3-Space Sensor Embedded

Ultra-Miniature Attitude & Heading Reference System

User's Manual

YEI Technology
630 Second Street
Portsmouth, Ohio 45662

www.YeiTechnology.com
www.3SpaceSensor.com

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Toll-Free: 888-395-9029
Phone: 740-355-9029

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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 YEI 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

YEI provides technical and user support via our toll-free number (888-395-9029) and via email (support@YostEngineering.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 YEI 3-Space Sensor

2.1 Introduction

The YEI 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 YEI 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 YEI 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.

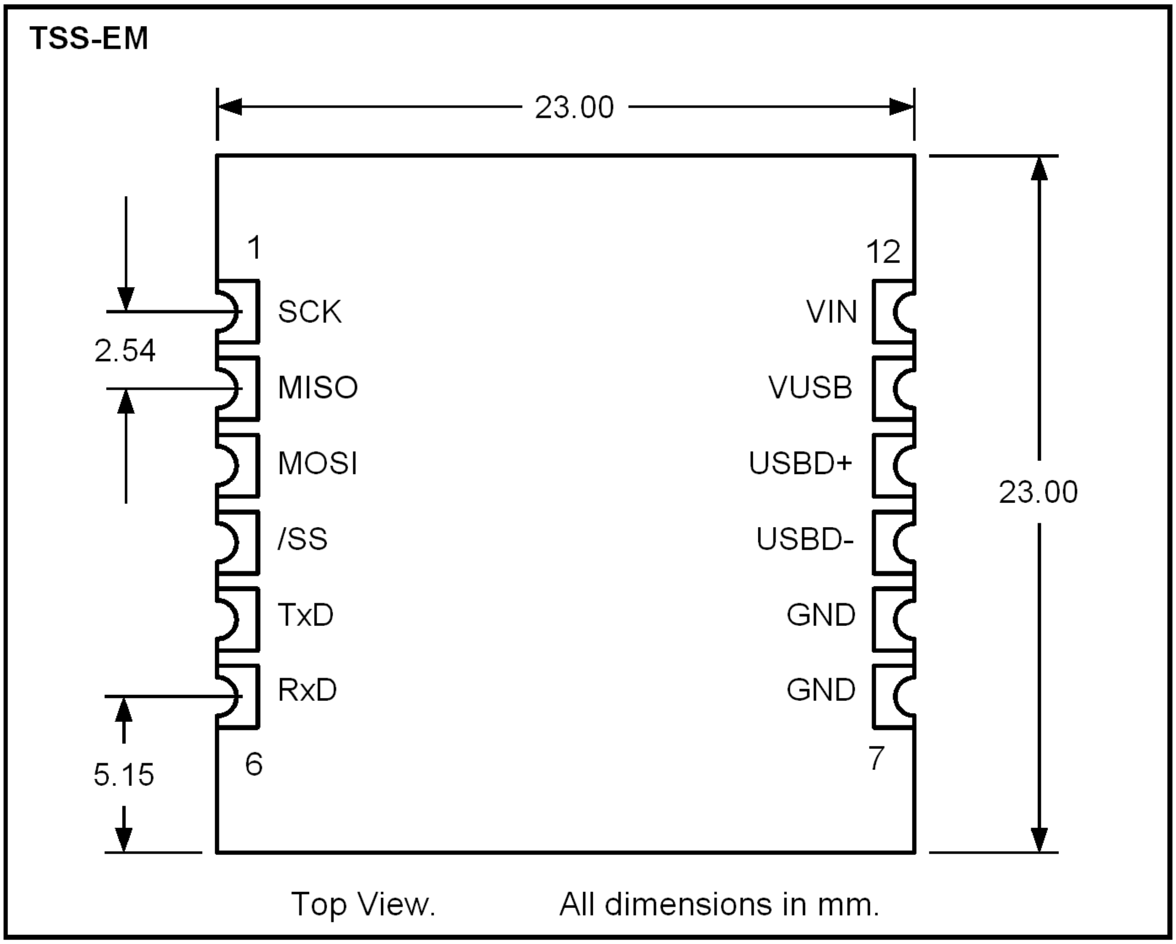
When used as a USB device, the Embedded 3-Space Sensor™ provides mouse emulation and joystick emulation modes that ease integration with existing applications.

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 YEI 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.

