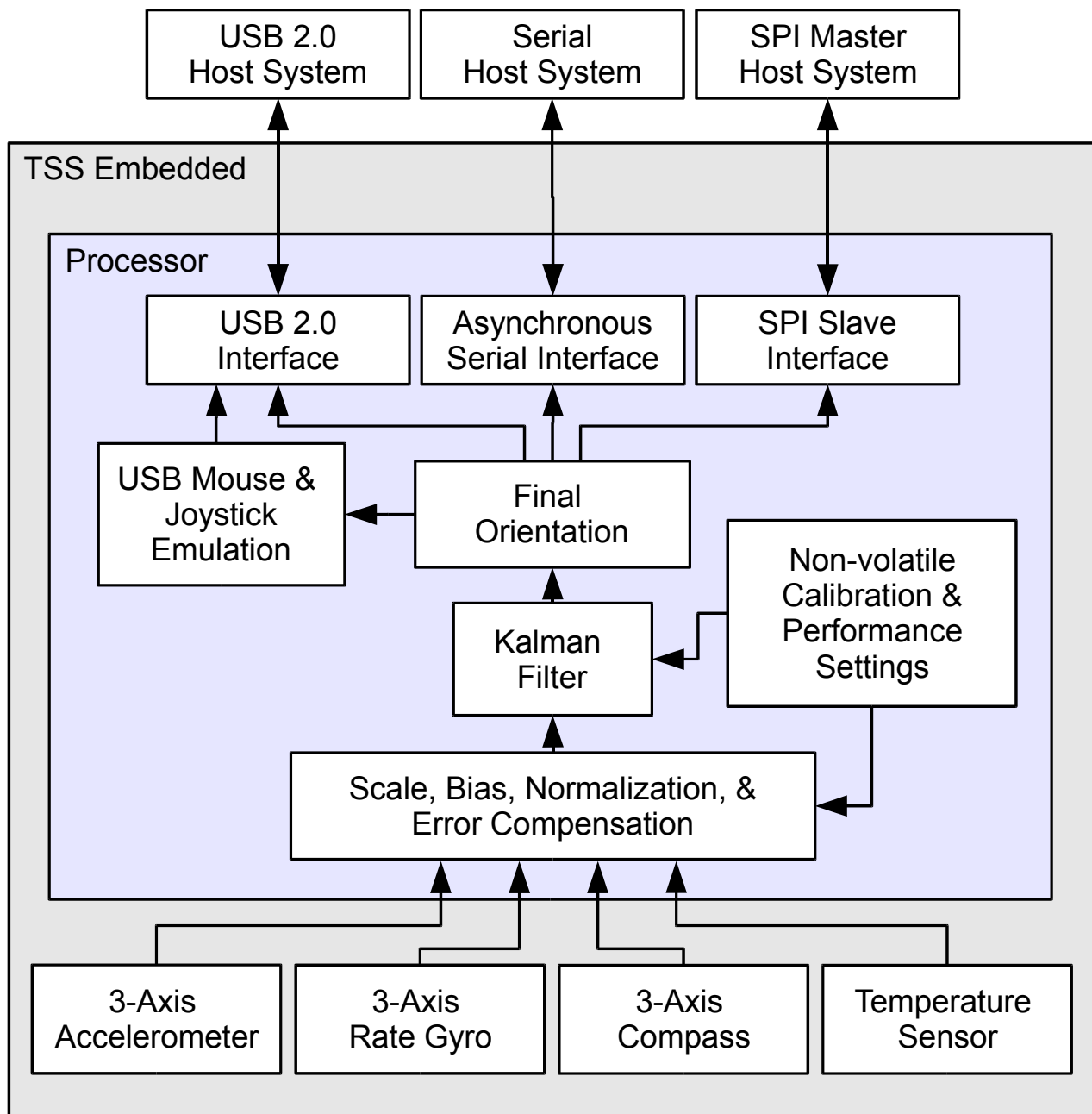
- Do not place untented pads, vias, or holes beneath the restricted area in the diagram.
- Do not place magnetic components such as speakers and motors in close proximity to the module since the magnetic fields generated can adversely affect the performance of the compass module.
- Do not place components containing ferrous metals in close proximity to the module since they may disturb earth's magnetic fields and thus adversely affect the performance of the compass module.
- Do not route high-current conductors or high-frequency digital signal lines in close proximity to the module since they may generate magnetic fields that may adversely affect the performance of the compass module.
- Do not reflow with the device on the bottom of a board. Since the module's components aren't glue-bonded to the module they may become dis-lodged if reflowed in non-up-facing orientations.
- Thoroughly test and characterize any PCB design that uses the module. Failure to test and characterize a system using the TSS-EM module may result in unforeseen performance consequences due to layout.

2.4 Features

The 3-Space Sensor Embedded has many features that allow it to be a flexible all-in-one solution for your orientation sensing needs. Below are some of the key features:

- Smallest and lightest high-performance AHRS available at 23mm x 23mm x 2mm and only 1.3 grams
- Fast sensor update and filter rate allow use in real-time applications, including stabilization, virtual reality, real-time immersive simulation, and robotics
- Highly customizable orientation sensing with options such as tunable filtering, oversampling, and orientation error correction
- Advanced integrated Kalman filtering allows sensor to automatically reduce the effects of sensor noise and sensor error
- Robust open protocol allows commands to be sent in human readable form, or more quickly in machine readable form
- Orientation output format available in absolute or relative terms in multiple formats (quaternion, rotation matrix, axis angle, two-vector)
- Absolute or custom reference axes
- Access to raw sensor data
- Flexible communication options: SPI, USB 2.0, or asynchronous serial
- USB communication through a virtual COM port
- When used as a USB device, USB joystick/mouse emulation modes ease integration with existing applications
- Castellated SMT edge pads provide secure SMT mounting and allow optional through-hole mounting
- Upgradeable firmware
- RGB status LED
- Programmable interrupt capability
- Development kit available
- RoHS Compliant
- +5v tolerant I/O signals

2.5 Block Diagram of Sensor Operation



2.6 Specifications

General	
Part number	TSS-EM
Dimensions	23mm x 23mm x 2.2mm (0.9 x 0.9 x 0.086 in.)
Weight	1.3 grams (0.0458 oz)
Supply voltage	+3.3v ~ +6.0v
Power consumption	45mA @ 5v
Communication interfaces	USB 2.0, SPI, Asynchronous Serial
Filter update rate	up to 250Hz with Kalman AHRS(higher with oversampling) up to 850Hz with QCOMP AHRS(higher with oversampling) up to 1350Hz in IMU mode
Orientation output	absolute & relative quaternion, Euler angles, axis angle, rotation matrix, two vector
Other output	raw sensor data, corrected sensor data, normalized sensor data, temperature
SPI clock rate	6 MHz max
Serial baud rate	1,200~921,600 selectable, default: 115,200
Shock survivability	5000g
Temperature range	-40C ~ 85C (-40F ~ 185F)
Processor	32-bit RISC running @ 60MHz
Sensor	
Orientation range	360° about all axes
Orientation accuracy	±2° for dynamic conditions & all orientations
Orientation resolution	<0.08°
Orientation repeatability	0.085° for all orientations
Accelerometer scale	±2g / ±4g / ±8g selectable
Accelerometer resolution	14 bit
Accelerometer noise density	99µg/√Hz
Accelerometer sensitivity	0.00024g/digit for ±2g range 0.00048g/digit for ±4g range 0.00096g/digit for ±8g range
Accelerometer temperature sensitivity	±0.008%/°C
Gyro scale	±250/±500/±2000 °/sec selectable
Gyro resolution	16 bit
Gyro noise density	0.03°/sec/√Hz
Gyro bias stability @ 25°C	11°/hr average for all axes
Gyro sensitivity	0.00875°/sec/digit for ±250°/sec 0.01750°/sec/digit for ±500°/sec 0.070°/sec/digit for ±2000°/sec
Gyro non-linearity	0.2% full-scale
Gyro temperature sensitivity	±0.016%/°C
Compass scale	±1.3 Ga default. Up to ±8.1 Ga available
Compass resolution	12 bit
Compass sensitivity	5 mGa/digit
Compass non-linearity	0.1% full-scale

2.7 Electrical Characteristics

2.7.1 Absolute Maximum Ratings*

Operating Temperature	-40C ~ 85C (-40F ~ 185F)
Storage Temperature	-60C ~ 150C (-76F ~ 302F)
Supply Voltage on VIN Pin with respect to Ground	-0.3v ~ 6.5v
Supply Voltage on VUSB Pin with respect to Ground	-0.3v ~ 6.5v
Voltage on I/O Pins with respect to Ground	-0.3v ~ 5.5v
Current Sink/Source from I/O pins	-4mA ~ +4mA

* NOTICE: Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or other conditions beyond those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may adversely affect device reliability.

2.7.2 DC Characteristics

The following characteristics are applicable to the operating temperature range: TA = -40°C to 85°C

Symbol	Parameter	Min.	Typ.	Max.	Units
V _{IN}	Operating Supply Voltage on VIN pin	3.2	3.3	6.0	V
V _{USB}	Operating Supply Voltage on VUSB pin	3.8	5.0	6.0	V
V _{IL}	Input Low-level Voltage	-0.3		+0.8	V
V _{IH}	Input High-level Voltage	2.0		5.5	V
V _{OL}	Output Low-level Voltage			0.4	V
V _{OH}	Output High-level Voltage	2.6			V
I _{OL}	Output Low-level Current			-4	mA
I _{OH}	Output High-level Current			4	mA
C _{IN}	Input Capacitance			7	pF
I _{ACT}	Active Current Consumption		45	60	mA

2.7.3 USB Characteristics

The on-chip USB interface complies with the Universal Serial Bus (USB) v2.0 standard. All AC parameters related to these buffers can be found within the USB 2.0 electrical specifications.

2.7.4 Asynchronous Serial Characteristics

The on-chip Asynchronous Serial interface is compatible with UARTs available on most micro-controllers. The device utilizes a minimum-wire configuration consisting of two communication wires: a TxD serial output and an RxD serial input. The Serial interface drives the TxD line at 3v logic-levels and the RxD input is 2.0~5.5v tolerant. Also note that since logic-level serial is voltage-based, the two connected systems must share a common ground reference.

For connection to alternate communication interfaces such as RS232, RS422, RS485, MIL-STD-188, EIA/TIA-562, and SpaceWire, additional external interface drivers may be added.

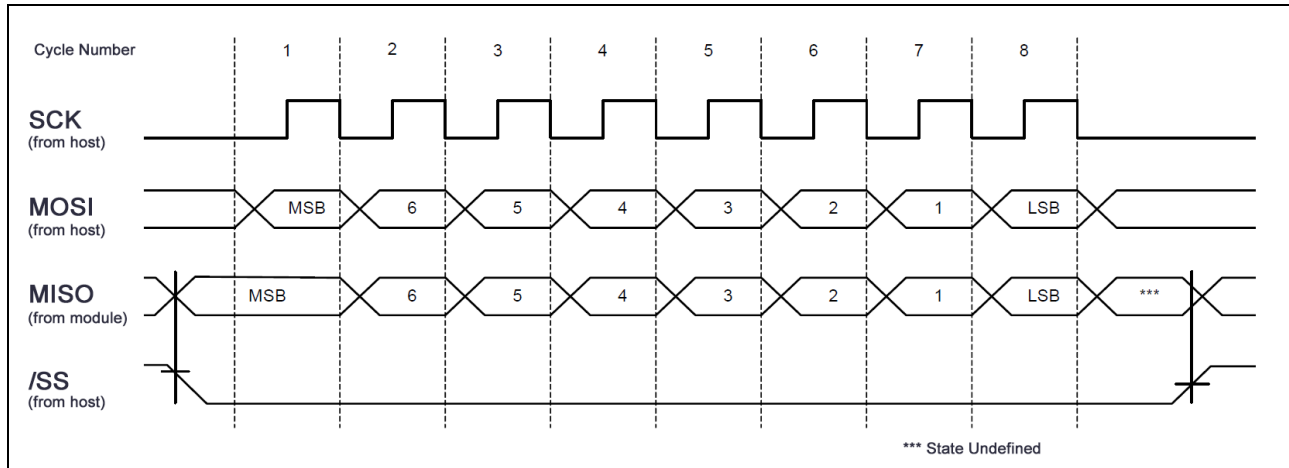
The Asynchronous Serial uses 8N1 (8 data bits, no parity, 1 stop bit) format and supports the following standard baud rates: 1200, 2400, 4800, 9600, 19200, 28800, 38400, 57600, 115200, 230400, 460800, 921600.

The factory default baud rate is 115200.

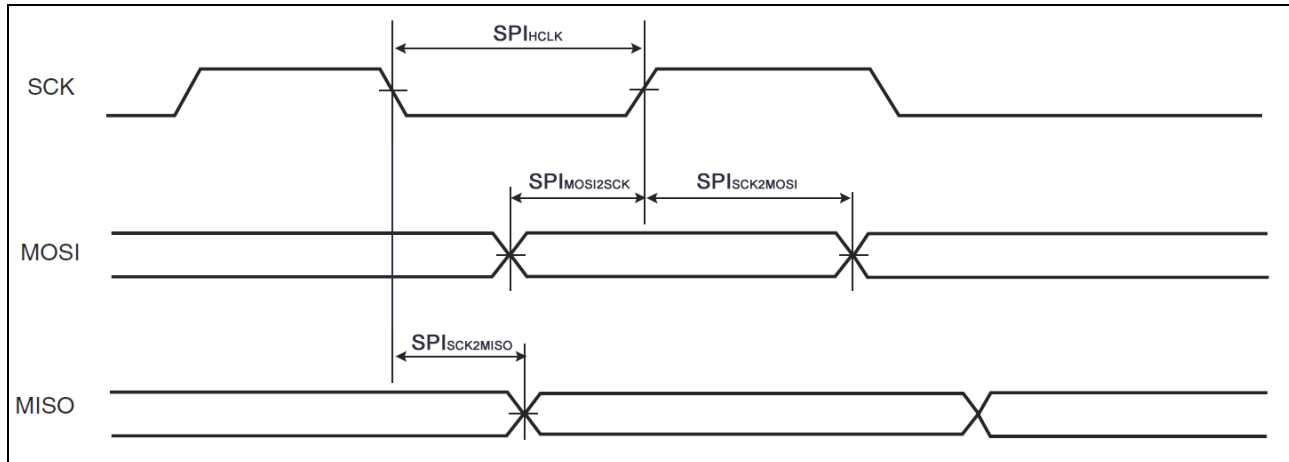
2.7.5 SPI Characteristics

The Serial Peripheral Interface or SPI is a full-duplex synchronous serial communication standard that is commonly supported on many micro-controllers and embedded systems.

The SPI interface is implemented as an SPI mode 0 slave device. This means that the SPI clock polarity is 0 (CPOL=0) and the SPI clock phase is 0 (CPHA=0). Bytes are transferred one bit at a time with the MSB being transferred first. The on-board SPI interface has been tested at speeds up to 6MHz. The diagram below illustrates a single complete SPI byte transfer.



The diagram and parameter table below illustrates additional timing requirements and limits of the SPI interface:



Symbol	Parameter	Min.	Max.	Units
SPI _{HCLK}	SPI Clock Cycle Period / 2	80		ns
SPI _{SCK2MISO}	SPI SCK falling to MISO Delay		26.5	ns
SPI _{MOSI2SCK}	SPI MOSI Setup time before SPI SCK rises	0		ns
SPI _{SCK2MOSI}	SPI MOSI Hold time after SPI SCK rises	1.5		ns

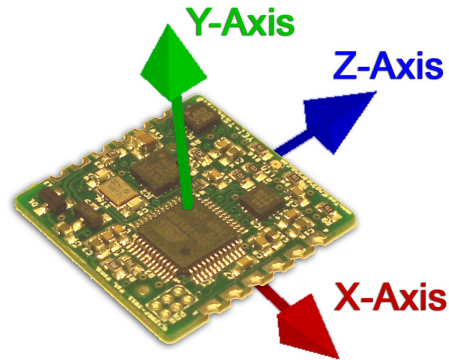
2.8 Axis Assignment

All 3-Space Sensor product family members have re-mappable axis assignments and axis directions. This flexibility allows axis assignment and axis direction to match the desired end-use requirements.

The natural axes of the 3-Space Sensor Embedded are as follows:

- The positive X-axis points out of the side of the sensor with pins 1 through 6.
- The positive Y-axis points out of the top of the sensor (the component side of the board).
- The positive Z-axis points out of the back of the sensor (the side with the LED, towards pins 6 and 7).

The natural axes are illustrated in the diagram below:



Bear in mind the difference between natural axes and the axes that are used in protocol data. While they are by default the same, they can be remapped so that, for example, data axis Y could contain data from natural axis X. This allows users to work with data in a reference frame they are familiar with.

3. Description of the 3-Space Sensor

3.1 Orientation Estimation

The primary purpose of the 3-Space Sensor is to estimate orientation. In order to understand how to handle this estimation and use it in a meaningful way, there are a few concepts about the sensor that should be understood. The following sections describe these concepts.

3.1.1 Component Sensors

The 3-Space Sensor estimates orientation by combining the data it gets from three types of sensors: a gyroscope, an accelerometer, and a compass. A few things you should know about each of these sensors:

- **Accelerometer:** This sensor measures the acceleration due to gravity, as well as any other accelerations that occur. Because of this, this sensor is at its best when the 3-Space Sensor is sitting still. Most jitter seen as the orientation of the sensor changes is due to shaking causing perturbations in the accelerometer readings. To account for this, by default, when the 3-Space Sensor is being moved, the gyroscope becomes more trusted (becomes a greater part of the orientation estimate), and the accelerometer becomes less trusted.
- **Gyroscope:** This sensor measures angular motion. It has no ability to give any absolute orientation information like the accelerometer or compass, and so is most useful for correcting the orientation during sensor motion. Its role during these times becomes vital, though, as the accelerometer readings can become unreliable during motion.
- **Compass:** This sensor measures magnetic direction. The readings from the compass and accelerometer are used together to form the absolute component of orientation, which is used to correct any short term changes the gyroscope makes. Its readings are much more stable than those of the accelerometer, but it can be adversely affected by any ferrous metal or magnetic objects. When the accelerometer is less trusted, the compass is treated in the same way so as to avoid updates to orientation based on partial absolute information.

3.1.2 Scale, Bias, and Cross-Axis Effect

The readings taken from each component sensor are not in a readily usable form. The compass and accelerometer readings are not unit vectors, and the gyroscope readings aren't yet in radians per second. To convert them to these forms, scale and bias must be taken into account. Scale is how much larger the range of data read from the component sensor is than the range of data should be when it is converted. For example, if the compass were to give readings in the range of -500 to 500 on the x axis, but we would like it to be in the range of -1 to 1, the scale would be 500. Bias is how far the center of the data readings is from 0. If another compass read from -200 to 900 on the x axis, the bias would be 350, and the scale would be 550. The last parameter used in turning this component sensor data into usable data is cross-axis effect. This is the tendency for a little bit of data on one axis of a sensor to get mixed up with the other two. This is an effect experienced by the accelerometer and compass. There are 6 numbers for each of these, one to indicate how much each axis is affected by each other axis. Values for these are generally in the range of 1 to 10%. These parameters are applied in the following order:

- 1) Bias is added to each axis
- 2) The three axes are treated as a vector and multiplied by a matrix representing scale and cross-axis parameters

Factory calibration provides default values for these parameters for the accelerometer and compass, and users should probably never need to change these values. To determine these parameters for the gyroscope, you must calibrate it. Read the Quick Start guide or the 3-Space Suite manual for more information on how to do this.

3.1.3 Component Sensor Data Types

Component sensor data is presented by the 3-Space Sensor in three different stages and is readily accessible via certain protocol commands.

- **Raw Sensor Data:** This refers to data that is read directly from each of the component sensors before any additional processing has occurred. This kind of data is well-suited for users who wish to perform their own calibration routines as well as applications where precise analysis of motion is not extremely critical. Raw data commands are listed in Section 4.4.5, “Raw Data Commands” and span commands 0x40 through 0x43.

Example: In the $\pm 2G$ range, a raw accelerometer vector might look like (144, -25904, 744). This would indicate a force that is mostly in a downward direction.

- **Corrected Sensor Data:** This refers to 'raw' data that has been biased and scaled to represent real-world units, using the steps as described in Section 3.1.2, “Scale, Bias and Cross-Axis Effect”. There is an additional scaling that occurs, which further alters the data reading based on each component sensor's device-specific values. This scaling provides the real-world equivalents for read data. For the accelerometer, these values are in units of g-forces, for the magnetometer, these values are in units of gauss, and for the gyroscope, these values are in units of radians/sec. This kind of data is well-suited for users who wish to accurately track the motion of objects in 3D space or measure the strength and direction of magnetic fields. Corrected data commands are listed in Section 4.4.3, “Corrected Data Commands” and span commands 0x25 through 0x28.

Example: In the $\pm 2G$ range, the same raw accelerometer vector from before, when corrected, might look like (.004, -.791, .023). Note that these values are in units of g, and would indicate that at the moment of the sample, the sensor is accelerating mostly downwards at a rate of 7.75 meters per second squared.

- **Normalized Sensor Data:** This refers to 'corrected' data that has been geometrically normalized. For the accelerometer and magnetometer, all normalized sensor readings are unit-vectors and as such, have lengths of 1. For the gyroscope, there is no difference between 'corrected' and 'normalized' data. This kind of data is well-suited for users who are only interested in the direction of acceleration or magnetic fields. Normalized data commands are listed in Section 4.4.2, “Normalized Data Commands” and span commands 0x20 through 0x23.

Example: The corrected accelerometer vector from before, when normalized, would look like (0.05, -0.998, 0.011). Note that the magnitude information is lost, and only the direction of the acceleration remains.

3.1.4 Additional Calibration

The 3-Space Sensor provides multiple calibration modes that can improve performance at the cost of additional setup and calibration routines. For more information on setting these additional modes, please refer to command 169.

- **Bias Mode:** Applies default range scaling to raw data readings. Also applies a bias offset to raw data, the values of which are taken from the provided calibration parameters command. (See section 4.3.7 for more information)
- **Bias / Scale Mode:** The default calibration mode. Applies default range scaling to raw data readings. Also applies a bias offset to the raw data as well as an additional scale matrix. Uses the matrix and vector portions from the provided calibration parameters command.
- **Ortho-Calibration Mode:** A more advanced calibration mode that requires initial setup steps (Please refer to the 3-Space Suite Quick Start Guide for information on how to supply ortho-calibration data) . Uses 24 orthogonal data points to provide accelerometer and compass correction factors for enhanced orientation accuracy.

3.1.5 Reference Vectors

In order to get an absolute estimation of orientation from the accelerometer and compass, the sensor needs a reference vector for each to compare to the data read from it. The most obvious choice for these are the standard direction of gravity(down) and the standard direction of magnetic force(north), respectively. However, the sensor does provide several different modes for determining which reference vector to use:

- **Single Manual:** Uses 2 reference vectors it is given as the reference vectors for the accelerometer and compass.
- **Single Auto:** When the sensor powers on or is put into this mode, it calculates gravity and north and uses those calculated vectors as the reference vectors.
- **Single Auto Continual:** The same as Single Auto, but the calculation happens constantly. This can account for some shifts in magnetic force due to nearby objects or change of location, and also can help to cope with the instability of the accelerometer.
- **Multiple:** Uses a set of reference vectors from which the best are picked each cycle to form a single, final reference vector. This mode has the ability to compensate for certain errors in the orientation. In this mode the sensor will have a slightly slower update rate, but will provide greater accuracy. For information on how to set up this mode, see the Quick Start guide or the 3-Space Suite manual.

3.1.6 Orientation Filtering

The 3-Space Sensor provides several different modes for providing orientation estimation. Note also that IMU data collection rate is bound to the update rate of the filter. For more information on setting these additional modes, please refer to command 123.

- **Kalman Filter:** The default filter mode. Normalized sensor data and reference vectors are fed into the Kalman filter, which uses statistical techniques to optimally combine the data into a final orientation reading. Provides the highest-accuracy orientation at the lowest performance.
- **Alternating Kalman Filter:** Uses the same Kalman filter as before, but skips every other update step. Slightly less accurate than the Kalman filter, but faster.
- **Complementary Filter:** Fuses low-pass filtered accelerometer/compass data with high-pass filtered gyroscope data to provide an orientation estimate. Less accurate than any Kalman filtering techniques, but provides significantly higher performance.
- **Quaternion Gradient Descent Filter:** Utilizes gradient descent techniques to avoid the high computational overhead of Kalman-based filters. Provides high performance and high accuracy.
- **IMU Mode:** Performs no orientation filtering, but allows IMU data to be read at the maximum update rate of 800 Hz.

3.1.7 Tare Orientation

Given the results of the Kalman filter, the sensor can make a good estimation of orientation, but it will likely be offset from the actual orientation of the device by a constant angle until it has been given a reference orientation. This reference orientation tells the sensor where you would like its zero orientation to be. The sensor will always consider the zero orientation to be the orientation in which the plug is facing towards you and top(the side with buttons on it) facing up. The sensor must be given a reference orientation that represents the orientation of the sensor when it is in the position in which you consider the plug to be towards you and the buttons up. The act of giving it this reference orientation to the sensor is called taring, just as some scales have a tare button which can be pressed to tell the scale that nothing is on it and it should read zero. For instructions on doing this, refer to the Quick Start guide or 3-Space Suite manual.

3.1.8 Offset Orientation

There are many applications for which it will be necessary or convenient to mount the sensor at odd angles, but it may also be desired in these situations that orientations can be treated as though the sensor were mounted normally. For example, if the sensor were mounted on a sloped surface of a vehicle like a car hood, it would be helpful if the orientations could read as though the sensor was mounted in a way that more closely matched the overall orientation of the vehicle, which does not include that slope.

The feature the sensor has to deal with mounting differences is the offset quaternion. This offset allows the sensor to pretend it is mounted in any given orientation while being actually mounted in any other actual orientation. To help understand the relationship between filtered orientation, tare orientation, and offset orientation, this is how the orientations are used by the sensor:

$$\mathit{orientation}_{final} = \mathit{orientation}_{tare} * \mathit{orientation}_{filtered} * \mathit{orientation}_{offset}$$

There are several ways to use this feature. The simplest way is if you happen to know the quaternion that represents the offset you want applied to the orientation, you can send this to the sensor by way of command 21(0x15). There are also commands to allow for more automated offset setting. To use these commands, do the following:

- 1) Place the sensor as close as possible to the mounting point, but in an orientation aligned with the overall vehicle or device the sensor is being mounted on, or in the orientation that you would like the sensor to act like it is in.
- 2) Call command 22, which sets a hidden variable called the “base offset” which affects the operation of the “Offset with current orientation” command. This will record your desired orientation later. If you ever want to reset this base offset, use command 20(0x14).
- 3) Mount the sensor onto the vehicle or device as you intend to for the end application.
- 4) Call command 19(0x13), which will set the offset based on the difference between the current orientation and the base offset. After this command is called, the sensor should now be acting as though it were in the desired orientation.
- 5) Make sure to commit the sensor settings to keep this change. Note that the base offset is not committable, but the offset itself is committable.

It should be noted that while it may seem like the set axis directions command could be used for the same purpose, this feature is the preferred way to deal with alternate mountings, as the axis directions mode has no way to account for a mounting that isn't a 90 degree based orientation away from the standard orientation. In addition, the axis direction mode does not handle switching the Euler angles to account for a different mounting, while this feature does.

3.1.9 Other Estimation Parameters

The 3-Space Sensor offers a few other parameters to filter the orientation estimate. Please note that these only affect the final orientation and not the readings of individual component sensors.