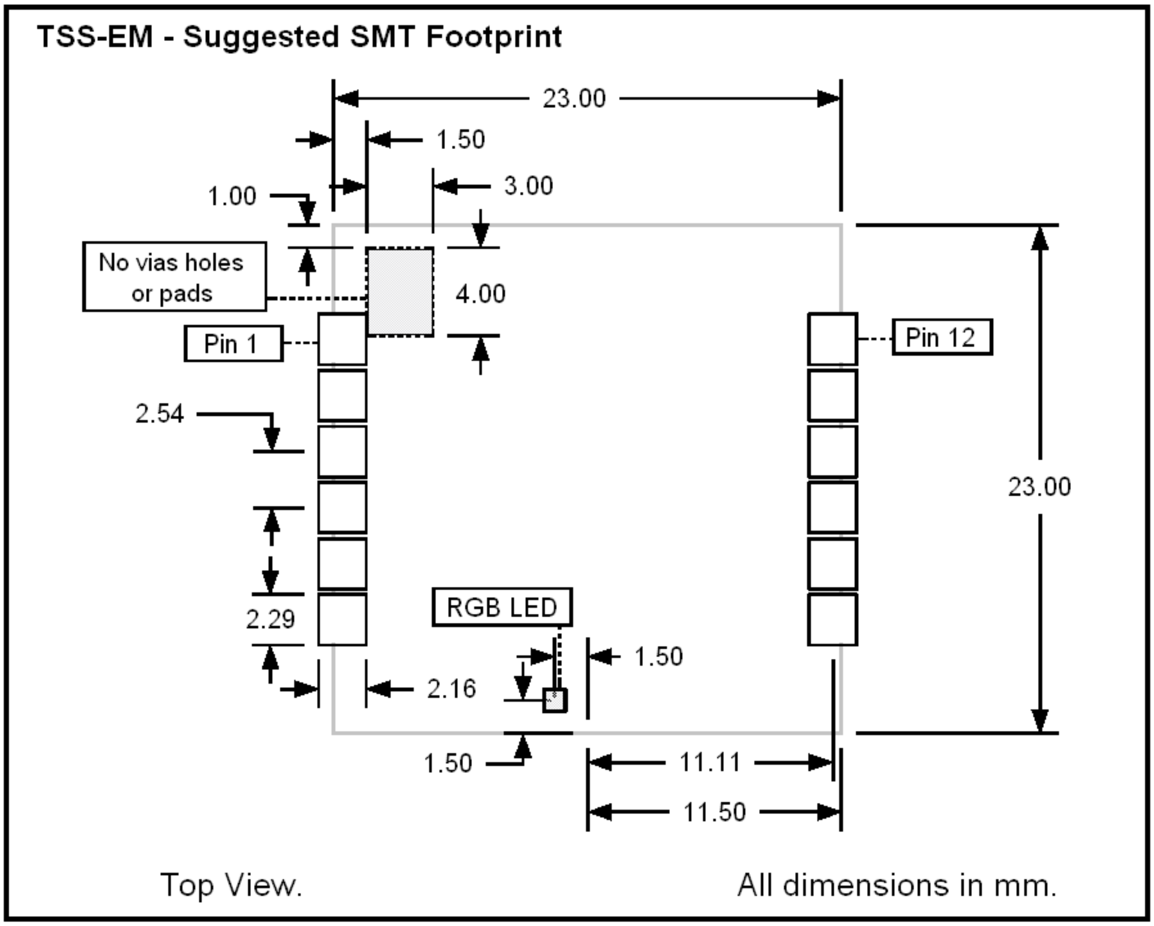


2.3.1 Pin Functions

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	USBD-	USB Data Minus. Only requires connection during USB mode use.
10	USBD+	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 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:

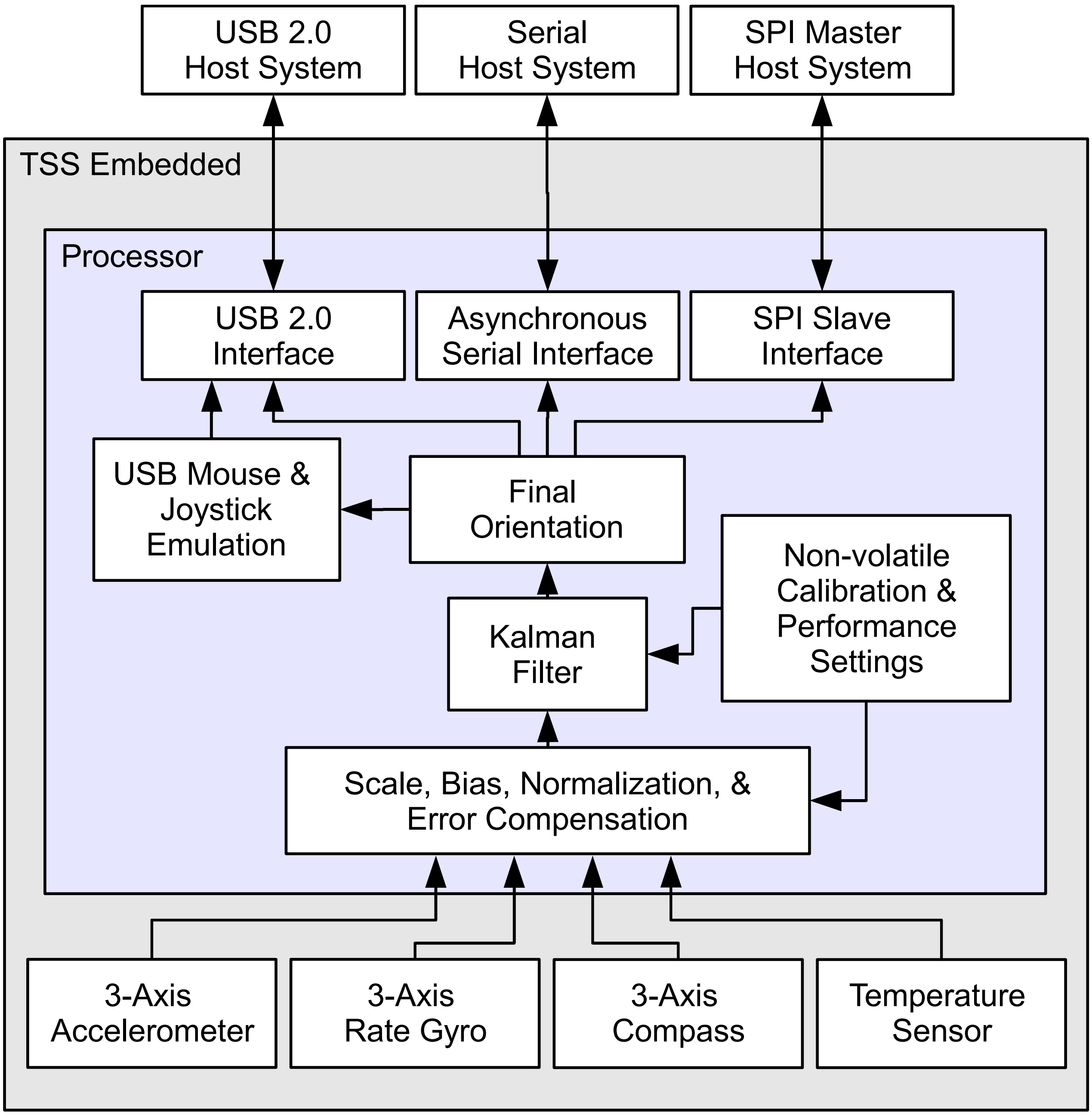
- Do not place untented pads, vias, or holes beneath the restricted area in the diagram.
- Do not place magnetic components such as speakers and motors in close proximity to the module since the magnetic fields generated can adversely affect the performance of the compass module.
- Do not place components 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 YEI 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 200Hz with full functionality
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	360º about all axes
Orientation accuracy	±2º for dynamic conditions & all orientations
Orientation resolution	<0.08º
Orientation repeatability	0.085º 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 º/sec selectable
Gyro resolution	16 bit
Gyro noise density	0.03º/sec/√ Hz
Gyro bias stability @ 25°C	11º/hr average for all axes
Gyro sensitivity	0.00875º/sec/digit for ±250º/sec 0.01750º/sec/digit for ±500º/sec 0.070º/sec/digit for ±2000º/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.