- **Oversampling:** Oversampling causes the sensor to take extra readings from each of the component sensors and average them before using them to estimate orientation. This can reduce noise, but also causes each cycle to take longer proportional to how many extra samples are being taken.
- **Running Average:** The final orientation estimate can be put through a running average, which will make the estimate smoother at the cost of introducing a small delay between physical motion and the sensor's estimation of that motion.
- **Trust Values:** As mentioned earlier, by default the accelerometer and compass are trusted less than the gyros when the sensor is in motion. These values involve parameters, one for the accelerometer and one for the compass, that indicate how much these component sensors are to be trusted relative to the gyroscope. These values range from 0 to 1, with 1 being fully trusted and 0 will be not trusted at all. There is a minimum and maximum truth value for each of the accelerometer and compass. The minimum will be used while the sensor is in motion, and the maximum will be used while it is still. To disable this sort of behavior, set both truth values to the same value. Note that the QGrad filter has its own set of trust values that can only be read or set while the sensor is in QGrad filter mode.

3.2 Communication

Obtaining data about orientation from the sensor or giving values for any of its settings is done through the sensor's communication protocol. The protocol can be used through either a USB connection, an asynchronous serial UART connection, or an SPI connection. A complete description of how to use this protocol is given in section 4 of this document. Also, you may instead use the 3-Space Suite, which provides a graphical method to communicate through USB or serial port. To learn how to use this, read the 3-Space Suite manual.

3.2.1 Wired Streaming Mode

The default mode of communication for the 3-Space Sensor is a call and response paradigm wherein you send a command and then receive a response. The sensor also features a streaming mode where it can be instructed to periodically send back the response from a command automatically, without any further communication from the host. To activate the streaming mode, use the following steps:

- 1) **Set up the streaming to call the commands you want data from. First, figure out which commands you want data from. The following commands are valid for streaming:**

- 0(0x00), Read tared orientation as quaternion
- 1(0x01), Read tared orientation as euler angles
- 2(0x02), Read tared orientation as rotation matrix
- 3(0x03), Read tared orientation as axis angle
- 4(0x04), Read tared orientation as two vector
- 5(0x05), Read difference quaternion
- 6(0x06), Read untared orientation as quaternion
- 7(0x07), Read untared orientation as euler angles
- 8(0x08), Read untared orientation as rotation matrix
- 9(0x09), Read untared orientation as axis angle
- 10(0x0a), Read untared orientation as two vector
- 11(0x0b), Read tared two vector in sensor frame
- 12(0x0c), Read untared two vector in sensor frame
- 32(0x20), Read all normalized component sensor data
- 33(0x21), Read normalized gyroscope vector
- 34(0x22), Read normalized accelerometer vector
- 35(0x23), Read normalized compass vector
- 37(0x25), Read all corrected component sensor data
- 38(0x26), Read corrected gyroscope vector
- 39(0x27), Read corrected accelerometer vector
- 40(0x28), Read corrected compass vector
- 41(0x29), Read corrected linear acceleration
- 43(0x2B) Read temperature C
- 44(0x2C), Read temperature F
- 45(0x2D), Read confidence factor
- 64(0x40), Read all raw component sensor data
- 65(0x41), Read raw gyroscope vector
- 66(0x42), Read raw accelerometer vector
- 67(0x43), Read raw compass vector
- 201(0xc9), Read battery voltage
- 202(0xca), Read battery percentage
- 203(0xcb), Read battery status
- 250(0xfa), Read button state
- 255(0xff), No command

There are 8 streaming slots available for use, and each one can hold one of these commands. These slots can be set using command 80(0x50), with the parameters being the 8 command bytes corresponding to each slot. Unused slots should be filled with 0xff so that they will output nothing.

Please note: The total amount of data the 8 slots can return at once is 256 bytes. If the resulting data exceeds

this, the set streaming slots command will fail.

- 2) **Set up the streaming interval, duration, and start delay.** These parameters control the timing of the streaming session. They can be set using command 82(0x52). All times are to be given in microseconds. They control the streaming as follows:

Interval determines how often the streaming session will output data from the requested commands. For example, an interval of 1000000 will output data once a second. An interval of 0 will output data as quickly as possible. The interval will be clamped to 1000 if the user attempts to set it in the range 1 – 1000.

Duration determines how long the streaming session will run for. For example, a duration of 5000000 indicates the session should stop after 5 seconds. A duration of 4294967295 (0xFFFFFFFF) means that the session will run indefinitely until a stop streaming command is explicitly issued.

Start Delay determines how long the sensor should wait after a start command is issued to actually begin streaming. For example, a start delay 200000 means the session will start after 200 milliseconds.

- 3) **Begin the streaming session.** This can be done using command 85(0x55). Once started, the session will run until the duration has elapsed, or until the stop command, 86(0x56) has been called. Please note that only binary data is supported. While streaming sessions can be started with ascii commands, only binary data will be returned. Also note that if the sensor is sending large amounts of data the host doesn't have time to handle, this can cause buffer overflows in some communication drivers, leading to slowdowns and loss of data integrity. If the firmware detects that the buffer has overflowed, the asynchronous session will be stopped. If this occurs, this is a sure sign that either the streaming interval is set too low, the program is not working fast enough to handle the amount of data or both.

Data is output over the same communication interface the streaming session is started with. For example, if the user sends the Start Streaming command via the USB interface, data will be streamed over the same USB connection. This also applies for RS-232 communication. Streaming for SPI communication is not supported. For more information on all these commands, see the Streaming Commands section in the command chart near the end of this document.

3.3 Input Device Emulation

3.3.1 Axes and Buttons

The 3-Space Sensor has the ability to act as a joystick and/or mouse. Both of these are defined in the same way, as a collection of axes and buttons. Axes are input elements that can take on a range of values, whereas buttons can only either be on or off. On a joystick, the stick part would be represented as 2 axes, and all the physical buttons on it as buttons. The 3-Space Sensor has no physical joystick and only 2 physical buttons, so there are a number of options to use properties of the orientation data as axes and buttons. Each input device on the 3-Space Sensor has 2 axes and 8 buttons. For more information on setting these up, see the 3-Space Suite manual. All communication for these input devices is done through the standard USB HID(Human Interface Device) protocol.

3.3.2 Joystick

As far as a modern operating system is concerned, a joystick is any random collection of axes and buttons that isn't a mouse or keyboard. Joysticks are mostly used for games, but can also be used for simulation, robot controls, or other applications. The 3-Space Sensor, as a joystick, should appear just like any other joystick to an operating system that supports USB HID(which most do).

3.3.3 Mouse

When acting as a mouse, the 3-Space Sensor will take control of the system's mouse cursor, meaning if the mouse portion is not properly calibrated, using it could easily leave you in a situation in which you are unable to control the mouse cursor at all. In cases like this, unplugging the 3-Space Sensor will restore the mouse to normal operation, and unless the mouse enabled setting was saved to the sensor's memory, plugging it back in should restore normal operation. Using the default mouse settings, caution should be exercised in making sure the orientation estimate is properly calibrated before turning on the mouse. For help with this, see the Quick Start guide.

The mouse defaults to being in Absolute mode, which means that the data it gives is meant to represent a specific position on screen, rather than an offset from the last position. This can be changed to Relative mode, where the data represents an offset. In this mode, the data which would have indicated the edges of the screen in Absolute mode will now represent the mouse moving as quickly as it can in the direction of that edge of the screen. For more information, see command 251 in section 4.3.7, or the 3-Space Suite manual.

3.4 Sensor Settings

3.4.1 Committing Settings

Changes made to the 3-Space Sensor will not be saved unless they are committed. This allows you to make changes to the sensor and easily revert it to its previous state by resetting the chip. For instructions on how to commit your changes, see the Quick Start guide or 3-Space Suite manual. Any changes relating to the multiple reference vector mode are an exception to this rule, as all these changes are saved immediately.

3.4.2 Natural Axes

All 3-Space Sensor product family members have re-mappable axis assignments and axis directions. This flexibility allows axis assignment and axis direction to match the desired end-use requirements.

The natural axes of the 3-Space Sensor Embedded are as follows:

- The positive X-axis points out of the side of the sensor with pins 1 through 6.
- The positive Y-axis points out of the top of the sensor (the component side of the board).
- The positive Z-axis points out of the back of the sensor (the side with the LED, towards pins 6 and 7).

Bear in mind the difference between natural axes and the axes that are used in protocol data. While they are by default the same, they can be remapped so that, for example, data axis Y could contain data from natural axis X. This allows users to work with data in a reference frame they are familiar with.

Upon restoration of factory settings, the axis are returned to the default configuration.

The natural axes are illustrated in section 2.8.

3.4.3 Settings and Defaults

Setting Name	Purpose	Default Value
Accelerometer Trust Values	Determine how trusted the accelerometer is	Minimum of 1/101, maximum of 1/6
Compass Trust Values	Determine how trusted the compass is	Minimum of 1/101, maximum of 1/6
Accelerometer Coefficients	Determines the scale, bias, and cross-axis parameters for the accelerometer	Factory calibrated
Compass Coefficients	Determines the scale, bias, and cross-axis parameters for the compass	Factory calibrated
Gyroscope Coefficients	Determines the scale, bias and cross-axis parameters for the gyroscope	Factory calibrated
Accelerometer Enabled	Determines whether the compass is enabled or not	TRUE
Compass Enabled	Determines whether the accelerometer is enabled or not	TRUE
Gyroscope Enabled	Determines whether the gyroscope is enabled or not	TRUE
Filter Mode	Determines how orientation is filtered.	1 (Kalman)
Accelerometer Reference Vector	Determines which vector the accelerometer should read in order for the sensor's untared orientation to be the identity orientation.	0, 1, 0
Compass Reference Vector	Dertemines which vector the compass should read in order for the sensor's untared orientation to be the identity orientation.	0, 0, 1 (Default mode is to re-calculate this vector on startup)
Reference Vector Mode	Determines how reference vectors are calculated for orientation estimation.	1 (Single automatic)
Euler Order	Determines the default composition order of euler angles returned by the sensor.	YXZ
Calibration Mode	Determines how raw sensor data is transformed into normalized data	1 (Scale-Bias)
Axis Directions	Determines what natural axis direction each data axis faces	+X, +Y, +Z
Sample Rate	Determines how many samples the sensor takes per cycle	1 from each component sensor
Running Average Percentage	Determines how heavy of a running average to run on the final orientation	0(no running average)
Desired Update Rate	Determines how long each cycle should take(ideally)	0 microseconds
RS232 Baud Rate	Determines the speed of RS232 communication	115200
CPU Speed	Determines how fast the CPU will run	60 MHz
LED Color	Determines the RGB color of the LED	0,0,1(Blue)
Joystick Enabled	Determines whether the joystick is enabled or not	TRUE
Mouse Enabled	Determines whether the mouse is enabled or not	FALSE
Button Gyro Disable Length	Determines how many cycles the gyro is ignored after a button is pressed	5
Multi Reference Weight Power	Determines what power each multi reference vector weight is raised to	10
Multi Reference Cell Divisions	Determines how many cells the multi reference lookup table is divided into per axis	4
Multi Reference Nearby Vectors	Determines how many nearby vectors each multi reference lookup table cell stores	8
Wired Response Header Bitfield	Determines what kind of data is prepended to response data.	0
Streaming Slots	Determines which commands are executed during a streaming session.	255, 255, 255, 255, 255, 255, 255, 255
Streaming Timing	Dertemines the streaming interval, duration and delay.	10000, 4294967295, 0

4. 3-Space Sensor Usage/Protocol

4.1 Usage Overview

4.1.1 Protocol Overview

The 3-Space Sensor receives messages from the controlling system in the form of sequences of serial communication bytes called packets. For ease of use and flexibility of operation, two methods of encoding commands are provided: binary and text. Binary encoding is more compact, more efficient, and easier to access programmatically. ASCII text encoding is more verbose and less efficient yet is easier to read and easier to access via a traditional terminal interface. Both binary and ASCII text encoding methods share an identical command structure and support the entire 3-Space command set. Only binary commands are available when using SPI.

The 3-Space Sensor buffers the incoming command stream and will only take an action once the entire packet has been received and the checksum has been verified as correct(ASCII mode commands do not use checksums for convenience). Incomplete packets and packets with incorrect checksums will be ignored. This allows the controlling system to send command data at leisure without loss of functionality. The command buffer will, however, be cleared whenever the 3-Space Sensor is either reset or powered off/on.

Specific details of the 3-Space Sensor protocol and its control commands are discussed in the following pages.

4.1.2 Computer Interfacing Overview

When interfacing with a computer, the 3-Space Sensor presents itself as a COM port, which provides an interface by which the serial communication the protocol requires may happen. The name of this COM port is specific to the operating system being used. It is possible to use multiple 3-Space Sensors on a single computer. Each will be assigned its own COM port. The easiest way to find out which COM port belongs to a certain sensor is to take note of what COM port appears when that sensor is plugged in(provided the drivers have been installed on that computer already. Otherwise, find out what COM port appears once driver installation has finished.) For more information on how to install the sensor software on a computer and begin using it, see the Quick Start guide.

4.1.3 Electronic Interfacing Overview

The 3-Space Sensor Embedded module offers three interfacing /communications options: USB 2.0, Asynchronous Serial, and Serial Peripheral Interface (SPI). One or more of the interfaces may be connected and used together. When using multiple interfaces, care should be taken to avoid the sending overlapping concurrent commands from multiple interfaces. Overlapping concurrent commands from multiple interfaces could result in a command being dropped. Thus, in situations where multiple overlapping concurrent commands cannot be avoided, a simple command verification, timeout, and retry paradigm should be used. The sections below describe the necessary pin connections and typical circuits used for using each of the respective interface options.

4.1.3.1 USB Interfacing

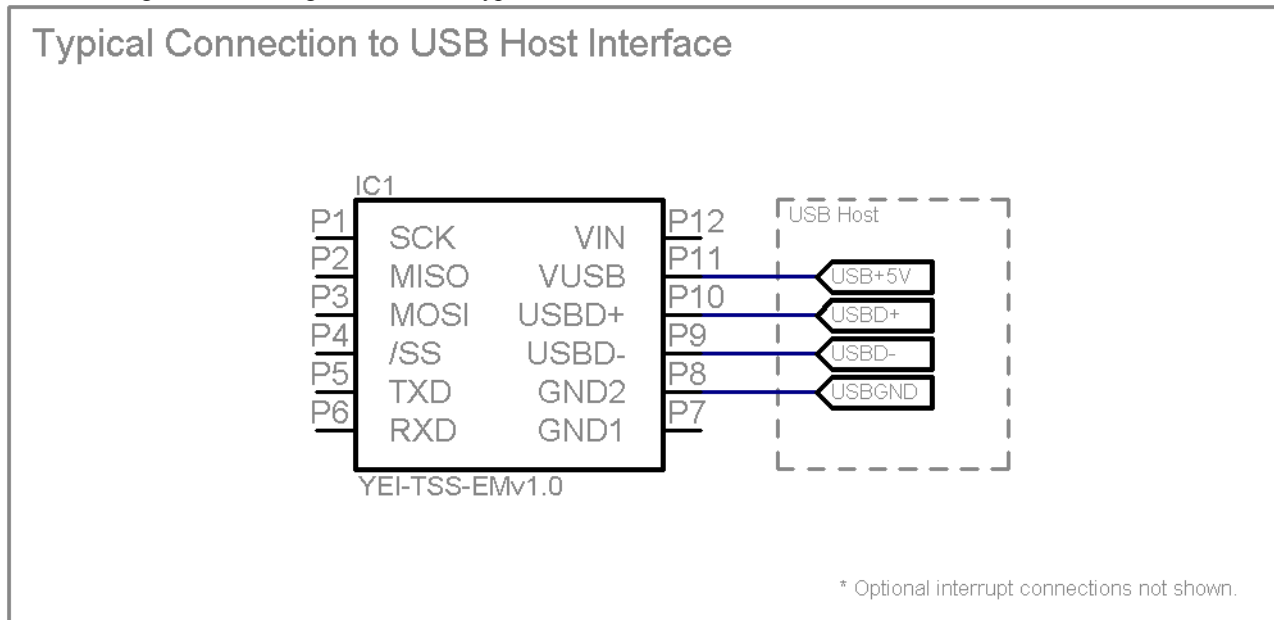
The USB 2.0 interface of the 3-Space Sensor Embedded requires the connection of signals as follows:

Pin	Signal	Description
8	GND	USB Ground. Required connection during USB mode use.
9	USBD-	USB Data Minus. Required connection during USB mode use.
10	USBD+	USB Data Plus. Required connection during USB mode use.
11	VUSB	+5v USB Power Supply Input . Required connection during USB mode use.

Additionally, one of the following optional interrupt pins may be configured for use during USB mode:

Pin	Signal	Description
2	MISO / INT	Configurable as filter update interrupt when SPI interface is unused.
5	TxD / INT	Configurable as filter update interrupt when asynchronous serial interface is unused.

The following schematic diagram illustrates typical USB interface connections:



4.1.3.2 Asynchronous Serial Interfacing

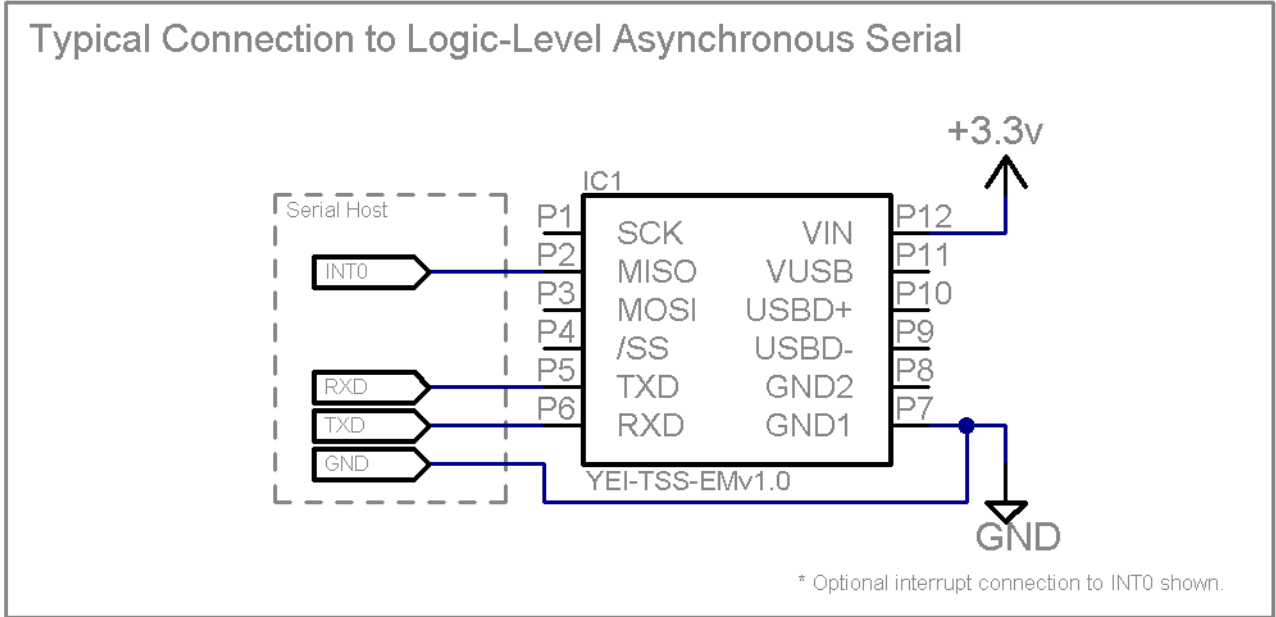
The asynchronous serial interface of the 3-Space Sensor Embedded requires the connection of signals as follows:

Pin	Signal	Description
5	TxD	UART Asynchronous Transmit Data. Output from Module.
6	RxD	UART Asynchronous Receive Data. Input to Module.
7,8	GND	Ground. Only one ground pad must be connected.
12	VIN	Voltage Input +3.3v ~ +6.0v. Only required when USB power is not being used.

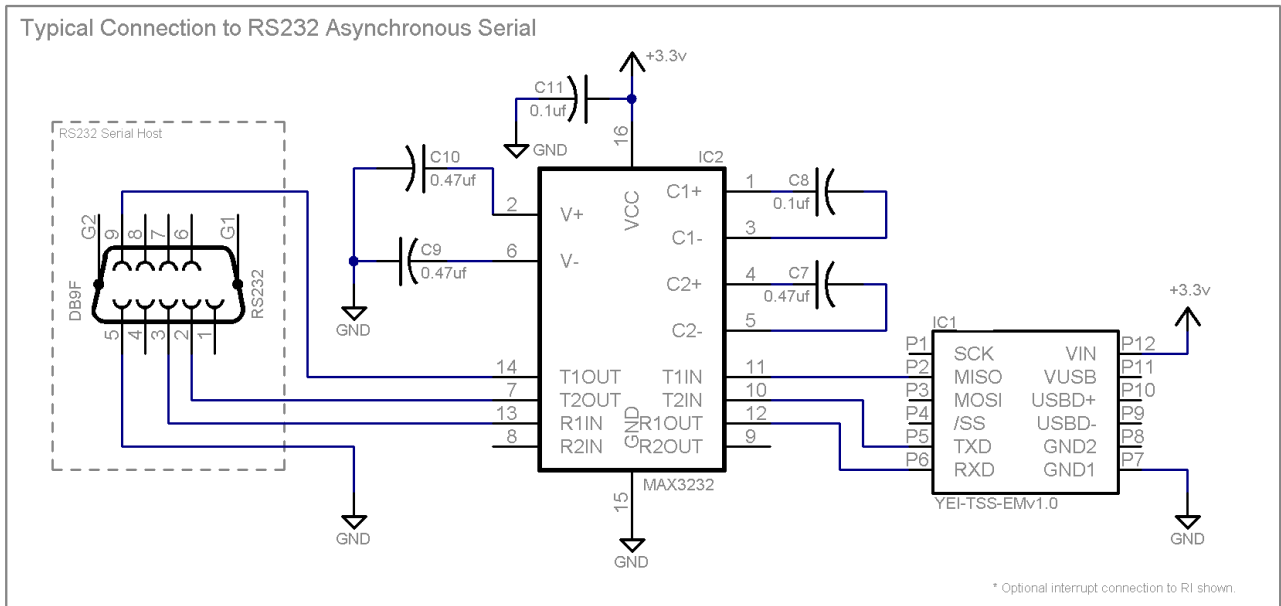
Additionally, the following optional interrupt pin may be configured for use during asynchronous serial mode:

Pin	Signal	Description
2	MISO / INT	Configurable as filter update interrupt when SPI interface is unused.

The following schematic diagram illustrates typical logic-level asynchronous serial interface connections:



The following schematic diagram illustrates typical RS232-level asynchronous serial interface connections:



4.1.3.3 SPI Interfacing

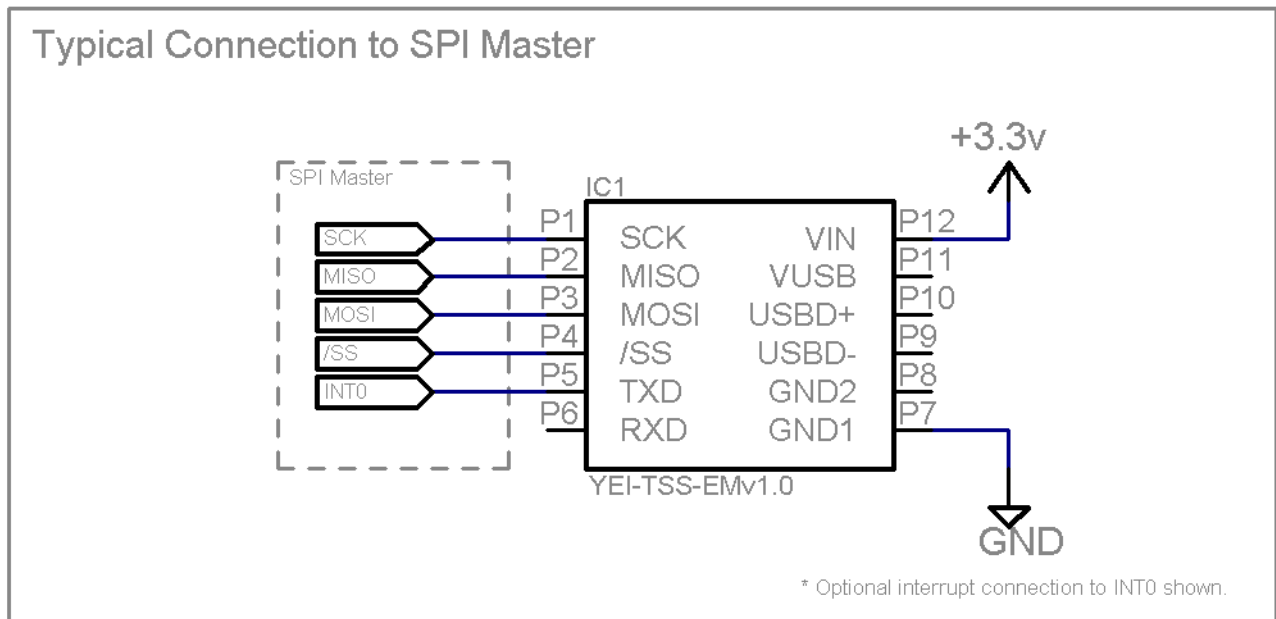
The Serial Peripheral Interface (SPI) of the 3-Space Sensor Embedded requires the connection of signals as follows:

Pin	Signal	Description
1	SCK	SPI Serial Clock. Input to Module.
2	MISO	SPI Master In Slave Out. Output from Module.
3	MOSI	SPI Master Out Slave In. Input to Module.
4	/SS	SPI Slave Select. Active Low Input to Module.

Additionally, the following optional interrupt pin may be configured for use during SPI mode:

Pin	Signal	Description
5	TxD / INT	Configurable as filter update interrupt when asynchronous serial interface is unused.

The following schematic diagram illustrates typical SPI interface connections:



4.1.3.4 Interrupt Generation

The Embedded 3-Space Sensor is capable of generating a signal on certain pins which can be used to trigger an interrupt when new orientation data becomes available. This pin will be high by default. The signal can be set to act in pulse mode, where the pin is set low for 5 microseconds and then pulled back to high, or it can be set to level mode, where the pin is set low until the interrupt status is read (see command 31(0x1f)). By default, no pin is set to act as the interrupt generation pin. Either the SPI MISO pin or the UART TXD pin may be set to act as the interrupt pin, meaning that while interrupt generation is active, either the UART or SPI will be unusable. For more information on setting the pin interrupt mode and which pin it uses, see command 29(0x1d).

Pin	Signal	Description
2	MISO / INT	Configurable as filter update interrupt when SPI interface is unused.
5	TxD / INT	Configurable as filter update interrupt when asynchronous serial interface is unused.

4.1.3.5 Button Settings

The Embedded 3-Space Sensor may be set up to have some of its pins act as digital inputs, or buttons. These buttons are used in the same way as the physical buttons on other versions of the 3-Space Sensor, in that the HID communication can report their state, and their state can also be requested through the button state command (command 250(0xfa)). This mode can be enabled using command 29(0x1d). Buttons are enabled in pairs, and using button mode will disable either the serial communication, or the SPI communication, depending on which set of pins is selected to be used as buttons. The following pins can be used as buttons:

Pin	Name	Description
2 and 3	MISO / MOSI	Configurable as buttons when SPI interface is unused.
5 and 6	TxD / RxD	Configurable as buttons when asynchronous serial interface is unused.

The buttons will report a state of 0 when a high signal is applied to the corresponding pin, or 1 when a low signal is applied. Pull up resistors on these pins cause it to default to high, or a value of 0.

4.2 Protocol Packet Format(USB and Serial)

4.2.1 Binary Packet Format

The binary packet size can be three or more bytes long, depending upon the nature of the command being sent to the controller. Each packet consists of an initial “**start of packet**” byte, followed by a “**command value**” specifier byte, followed by zero or more “**command data**” bytes, and terminated by a packet “**checksum value**” byte.