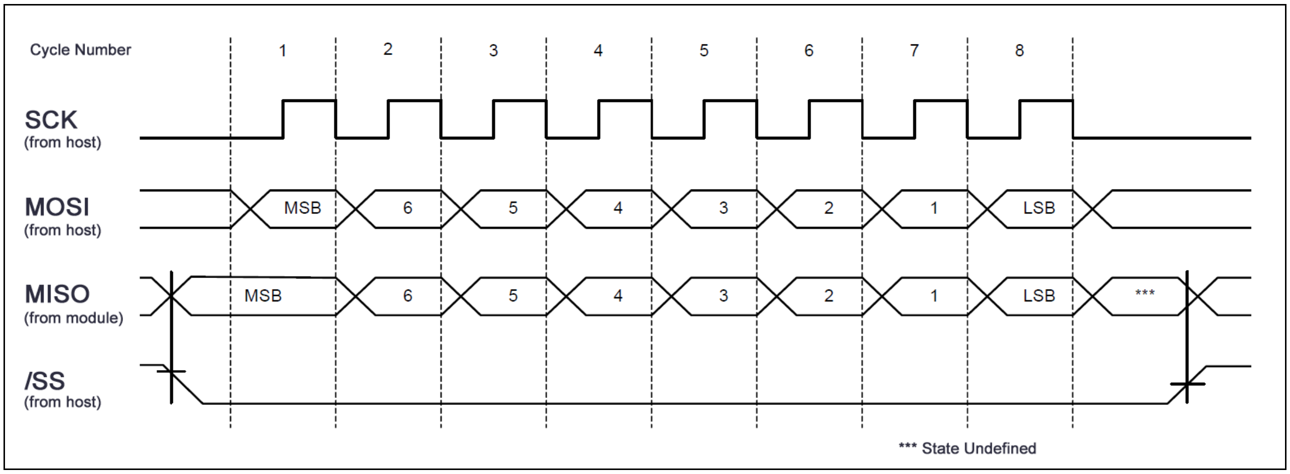
The Asynchronous Serial uses 8N1 (8 data bits, no parity, 1 stop bit) format and supports the following standard baud rates: 1200, 2400, 4800, 9600, 19200, 28800, 38400, 57600, 115200, 230400, 460800, 921600.

The factory default baud rate is 115200.

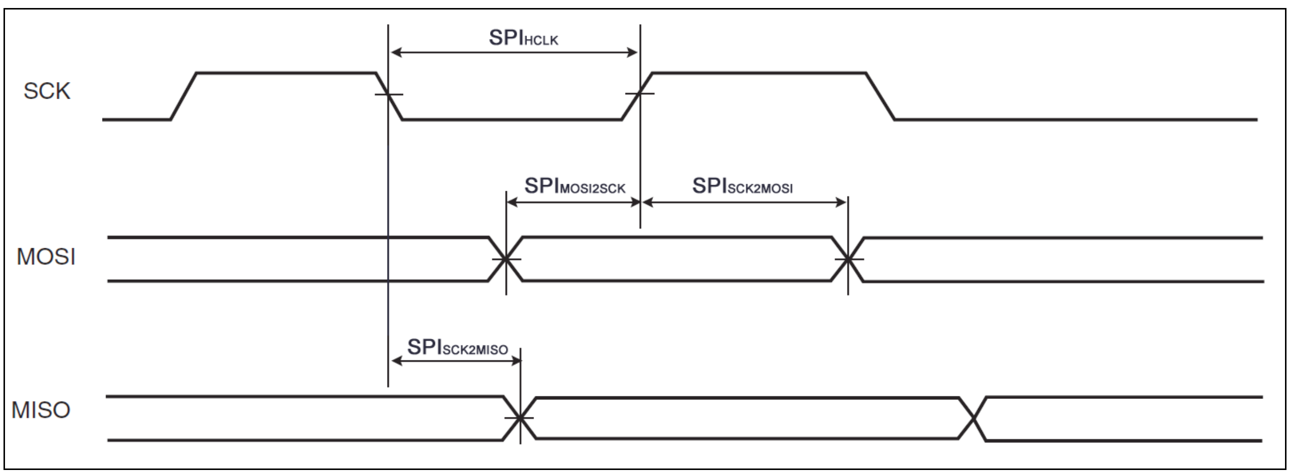
2.7.5 SPI Characteristics

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

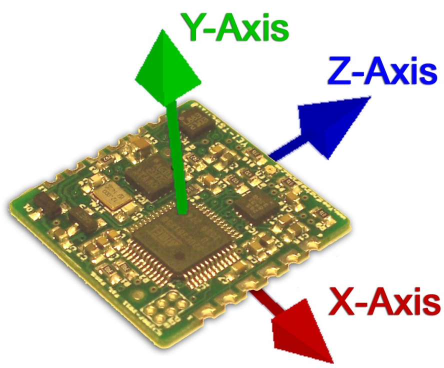
2.8 Axis Assignment

All YEI 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 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 matrix and vector 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.