Each binary packet is at least 3 bytes in length and is formatted as shown in figure 1

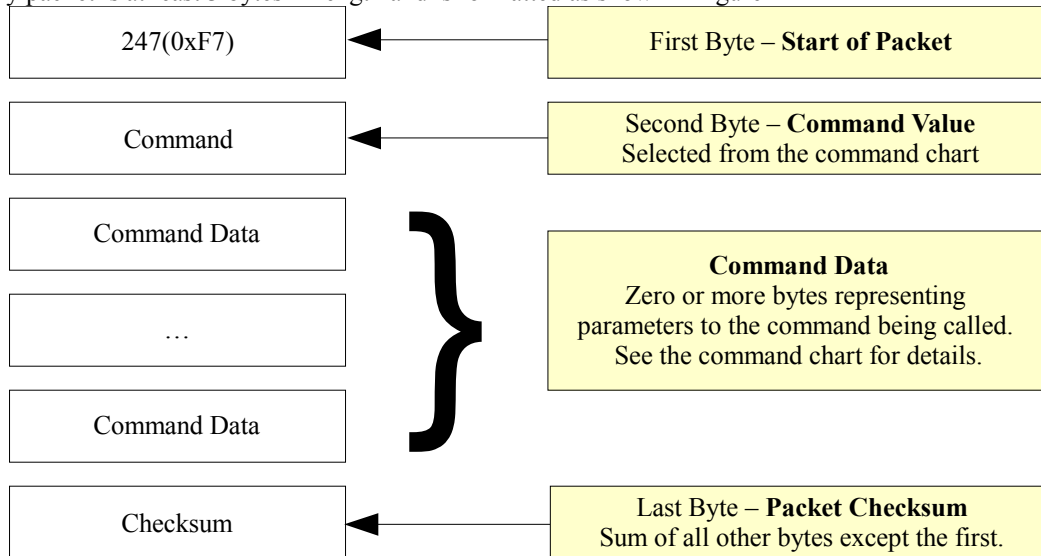


Figure 1 - Typical Binary Command Packet Format

Binary Return Values:

When a 3 Space Sensor command is called in binary mode, any data it returns will also be in binary format. For example, if a floating point number is returned, it will be returned as its 4 byte binary representation.

For information on the floating point format, go here: http://en.wikipedia.org/wiki/Single_precision_floating-point_format

Also keep in mind that integer and floating point values coming from the sensor are stored in big-endian format.

The Checksum Value:

The checksum is computed as an arithmetic summation of all of the characters in the packet (except the checksum value itself) modulus 256. This gives a resulting checksum in the range 0 to 255. The checksum for binary packets is transmitted as a single 8-bit byte value.

4.2.2 ASCII Text Packet Format

ASCII text command packets are similar to binary command packets, but are received as a single formatted line of text. Each text line consists of the following: an ASCII colon character followed by an integral command id in decimal, followed by a list of ASCII encoded floating-point command values, followed by a terminating newline character. The command id and command values are given in decimal. The ASCII encoded command values must be separated by an ASCII comma character or an ASCII space character. Thus, legal command characters are: the colon, the comma, the period, the digits 0 through 9, the minus sign, the new-line, the space, and the backspace. When a command calls for an integer or byte sized parameter, the floating point number given for that parameter will be interpreted as being the appropriate data type. For simplicity, the ASCII encoded commands follow the same format as the binary encoded commands, but ASCII text encodings of values are used rather than raw binary encodings.

Each ASCII packet is formatted as shown in figure 2.

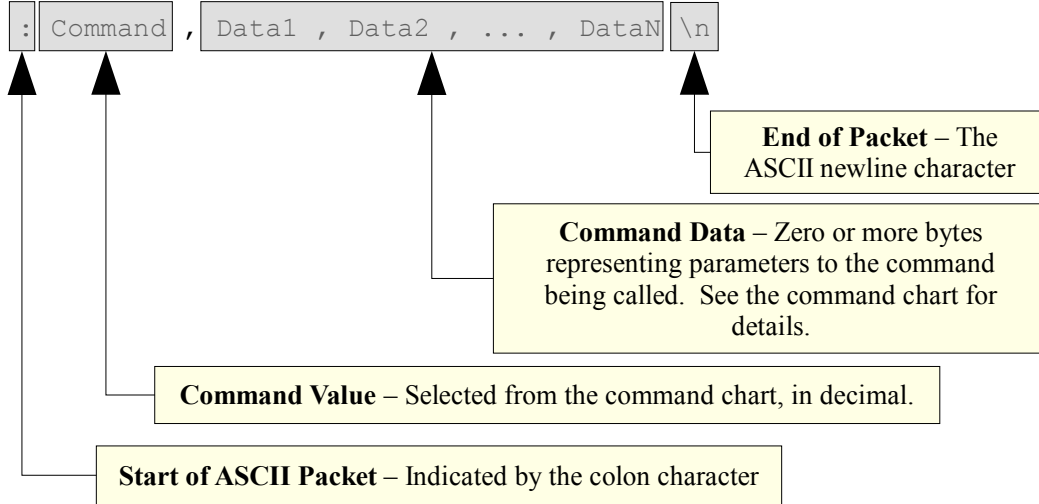


Figure 2 - Typical ASCII Command Packet Format

Thus the ASCII packet consists of the the following characters:

- **:** – the ASCII colon character signifies the start of an ASCII text packet.
- **,** – the ASCII comma character acts as a value delimiter when multiple values are specified.
- **.** – the ASCII period character is used in floating point numbers.
- **0~9** – the ASCII digits are used to in integer and floating point values.
- **-** – the ASCII minus sign is used to indicate a negative number
- **\n** – the ASCII newline character is used to signify the end of an ASCII command packet.
- **\b** – the ASCII backspace character can be used to backup through the partially completed line to correct errors.

If a command is given in ASCII mode but does not have the right number of parameters, the entire command will be ignored.

Sample ASCII commands:

:0\n	Read orientation as a quaternion
:106,2\n	Set oversample rate to 2

ASCII Return Values:

All values are returned in ASCII text format when an ASCII-format command is issued. To read the return data, simply read data from the sensor until a Windows newline(a carriage return and a line feed) is encountered..

4.3 Response Header Format

4.3.1 Wired Response Header

The 3-Space Sensor is capable of returning additional data that can be prepended to all command responses. This capability is managed via the Response Header Bitfield, which can be configured using command 221 (0xDD). Each bit in the field, if enabled, corresponds to a different piece of information that will be output prior to the expected response data. To use the Response Header Bitfield, use the following steps:

1.) Determine which additional data you would like to have output as the response header. The list of options are:

0x1 (Bit 0) – Success/Failure; comprised of one byte with non-zero values indicating failure.

0x2 (Bit 1) – Timestamp; comprised of four bytes representing the most recent sample time in microseconds. Note that this is not a difference, but a total accumulated time.

0x4 (Bit 2) – Command echo; comprised of one byte. Echoes back the previous command.

0x8 (Bit 3) – Additive checksum; comprised of one byte summed over the response data modulus 256. Note that this does not include the Response Header itself.

0x10 (Bit 4) – Logical ID; comprised of one byte indicating the logical ID of the received packet. For wired communication, this always returns 0xFE.

0x20 (Bit 5) – Serial number; comprised of four bytes.

0x40 (Bit 6) – Data length; comprised of one byte. Represents the amount of response data. Note that this does not include the Response Header itself.

For example, if you wanted all future data to be preceded with a timestamp and a data length, you would want to use bits 1 and 6, which corresponds to the value 66 (0x00000042). This is the value that would be passed into the Set Wired Response Header Bitfield command (Command 221).

2.) Call command 221 passing in the specified value. Keep in mind that this is a 4-byte value.

3.) Ask for data using the Response Header Start Byte.

Typical wired binary commands use 0xF7 to indicate the start of a command packet. If 0xF7 is used, response data will never contain a Response Header. Instead, the user should use 0xF9 instead of 0xF7. This will cause the resulting command to prepend the requested Response Header to the response data. Typical wired ascii commands use ':' to indicate the start of a typical command packet and the ';' character to indicate to the sensor that the data should have the Response Header prepended. Also note that all Response Header will be output in ascending order, starting with the lowest enabled bit and continuing on to the highest enabled bit. Response headers are not supported for SPI communication.

4.) Parse the Response Header data.

Assume we wanted to ask for the raw accelerometer data along with the timestamp and data length and that we have already called command 221 with a parameter of 66. We then send the following to the sensor:

```
0xf9 0x42 0x42
```

We receive the following response from the sensor:

```
0x17 0x39 0x15 0x93 0x0c 0xc4 0x86 0x0 0x0 0xc5 0x54 0x0 0x0 0x46 0x7c 0xc0 0x0
```

Going in order, we used bits 1 and 6, so we can parse out the timestamp first, which is 4 bytes, and then the data length, which is 1 byte:

```
Timestamp: 0x17 0x39 0x15 0x93 (389617043)
```

```
Data Length: 0x0c (12)
```

```
Data: 0xc4 0x86 0x0 0x0 0xc5 0x54 0x0 0x0 0x46 0x7c 0xc0 0x0 (-1072.0, -3392.0, 16176.0)
```


For the ascii version, we would send the following:

```
“;66\n”
```

We would receive the following response:

```
“389617043,37,-1072.00000,-3392.00000,16176.00000\r\n”
```

4.3.2 Wired Streaming with Response Header

Streaming data can also have Response Header data prepended to each streamed packet. This can be accomplished by calling the Start Streaming command (0x55) with the Response Header Packet Byte. Assuming that streaming has been configured properly and a non-zero Wired Response Header bitfield has been set, the following examples will start streaming with Response Headers disabled and enabled, respectively:

```
0xf7 0x55 0x55 //Start streaming WITHOUT response header prepended  
0xf9 0x55 0x55 //Start streaming WITH response header prepended
```

Keep in mind that the actual start command will also have a Response Header attached that must be successfully parsed.

4.4 Protocol Packet Format(SPI)

4.4.1 Command Packet Format

In order to initiate an SPI data transfer, the byte 0xF6 must be sent to signal the start of an incoming command packet. Afterwards, the command byte should be sent as well as any required command parameter bytes. After the command has been processed, the byte 0xFF must be sent repeatedly to read any bytes returned from the sensor. While the sensor is not currently processing a command, any byte sent to it other than 0xF6 and 0xFF will cause the internal data buffer to reset, thus clearing any response data prepared by the sensor. Once the sensor has responded with a 1 (indicating the command has finished), the user must send repeated bytes of 0xFF until all command data is read. In other words, if a command returns 12 bytes, 12 bytes of 0xFF must be sent after the 1 has been received. Additionally, there are several internal states that the sensor maintains while processing SPI commands:

0x0 (IDLE) The sensor is waiting on a command. Any bytes sent to the sensor besides 0xF6 will have no effect.

0x1 (READY) The sensor has processed a command and data is available to read. Any byte sent to the sensor other than 0xFF will reset the internal data buffer.

0x2 (BUSY) The sensor is currently processing a command.

0x4 (ACCUMULATING) The sensor is accumulating command bytes, but has not received enough to run the command. Anything sent to the sensor in this state will be interpreted as command data.

The following diagram illustrates the process for sending command data and reading response data. Command 230(0xE6) is the id command, and returns 32 total bytes, where the first three bytes are "TSS". First, 0xF6 is sent to the sensor over SPI, which responds with a 0x0. The 0xE6 byte is sent to the sensor over SPI, which will receive a response of 0x4. The byte 0xFF is sent to the sensor until it responds with a 1. Once it does, 32 bytes of 0xFF are sent to the sensor until all data is retrieved. Only 3 of the data byte communications are illustrated here for brevity.

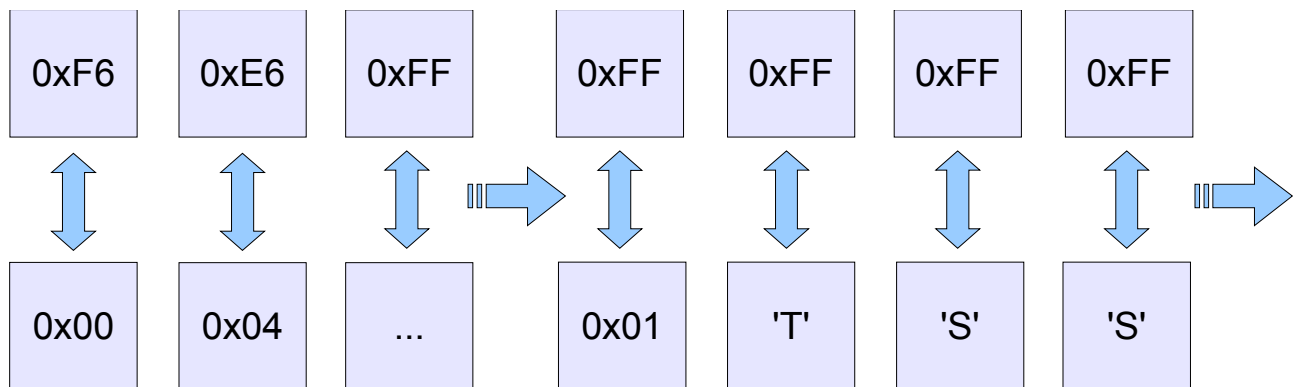


Figure 3 – Sample SPI Communication

4.5 Command Overview

There are over 90 different command messages that are grouped numerically by function. Unused command message bytes are reserved for future expansion.

When looking at the following command message tables, note the following:

- The “Data Len” field indicates the number of additional data-bytes the command expects to follow the command-byte itself. This number doesn't include the Start of Packet, Command, or Checksum bytes for USB and serial packets. Thus, the total message size for USB and serial can be calculated by adding three bytes to the “Data Len” listed in the table. The total message size for SPI is Data Len plus the one Command byte.
- Likewise, the “Return Data Len” field indicates the number of data-bytes the command delivers back to the sender once the command has finished executing.
- Under “Return Data Details”, each command lists the sort of data which is being returned and next to this in parenthesis the form this data takes. For example, a quaternion is represented by 4 floating point numbers, so a command which returns a quaternion would list “Quaternion(float x4)” for its return data details.
- Command length information only applies to binary commands, as ASCII commands can vary in length.
- For quaternions, data is always returned in x, y, z, w order.
- Euler angles are always returned in pitch, yaw, roll order.
- When calling commands in ASCII mode, there is no fixed byte length for the parameter data or return data, as the length depends on the ASCII encoding.

4.5.1 Orientation Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
0(0x00)	Get tared orientation as quaternion	Returns the filtered, tared orientation estimate in quaternion form	16	Quaternion (float x4)	0	
1(0x01)	Get tared orientation as euler angles	Returns the filtered, tared orientation estimate in euler angle form	12	Euler Angles (float x3)	0	
2(0x02)	Get tared orientation as rotation matrix	Returns the filtered, tared orientation estimate in rotation matrix form	36	Rotation Matrix (float x9)	0	
3(0x03)	Get tared orientation as axis angle	Returns the filtered, tared orientation estimate in axis-angle form	16	Axis (float x3), Angle in Radians (float)	0	
4 (0x04)	Get tared orientation as two vector.	Returns the filtered, tared orientation estimate in two vector form, where the first vector refers to forward and the second refers to down.	24	Forward Vector (float x3), Down Vector (float x3)	0	
5(0x05)	Get difference quaternion	Returns the difference between the measured orientation from last frame and this frame.	16	Quaternion (float x4)	0	
6(0x06)	Get untared orientation as quaternion	Returns the filtered, untared orientation estimate in quaternion form.	16	Quaternion (float x4)	0	
7(0x07)	Get untared orientation as euler angles	Returns the filtered, untared orientation estimate in euler angle form	12	Euler Angles (float x3)	0	
8(0x08)	Get untared orientation as rotation matrix	Returns the filtered, untared orientation estimate in rotation matrix form	36	Rotation Matrix (float x9)	0	
9(0x09)	Get untared orientation as axis angle	Returns the filtered, untared orientation estimate in axis-angle form	16	Axis (float x3), Angle in Radians (float)	0	
10(0x0A)	Get untared orientation as two vector.	Returns the filtered, untared orientation estimate in two vector form, where the first vector refers to north and the second refers to gravity.	24	North Vector (float x3), Gravity Vector (float x3)	0	
11(0x0B)	Get tared two vector in sensor frame	Returns the filtered, tared orientation estimate in two vector form, where the first vector refers to forward and the second refers to down. These vectors are given in the sensor reference frame and not the global reference frame.	24	Forward Vector (float x3), Down Vector (float x3)	0	
12(0x0C)	Get untared two vector in sensor frame	Returns the filtered, untared orientation estimate in two vector form, where the first vector refers to forward and the second refers to down. These vectors are given in the sensor reference frame and not the global reference frame.	24	North Vector (float x3), Gravity Vector (float x3)	0	

4.5.2 Embedded Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
29(0x1D)	Set pin mode	Sets the pin mode of the sensor. First parameter is mode, which will be 0 for off, 1 for pulse mode, 2 for level, 3 for SPI pulse and 4 for button. Second parameter is pin, which will be 0 for TXD(for button, also RXD) or 1 for MISO(for button, also MOSI).	0		2	Mode (Byte), Pin (Byte)
30(0x1E)	Get pin mode	Read the interrupt mode of the sensor. First parameter is mode, which will be 0 for off, 1 for pulse mode, 2 for level, 3 for SPI pulse and 4 for button. Second parameter is pin, which will be 0 for TXD(for button, also RXD) or 1 for MISO(for button, also MOSI).	2	Mode (Byte), Pin (Byte)	0	
31(0x1F)	Get interrupt status	Read the current interrupt status. This value will be 1 if the filter has updated since the last time the value was read or 0 otherwise.	1	Status (Byte)	0	

4.5.3 Normalized Data Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
32(0x20)	Get all normalized component sensor data	Returns the normalized gyro rate vector, accelerometer vector, and compass vector. Note that the gyro vector is in units of radians/sec, while the accelerometer and compass are unit-length vectors indicating the direction of gravity and north, respectively. These two vectors do not have any magnitude data associated with them.	36	Gyro Rate in units of radians/sec (Vector x3), Gravity Direction (Vector x3), North Direction (Vector x3)	0	
33(0x21)	Get normalized gyro rate	Returns the normalized gyro rate vector, which is in units of radians/sec.	12	Gyro Rate in units of radians/sec (float x3)	0	
34(0x22)	Get normalized accelerometer vector	Returns the normalized accelerometer vector. Note that this is a unit-vector indicating the direction of gravity. This vector does not have any magnitude data associated with it.	12	Gravity Direction (Vector x3)	0	
35(0x23)	Get normalized compass vector	Returns the normalized compass vector. Note that this is a unit-vector indicating the direction of gravity. This vector does not have any magnitude data associated with it.	12	North Direction (Vector x3)	0	

4.5.4 Corrected Data Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
37(0x25)	Get all corrected component sensor data	Returns the corrected gyro rate vector, accelerometer vector, and compass vector. Note that the gyro vector is in units of radians/sec, the accelerometer vector is in units of G, and the compass vector is in units of gauss.	36	Gyro Rate in units of radians/sec (Vector x3), Acceleration Vector in units of G (Vector x3), Compass Vector in units of gauss (Vector x3)	0	
38(0x26)	Get corrected gyro rate	Returns the corrected gyro rate vector, which is in units of radians/sec. Note that this result is the same data returned by the normalized gyro rate command.	12	Gyro Rate in units of radians/sec (float x3)	0	
39(0x27)	Get corrected accelerometer vector	Returns the acceleration vector in units of G. Note that this acceleration will include the static component of acceleration due to gravity.	12	Acceleration Vector in units of G (float x3)	0	
40(0x28)	Get corrected compass vector	Returns the compass vector in units of gauss.	12	Compass Vector in units of gauss (float x3)	0	
41(0x29)	Get corrected linear acceleration in global space	Returns the linear acceleration of the device, which is the overall acceleration which has been orientation compensated and had the component of acceleration due to gravity removed. Uses the tared orientation.	12	Acceleration Vector in units of G (float x3)	0	
48(0x30)	Correct raw gyro data	Converts the supplied raw data gyroscope vector to its corrected data representation.	12	Gyro Rate in units of radians/sec (float x3)	12	Gyro Rate in counts per degrees/sec (Vector x3)
49(0x31)	Correct raw accel data	Converts the supplied raw data accelerometer vector to its corrected data representation.	12	Acceleration Vector in units of G (float x3)	12	Acceleration Vector in counts per g (Vector x3)
50(0x32)	Correct raw compass data	Converts the supplied raw data compass vector to its corrected data representation.	12	Compass Vector in units of gauss (float x3)	12	Compass Vector in counts per gauss (Vector x3)

4.5.5 Other Data Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
43(0x2B)	Get temperature C	Returns the temperature of the sensor in Celsius.	4	Temperature (float)	0	
44(0x2C)	Get temperature F	Returns the temperature of the sensor in Fahrenheit	4	Temperature (float)	0	
45(0x2D)	Get confidence factor	Returns a value indicating how much the sensor is being moved at the moment. This value will return 1 if the sensor is completely stationary, and will return 0 if it is in motion. This command can also return values in between indicating how much motion the sensor is experiencing.	4	Confidence Factor (float)	0	

4.5.6 Raw Data Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
64(0x40)	Get all raw component sensor data	Returns the raw gyro rate vector, accelerometer vector and compass vector as read directly from the component sensors without any additional post-processing. The range of values is dependent on the currently selected range for each respective sensor.	36	Gyro Rate in counts per degrees/sec (Vector x3), Acceleration Vector in counts per g (Vector x3), Compass Vector in counts per gauss (Vector x3)	0	
65(0x41)	Get raw gyroscope rate	Returns the raw gyro rate vector as read directly from the gyroscope without any additional post-processing.	12	Gyro Rate in counts per degrees/sec (Vector x3)	0	
66(0x42)	Get raw accelerometer data	Returns the raw acceleration vector as read directly from the accelerometer without any additional post-processing.	12	Acceleration Vector in counts per g (Vector x3)	0	
67(0x43)	Get raw compass data	Returns the raw compass vector as read directly from the compass without any additional post-processing.	12	Compass Vector in counts per gauss (Vector x3)	0	

4.5.7 Streaming Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
80(0x50)	Set streaming slots	Configures data output slots for streaming mode. Command accepts a list of eight bytes, where each byte corresponds to a different data command. Every streaming iteration, each command will be executed in order and the resulting data will be output in the specified slot. Valid commands are commands in the ranges 0x0 – 0x10, 0x20 – 0x30, 0x40 – 0x50, 0xC9 – 0xCA (for battery-powered sensors) and 0xFA. A slot value of 0xFF 'clears' the slot and prevents any data from being written in that position. This command can fail if there is an invalid command passed in as any of the parameters or if the total allotted size is exceeded. Upon failure, all slots will be reset to 0xFF. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		8	Commands (Byte x8)
81(0x51)	Get streaming slots	Returns the current streaming slots configuration.	8	Commands (Byte x8)	0	
82(0x52)	Set streaming timing	Configures timing information for a streaming session. All parameters are specified in microseconds. The first parameter is the interval, which specifies how often data will be output. A value of 0 means that data will be output at the end of every filter loop. Aside from 0, values lower than 1000 will be clamped to 1000. The second parameter is the duration, which specifies the length of the streaming session. If this value is set to 0xFFFFFFFF, streaming will continue indefinitely until it is stopped via command 0x56. The third parameter is the delay, which specifies a n amount of time the sensor will wait before outputting the first packet of streaming data. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		12	Interval (Unsigned int), Duration (Unsigned int), Delay (Unsigned int)
83(0x53)	Get streaming timing	Returns the current streaming timing information.	12	Interval (Unsigned int), Duration (Unsigned int), Delay (Unsigned int)	0	
84(0x54)	Get streaming batch	Return a single packet of streaming data using the current slot configuration.	Varies		0	
85(0x55)	Start streaming	Start a streaming session using the current slot and timing configuration.	0		0	
86(0x56)	Stop streaming	Stop the current streaming session.	0		0	
95(0x5F)	Update current timestamp	Set the current internal timestamp to the specified value.	0		4	Timestamp (Unsigned int)

4.5.8 Configuration Write Commands

16(0x10)	Set euler angle decomposition order	Sets the current euler angle decomposition order, which determines how the angles returned from command 0x1 are decomposed from the full quaternion orientation. Possible values are 0x0 for XYZ, 0x1 for YZX, 0x2 for ZXY, 0x3 for ZYX, 0x4 for XZY or 0x5 for YXZ (default).	0		1	Euler angle decomposition order (byte)
17(0x11)	Set magnetoresistive threshold	Sets required parameters that are necessary to trigger magnetometer resistance mode. First parameter to the command specifies the change in magnetometer field strength that is required to trigger the resistance. Once this field has been detected, the magnetometer will enter a period where it is completely locked out of the orientation calculation—this period will increase while magnetic perturbations are still being detected, but will dissipate as the sensor remains stationary. Once this period is over, the sensor orientation will slowly begin trusting the magnetometer again. The second parameter represents the number of frames that must elapse before the magnetometer is fully trusted again. The third parameter represents a decay value between 0 and 1 that indicates how quickly the outright magnetometer rejection state will fall off. Values closer to 1 result in the magnetometer rejection lasting longer. The final parameter represents how quickly a magnetic perturbation is detected. Values closer to 1 result in the magnetometer rejection occurring more slowly. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		16	Magnetoresistive threshold in gauss(float), Number of magnetometer trust frames (unsigned int), magnetometer lockout decay value (float), magnetometer perturbation detection value (float)
18(0x12)	Set accelerometer resistance threshold	Sets required parameters that are necessary to trigger accelerometer rejection. During the accelerometer rejection period, the contribution of the accelerometer to the selected orientation estimation algorithm will be zero. The arguments to this command specify the accelerometer threshold and the number of frames that the rejection is active, respectively. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		8	Accelerometer threshold in g's (float), Number of accelerometer lockout frames (unsigned int),
19(0x13)	Offset with current orientation	Sets the offset orientation to be the same as the current filtered orientation.	0		0	
20(0x14)	Reset base offset	Sets the base offset to an identity quaternion.	0		0	
21(0x15)	Offset with quaternion	Sets the offset orientation to be the same as the supplied orientation, which should be passed as a quaternion.	0		16	Quaternion (float x4)
22(0x16)	Set base offset with current orientation	Sets the base offset orientation to be the same as the current filtered orientation.	0		0	
96(0x60)	Tare with current orientation	Sets the tare orientation to be the same as the current filtered orientation.	0		0	
97(0x61)	Tare with quaternion	Sets the tare orientation to be the same as the supplied orientation, which should be passed as a quaternion.	0		16	Quaternion (float x4)
98(0x62)	Tare with rotation matrix	Sets the tare orientation to be the same as the supplied orientation, which should be passed as a rotation matrix.	0		36	Rotation Matrix (float x9)
99(0x63)	Set static accelerometer trust value	Determines how trusted the accelerometer contribution is to the overall orientation estimation. Trust is 0 to 1, with 1 being fully trusted and 0 being not trusted at all.	0		4	Accelerometer trust value (float)
100(0x64)	Set confidence accelerometer trust values	Determines how trusted the accelerometer contribution is to the overall orientation estimation. Instead of using a single value, uses a minimum and maximum value. Trust values will be selected from this range depending on the confidence factor. This can have the effect of smoothing out the accelerometer when the sensor is in motion.	0		8	Minimum accelerometer trust value (float), Maximum accelerometer trust value (float)
101(0x65)	Set static compass trust value	Determines how trusted the accelerometer contribution is to the overall orientation estimation. Trust is 0 to 1, with 1 being fully trusted and 0 being not trusted at all.	0		4	Compass trust value (float)

102(0x66)	Set confidence compass trust values	Determines how trusted the compass contribution is to the overall orientation estimation. Instead of using a single value, uses a minimum and maximum value. Trust values will be selected from this range depending on the confidence factor. This can have the effect of smoothing out the compass when the sensor is in motion.	0	8	Minimum compass trust value (float), Maximum compass trust value (float)
103(0x67)	Set desired update rate	Causes the processor to wait for the specified number of microseconds at the end of each update loop. Can be useful for bounding the overall update rate of the sensor if necessary.	0	4	Microsecond update rate (unsigned integer)
104(0x68)	Set multi reference vectors with current orientation	Uses the current tared orientation to set up the reference vector for the nearest orthogonal orientation. This is an advanced command that is best used through 3-Space Sensor Suite calibration utilities. For more information, please refer to the 3-Space Sensor Suite Quick Start Guide.	0	0	
105(0x69)	Set reference vector mode	Set the current reference vector mode. Parameter can be 0 for single static mode, which uses a certain reference vector for the compass and another certain vector for the accelerometer at all times, 1 for single auto mode, which uses (0, -1, 0) as the reference vector for the accelerometer at all times and uses the average angle between the accelerometer and compass to calculate the compass reference vector once upon initiation of this mode, 2 for single auto continuous mode, which works similarly to single auto mode, but calculates this continuously, or 3 for multi-reference mode, which uses a collection of reference vectors for the compass and accelerometer both, and selects which ones to use before each step of the filter.	0	1	Mode (Byte)
106(0x6A)	Set oversample rate	Sets the number of times to sample each component sensor for each iteration of the filter. This can smooth out readings at the cost of responsiveness. If this value is set to 0 or 1, no oversampling occurs—otherwise, the number of samples per iteration depends on the specified parameter, up to a maximum of 65535. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0	6	Gyro Samples (unsigned short), Accel Samples (unsigned short), Compass Samples (unsigned short)
107(0x6B)	Set gyroscope enabled	Enable or disable gyroscope readings as inputs to the orientation estimation. Note that updated gyroscope readings are still accessible via commands. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0	1	Enabled (Byte)
108(0x6C)	Set accelerometer enabled	Enable or disable accelerometer readings as inputs to the orientation estimation. Note that updated accelerometer readings are still accessible via commands. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0	1	Enabled (Byte)
109(0x6D)	Set compass enabled	Enable or disable compass readings as inputs to the orientation estimation. Note that updated compass readings are still accessible via commands. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0	1	Enabled (Byte)
110(0x6E)	Reset multi-reference vectors to zero	Resets all reference vectors in the multi-reference table to zero. Intended for advanced users.	0	0	
111(0x6F)	Set multi-reference table resolution	Sets the number of cell dimensions and number of nearby vectors per cell for the multi-reference lookup table. First parameter indicates the number of cell divisions—as an example, multi-reference mode, by default, only handles orientations reachable by successive rotations of ninety degrees about any of the three axes, and hence, has a resolution of 4 (360 / 4 == 90). Thus, a resolution of 8 would provide rotations of forty-five degrees about any of the three axes (360 / 8 == 45). The second parameter indicates the number of adjacent vectors that will be checked for each. In addition, the number of checked vectors can be adjusted as well. The second parameters refers to the number of adjacent reference vectors that are 'averaged' to produce the final reference vector for the particular orientation, up to a maximum of 32. Intended for advanced users.	0	2	Resolution (Byte), Number of Check Vectors (Byte)

112(0x70)	Set compass multi-reference vector	Directly set the multi-reference compass vector at the specified index. First parameter is index, second parameter is compass vector. Intended for advanced users.	0		13	Index (Byte), Compass Reference Vector (float x3)
113(0x71)	Set compass multi-reference check vector	Set the compass reading to be used as a check vector to determine which cell index to draw the reference vector from. First parameter is an index, second parameter is the compass vector. Intended for advanced users.	0		13	Index (Byte), Compass Check Vector (float x3)
114(0x72)	Set accelerometer multi-reference vector	Directly set the multi-reference accelerometer vector at the specified index. First parameter is index, second parameter is compass vector. Intended for advanced users.	0		13	Index (Byte), Accelerometer Reference Vector (float x3)
115(0x73)	Set accelerometer multi-reference check vector	Set the accelerometer reading to be used as a check vector to determine which cell index to draw the reference vector from. First parameter is an index, second parameter is the accelerometer vector. Intended for advanced users.	0		13	Index (Byte), Accelerometer Check Vector (float x3)
116(0x74)	Set axis directions	<p>Sets alternate directions for each of the natural axes of the sensor. The only parameter is a bitfield representing the possible combinations of axis swapping. The lower 3 bits specify where each of the natural axes appears:</p> <p>000: X Right, Y: Up, Z: Forward (left-handed system, standard operation) 001: X Right, Y: Forward, Z: Up (right-handed system) 002: X Up, Y: Right, Z: Forward (right-handed system) 003: X Forward, Y: Right, Z: Up (left-handed system) 004: X Up, Y: Forward, Z: Right (left-handed system) 005: X Forward, Y: Up, Z: Right (right-handed system)</p> <p>(For example, using X: Right, Y: Forward, Z: Up means that any values that appear on the positive vertical(Up) axis of the sensor will be the third(Z) component of any vectors and will have a positive sign, and any that appear on the negative vertical axis will be the Z component and will have a negative sign.)</p> <p>The 3 bits above those are used to indicate which axes, if any, should be reversed. If it is cleared, the axis will be pointing in the positive direction. Otherwise, the axis will be pointed in the negative direction. (Note: These are applied to the axes after the previous conversion takes place).</p> <p>Bit 4: Positive/Negative Z (Third resulting component) Bit 5: Positive/Negative Y (Second resulting component) Bit 6: Positive/Negative X (First resulting component)</p> <p>Note that for each negation that is applied, the handedness of the system flips. So, if X and Z are negative and you are using a left-handed system, the system will still be left handed, but if only X is negated, the system will become right-handed.</p>	0		1	Axis Direction Byte (byte)
117(0x75)	Set running average percent	<p>Sets what percentage of running average to use on a component sensor, or on the sensor's orientation. This is computed as follows:</p> $\text{total_value} = \text{total_value} * \text{percent}$ $\text{total_value} = \text{total_value} + \text{current_value} * (1 - \text{percent})$ $\text{current_value} = \text{total_value}$ <p>If the percentage is 0, the running average will be shut off completely. Maximum value is 1. This setting can be saved to non-volatile flash memory using the Commit Settings command.</p>	0		16	Gyro percent (float), accel percent (float), compass percent (float), orientation percent (float)

118(0x76)	Set compass reference vector	Sets the static compass reference vector for Single Reference Mode.	0		12	Compass Reference Vector (float x3)
119(0x77)	Set accelerometer reference vector	Sets the static accelerometer reference vector for Single Reference Mode.	0		12	Accelerometer Reference Vector (float x3)
120(0x78)	Reset filter	Resets the state of the currently selected filter	0		0	
121(0x79)	Set accelerometer range	Only parameter is the new accelerometer range, which can be 0 for $\pm 2g$ (Default range), which can be 1 for $\pm 4g$, or 2 for $\pm 8g$. Higher ranges can detect and report larger accelerations, but are not as accurate for smaller accelerations. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		1	Accelerometer range setting (byte)
122(0x7a)	Set multi-reference weight power	Set weighting power for multi reference vector weights. Multi reference vector weights are all raised to the weight power before they are summed and used in the calculation for the final reference vector. Setting this value nearer to 0 will cause the reference vectors to overlap more, and setting it nearer to infinity will cause the reference vectors to influence a smaller set of orientations.	0		4	Weight power (float)
123(0x7b)	Set filter mode	Used to disable the orientation filter or set the orientation filter mode. Changing this parameter can be useful for tuning filter-performance versus orientation-update rates. Passing in a parameter of 0 places the sensor into IMU mode, a 1 places the sensor into Kalman Filtered Mode (Default mode), a 2 places the sensor into Alternating Kalman Filter Mode, a 3 places the sensor into Complementary Filter Mode, a 4 places the sensor into Quaternion Gradient Descent Filter Mode, and a 5 places the sensor into Magnetoresistive Quaternion Gradient Descent Filter Mode. More information can be found in Section 3.1.5. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		1	Mode (Byte)
124(0x7c)	Set running average mode	Used to further smooth out the orientation at the cost of higher latency. Passing in a parameter of 0 places the sensor into a static running average mode, a 1 places the sensor into a confidence-based running average mode, which changes the running average factor based upon the confidence factor, which is a measure of how 'in motion' the sensor is. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		1	Mode (Byte)
125(0x7d)	Set gyroscope range	Only parameter is the new gyroscope range, which can be 0 for ± 250 DPS, 1 for ± 500 DPS, or 2 for ± 2000 DPS (Default range). Higher ranges can detect and report larger angular rates, but are not as accurate for smaller angular rates. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		1	Gyroscope range setting (Byte)
126(0x7e)	Set compass range	Only parameter is the new compass range, which can be 0 for $\pm 0.88G$, 1 for $\pm 1.3G$ (Default range), 2 for $\pm 1.9G$, 3 for $\pm 2.5G$, 4 for $\pm 4.0G$, 5 for $\pm 4.7G$, 6 for $\pm 5.6G$, or 7 for $\pm 8.1G$. Higher ranges can detect and report larger magnetic field strengths but are not as accurate for smaller magnetic field strengths. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		1	Compass range setting (Byte)

4.5.9 Configuration Read Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
128(0x80)	Get tare orientation as quaternion	Returns the current tare orientation as a quaternion.	16	Quaternion (float x4)	0	
129(0x81)	Get tare orientation as rotation matrix	Returns the current tare orientation as a rotation matrix.	36	Rotation Matrix (float x9)	0	
130(0x82)	Get accelerometer trust values	Returns the current accelerometer min and max trust values. If static trust values were set, both of these will be the same.	8	Accelerometer trust values, min and max (float x2)	0	
131(0x83)	Get compass trust values	Returns the current compass min and max trust values. If static trust values were set, both of these will be the same.	8	Compass trust values, min and max (float x2)	0	
132(0x84)	Get current update rate	Reads the amount of time taken by the last filter update step.	4	Last update time in microseconds (int)	0	
133(0x85)	Get compass reference vector	Reads the current compass reference vector. Note that this is not valid if the sensor is in Multi Reference Vector mode.	12	Compass reference vector (float x3)	0	
134(0x86)	Get accelerometer reference vector	Reads the current compass reference vector. Note that this is not valid if the sensor is in Multi Reference Vector mode.	12	Accelerometer reference vector (float x4)	0	
135(0x87)	Get reference vector mode	Reads the current reference vector mode. Return value can be 0 for single static, 1 for single auto, 2 for single auto continuous or 3 for multi.	1	Mode (byte)	0	
136(0x88)	Get compass multi-reference vector	Reads the multi-reference mode compass reference vector at the specified index. Intended for advanced users.	12	Compass multi-reference reference vector (float x3)	1	Index (byte)
137(0x89)	Get compass multi-reference check vector	Reads the multi-reference mode compass reference check vector at the specified index. Intended for advanced users.	12	Compass multi-reference reference check vector (float x3)	1	Index (byte)
138(0x8a)	Get accelerometer multi-reference vector	Reads the multi-reference mode accelerometer reference vector at the specified index. Intended for advanced users.	12	Accelerometer multi-reference reference vector (float x3)	1	Index (byte)
139(0x8b)	Get accelerometer multi-reference check vector	Reads the multi-reference mode accelerometer reference check vector at the specified index. Intended for advanced users.	12	Accelerometer multi-reference reference check vector (float x3)	1	Index (byte)
140(0x8c)	Get gyroscope enabled state	Returns a value indicating whether the gyroscope contribution is currently part of the orientation estimate: 0 for off, 1 for on.	1	Gyroscope enabled value (byte)	0	
141(0x8d)	Get accelerometer enabled state	Returns a value indicating whether the accelerometer contribution is currently part of the orientation estimate: 0 for off, 1 for on.	1	Accelerometer enabled value (byte)	0	
142(0x8e)	Get compass enabled state	Returns a value indicating whether the compass contribution is currently part of the orientation estimate: 0 for off, 1 for on.	1	Compass enabled value (byte)	0	
143(0x8f)	Get axis direction	Returns a value indicating the current axis direction setup. For more information on the meaning of this value, please refer to the Set Axis Direction command (116).	1	Axis direction value (byte)	0	
144(0x90)	Get oversample rate	Returns values indicating how many times each component sensor is sampled before being stored as raw data. A value of 1 indicates that no oversampling is taking place, while a value that is higher indicates the number of samples per component sensor per filter update step.	6	Gyro Samples (unsigned short), Accel Samples (unsigned short), Compass Samples (unsigned short)	0	
145(0x91)	Get running average percent	Returns the running average percent value for each component sensor and for the orientation. The value indicates what portion of the previous reading is kept and incorporated into the new reading.	16	Gyro percent (float), accel percent (float), compass percent (float), orientation percent (float)	0	
146(0x92)	Get desired update rate	Returns the current desired update rate. Note that this value does not indicate the actual update rate, but instead indicates the value that should be spent 'idling' in the main loop. Thus, without having set a specified desired update rate, this value should read 0.	4	Desired update rate in microseconds (int)	0	
148(0x94)	Get accelerometer range	Return the current accelerometer measurement range, which can be a 0 for ±2g, 1 for ±4g or a 2 for ±8g.	1	Accelerometer range setting (byte)	0	
149(0x95)	Get multi-reference mode power weight	Read weighting power for multi-reference vector weights. Intended for advanced users.	4	Weight (float)	0	

150(0x96)	Get multi-reference resolution	Reads number of cell divisions and number of nearby vectors per cell for the multi-reference vector lookup table. For more information on these values, please refer to the Set Multi-Reference Resolution command (111). Intended for advanced users.	2	Number of cell divisions (byte), number of nearby vectors (byte)	0
151(0x97)	Get number of multi-reference cells	Reads the total number of multi-reference cells. Intended for advanced users.	4	Number of cells (int)	0
152(0x98)	Get filter mode	Returns the current filter mode, which can be 0 for IMU mode, 1 for Kalman, 2 for Alternating Kalman, 3 for Complementary, or 4 for Quaternion Gradient Descent. For more information, please refer to the Set Filter Mode command (123).	1	Filter mode (byte)	0
153(0x99)	Get running average mode	Reads the selected mode for the running average, which can be 0 for normal or 1 for confidence.	1	Running average mode (byte)	0
154(0x9a)	Get gyroscope range	Reads the current gyroscope measurement range, which can be 0 for ± 250 DPS, 1 for ± 500 DPS or 2 for ± 2000 DPS.	1	Gyroscope range setting (byte)	0
155(0x9b)	Get compass range	Reads the current compass measurement range, which can be 0 for ± 0.88 G, 1 for ± 1.3 G, 2 for ± 1.9 G, 3 for ± 2.5 G, 4 for ± 4.0 G, 5 for ± 4.7 G, 6 for ± 5.6 G or 7 for ± 8.1 G.	1	Compass range setting (byte)	0
156(0x9c)	Get euler angle decomposition order	Reads the current euler angle decomposition order.	1	Euler angle decomposition order (byte)	0
157(0x9d)	Get magnetoresistive threshold	Reads the current magnetoresistive threshold parameters.	16	Magnetoresistive threshold in gauss(float), Number of magnetometer trust frames (unsigned int), magnetometer lockout decay value (float), magnetometer perturbation detection value (float)	0
158(0x9e)	Get accelerometer resistance threshold	Reads the current accelerometer threshold parameters.	8	Accelerometer threshold in g's (float), Number of accelerometer lockout frames (unsigned int),	0
159(0x9f)	Get offset orientation as quaternion	Returns the current offset orientation as a quaternion.	16	Quaternion (float x4)	0

4.5.10 Calibration Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
160(0xa0)	Set compass calibration coefficients	Sets the current compass calibration parameters to the specified values. These consist of a bias which is added to the raw data vector and a matrix by which the value is multiplied. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		48	Matrix (float x9), Bias (float x3)
161(0xa1)	Set accelerometer calibration coefficients	Sets the current accelerometer calibration parameters to the specified values. These consist of a bias which is added to the raw data vector and a matrix by which the value is multiplied. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		48	Matrix (float x9), Bias (float x3)
162(0xa2)	Get compass calibration coefficients	Return the current compass calibration parameters.	48	Matrix (float x9), Bias (float x3)		
163(0xa3)	Get accelerometer calibration coefficients	Return the current accelerometer calibration parameters.	48	Matrix (float x9), Bias (float x3)		
164(0xa4)	Get gyroscope calibration coefficients	Return the current gyroscope calibration parameters.	48	Matrix (float x9), Bias (float x3)		
165(0xa5)	Begin gyroscope auto-calibration	Performs auto-gyroscope calibration. Sensor should remain still while samples are taken. The gyroscope bias will be automatically placed into the bias part of the gyroscope calibration coefficient list.	0		0	
166(0xa6)	Set gyroscope calibration coefficients	Sets the current gyroscope calibration parameters to the specified values. These consist of a bias which is added to the raw data vector and a matrix by which the value is multiplied. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		48	Matrix (float x9), Bias (float x3)
169(0xa9)	Set calibration mode	Bias, 1 for Scale-Bias and 2 for Ortho-Calibration. For more information, refer to section 3.1.3 Additional Calibration. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		1	Mode (Byte)
170(0xaa)	Get calibration mode	Reads the current calibration mode, which can be 0 for Bias, 1 for Scale-Bias or 2 for Ortho-Calibration. For more information, refer to section 3.1.3 Additional Calibration.	1	Mode (byte)	0	
171(0xab)	Set ortho-calibration data point from current orientation	Set the ortho-calibration compass and accelerometer vectors corresponding to this orthogonal orientation. Intended for advanced users.	0		0	
172(0xac)	Set ortho-calibration data point from vector	Directly set a vector corresponding to this orthogonal orientation. First parameter is type, where 0 is for compass and 1 is for accelerometer. Second parameter is index, which indicates the orthogonal orientation. Intended for advanced users.	0		14	Type (Byte), Index (Byte), Accelerometer or Compass Vector (float x3)
173(0xad)	Get ortho-calibration data point	Return the vector corresponding to the orthogonal orientation given by index. First parameter is type, where 0 is for compass and 1 is for accelerometer. Second parameter is index, which indicates the orthogonal orientation. Intended for advanced users.	12	Accelerometer or compass vector (float x3)	2	Type (Byte), Index (Byte)
174(0xae)	Perform ortho-calibration	Stores accelerometer and compass data in the ortho-lookup table for use in the orientation fusion algorithm. For best results, each of the 24 orientations should be filled in with component sensor data. Note also that ortho-calibration data will not be used unless the calibration mode is set to Ortho-Calibration. For more information, refer to Section 3.1.3 Additional Calibration. Intended for advanced users.	0		0	
175(0xaf)	Clear ortho-calibration data	Clear out all ortho-lookup table data. Intended for advanced users.	0		0	

4.5.11 General Commands

196(0xc4)	Set LED Mode	Allows finer-grained control over the sensor LED. Accepts a single parameter that can be 0 for standard, which displays all standard LED status indicators or 1 for static, which displays only the LED color as specified by command 238.	0		1	LED mode (byte)
200(0xc8)	Get LED Mode	Returns the current sensor LED mode, which can be 0 for standard or 1 for static.	1	LED mode (byte)	0	
221(0xdd)	Set wired response header bitfield	Configures the response header for data returned over a wired connection. The only parameter is a four-byte bitfield that determines which data is prepended to all data responses. The following bits are used: 0x1: (1 byte) Success/Failure, with non-zero values representing failure. 0x2: (4 bytes) Timestamp, in microseconds. 0x4: (1 byte) Command echo—outputs the called command. Returns 0xFF for streamed data. 0x8: (1 byte) Additive checksum over returned data, but not including response header. 0x10: (1 byte) Logical ID, returns 0xFE for wired sensors. Meant to be used with 3-Space Dongle response header (For more info, see command 0xDB). 0x20: (4 bytes) Serial number 0x40: (1 byte) Data length, returns the length of the requested data, not including response header. This setting can be committed to non-volatile flash memory by calling the Commit Settings command. For more information on Response Headers, please refer to Section 4.4.	0		4	Response header configuration (Unsigned int)
222(0xde)	Get wired response header bitfield	Returns the current wired response header bitfield. For more information, please refer to Section 4.4.	4	Response header configuration (Unsigned int)	0	
223(0xdf)	Get firmware version string	Returns a string indicating the current firmware version.	12	Firmware version (string)	0	
224(0xe0)	Restore factory settings	Return all non-volatile flash settings to their original, default settings.	0		0	
225(0xe1)	Commit settings	Commits all current sensor settings to non-volatile flash memory, which will persist after the sensor is powered off. For more information on which parameters can be stored in this manner, refer to Section 3.4 Sensor Settings.	0		0	
226(0xe2)	Software reset	Resets the sensor.	0		0	
227(0xe3)	Set sleep mode	Sets the current sleep mode of the sensor. Supported sleep modes are 0 for NONE and 1 for IDLE. IDLE mode merely skips all filtering steps. NONE is the default state.	0		1	Sleep mode (byte)
228(0xe4)	Get sleep mode	Reads the current sleep mode of the sensor, which can be 0 for NONE or 1 for IDLE.	1	Sleep mode (byte)	0	
229(0xe5)	Enter bootloader mode	Places the sensor into a special mode that allows firmware upgrades. This will cause normal operation until the firmware update mode is instructed to return the sensor to normal operation. For more information on upgrading firmware, refer to the 3-Space Sensor Suite Quick Start Guide.	0		0	
230(0xe6)	Get hardware version string	Returns a string indicating the current hardware version.	32	Hardware version (string)	0	
231(0xe7)	Set UART baud rate	Sets the baud rate of the physical UART. This setting does not need to be committed, but will not take effect until the sensor is reset. Valid baud rates are 1200, 2400, 4800, 9600, 19200, 28800, 38400, 57600, 115200 (default), 230400, 460800 and 921600. Note that this is only applicable for sensor types that have UART interfaces.	0		4	Baud rate (int)
232(0xe8)	Get UART baud rate	Returns the baud rate of the physical UART. Note that this is only applicable for sensor types that have UART interfaces.	4	Baud rate (int)	0	

233(0xe9)	Set USB Mode	Sets the communication mode for USB. Accepts one value that can be 0 for CDC (default) or 1 for FTDI.	0		1	USB communication mode (byte)
234(0xea)	Get USB Mode	Returns the current USB communication mode.	1	USB communication mode (byte)	0	
237(0xed)	Get serial number	Returns the serial number, which will match the value etched onto the physical sensor.	4	Serial number (int)	0	
238(0xee)	Set LED color	Sets the color of the LED on the sensor to the specified RGB color. This setting can be committed to non-volatile flash memory by calling the Commit Wireless Settings command.	0		12	RGB Color (float x3)
239(0xef)	Get LED color	Returns the color of the LED on the sensor.	12	RGB Color (float x3)	0	

4.5.12 Wired HID Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
240(0xf0)	Enable/disable joystick	Enable or disable streaming of joystick HID data for this sensor.	0		1	Joystick enabled state (byte)
241(0xf1)	Enable/disable mouse	Enable or disable streaming of mouse HID data for this sensor.	0		1	Mouse enabled state (byte)
242(0xf2)	Get joystick enabled	Read whether the sensor is currently streaming joystick HID data.	1	Joystick enabled state (byte)	0	
243(0xf3)	Get mouse enabled	Read whether the sensor is currently streaming mouse HID data.	1	Mouse enabled state (byte)	0	

4.5.13 General HID Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
244(0xf4)	Set control mode	<p>Sets the operation mode for one of the controls. The first parameter is the control class, which can be 0 for Joystick Axis, 1 for Joystick Button, 2 for Mouse Axis or 3 for Mouse Button. There are two axes and eight buttons on the joystick and mouse. The second parameter, the control index, selects which one of these axes or buttons you would like to modify. The third parameter, the handler index, specifies which handler you want to take care of this control. These can be the following:</p> <p>Turn off this control: 255</p> <p>Axes: Global Axis: 0 Screen Point: 1</p> <p>Buttons: Hardware Button: 0 Orientation Button: 1 Shake Button: 2</p>	0		3	Control class (byte), control index (byte), handler index (byte)
245(0xf5)	Set control data	Sets parameters for the specified control's operation mode. The control classes and indices are the same as described in command 244. Each mode can have up to 10 data points associated with it. How many should be set and what they should be set to is entirely based on which mode is being used.	0		7	Control class (byte), control index (byte), data point index (byte), data point (float)
246(0xf6)	Get control mode	Reads the handler index of this control's mode. The control classes and indices are the same as described in command 244.	1	Handler index (byte)	2	Control class (byte), control index (byte)
247(0xf7)	Get control data	Reads the value of a certain parameter of the specified control's operation mode. The control classes and indices are the same as described in command 244.	4	Data point (float)	3	Control class (byte), control index (byte), data point index (byte)
248(0xf8)	Set button gyro disable length	Determines how long, in frames, the gyros should be disabled after one of the physical buttons on the sensor is pressed. A setting of 0 means they won't be disabled at all. This setting helps to alleviate gyro disturbances caused by the buttons causing small shockwaves in the sensor.	0		1	Number of frames (byte)
249(0xf9)	Get button gyro disable length	Returns the current button gyro disable length.	1	Number of frames (byte)	0	
250(0xfa)	Get button state	Reads the current state of the sensor's physical buttons. This value returns a byte, where each bit represents the state of the sensor's physical buttons.	1	Button state (byte)	0	
251(0xfb)	Set mouse absolute/relative mode	Puts the mode in absolute or relative mode. This change will not take effect immediately and the sensor must be reset before the mouse will enter this mode. The only parameter can be 0 for absolute (default) or 1 for relative.	0		1	Absolute or relative mode (byte)
252(0xfc)	Get mouse absolute/relative mode	Return the current mouse absolute/relative mode. Note that if the sensor has not been reset since it has been put in this mode, the mouse will not reflect this change yet, even though the command will.	1	Absolute or relative mode (byte)	0	
253(0xfd)	Set joystick and mouse present/removed	Sets whether the joystick and mouse are present or removed. The first parameter is for the joystick, and can be 0 for removed or 1 for present. The second parameter is for the mouse. If removed, they will not show up as devices on the target system at all. For these changes to take effect, the sensor driver may need to be reinstalled.	0		2	Joystick present/removed (byte), Mouse present/removed (byte)
254(0xfe)	Get joystick and mouse present/removed	Returns whether the joystick and mouse are present or removed.	2	Joystick present/removed (byte), Mouse present/removed (byte)	0	

Appendix

Hex / Decimal Conversion Chart

		<i>Second Hexadecimal digit</i>															
		<i>0</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>6</i>	<i>7</i>	<i>8</i>	<i>9</i>	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>	<i>F</i>
First Hexadecimal Digit	<i>0</i>	000	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015
	<i>1</i>	016	017	018	019	020	021	022	023	024	025	026	027	028	029	030	031
	<i>2</i>	032	033	034	035	036	037	038	039	040	041	042	043	044	045	046	047
	<i>3</i>	048	049	050	051	052	053	054	055	056	057	058	059	060	061	062	063
	<i>4</i>	064	065	066	067	068	069	070	071	072	073	074	075	076	077	078	079
	<i>5</i>	080	081	082	083	084	085	086	087	088	089	090	091	092	093	094	095
	<i>6</i>	096	097	098	099	100	101	102	103	104	105	106	107	108	109	110	111
	<i>7</i>	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127
	<i>8</i>	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143
	<i>9</i>	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159
	<i>A</i>	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175
	<i>B</i>	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191
	<i>C</i>	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207
	<i>D</i>	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223
	<i>E</i>	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239
	<i>F</i>	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255

Notes:

Serial Number: _____



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