3.1.4 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.

3.1.5 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.
- **IMU Mode:** Performs no orientation filtering, but allows IMU data to be read at the maximum update rate of 800 Hz.

3.1.6 Reference Orientation/Taring

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.

3.1.7 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.
- **Rho Values:** As mentioned earlier, by default the accelerometer and compass are trusted less than the gyros when the sensor is in motion. Rho values are the mechanism that handles the concept of trust. They 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. A lower value for the parameter means more trust. The default mode for this is “confidence mode”, where the rho value chooses between a minimum and maximum value based on how much the sensor is moving. The other option is to have a single, static rho value.

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.

3.3 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 YEI 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 Rho Value	Determine how trusted the accelerometer is	Confidence Mode, 5 to 100
Compass Rho Value	Determine how trusted the compass is	Confidence Mode, 5 to 100
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)
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
Reference Mode	Determines how the accelerometer and compass reference vectors are determined	Single Auto
UART Baud Rate	Determines the speed of the Serial UART 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
Interrupt Generation Mode	Determines how interrupts are generated	Off, pin TXD

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

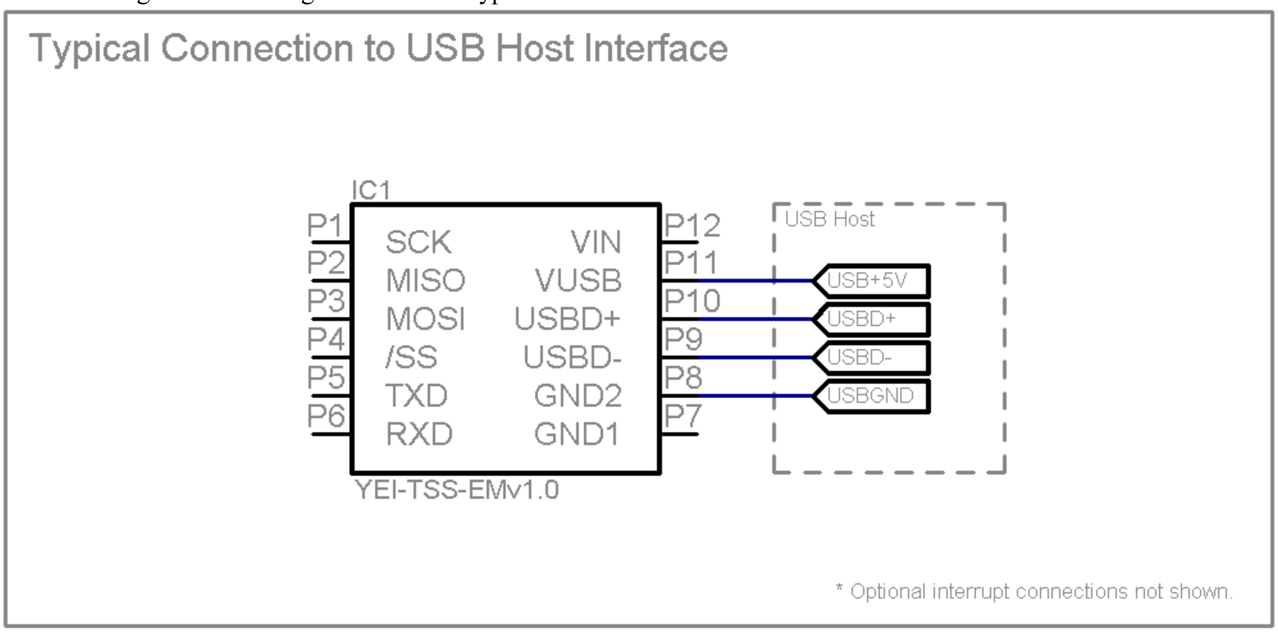
The USB 2.0 interface of the 3-Space Sensor Embedded requires the connection of signals as follows:

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

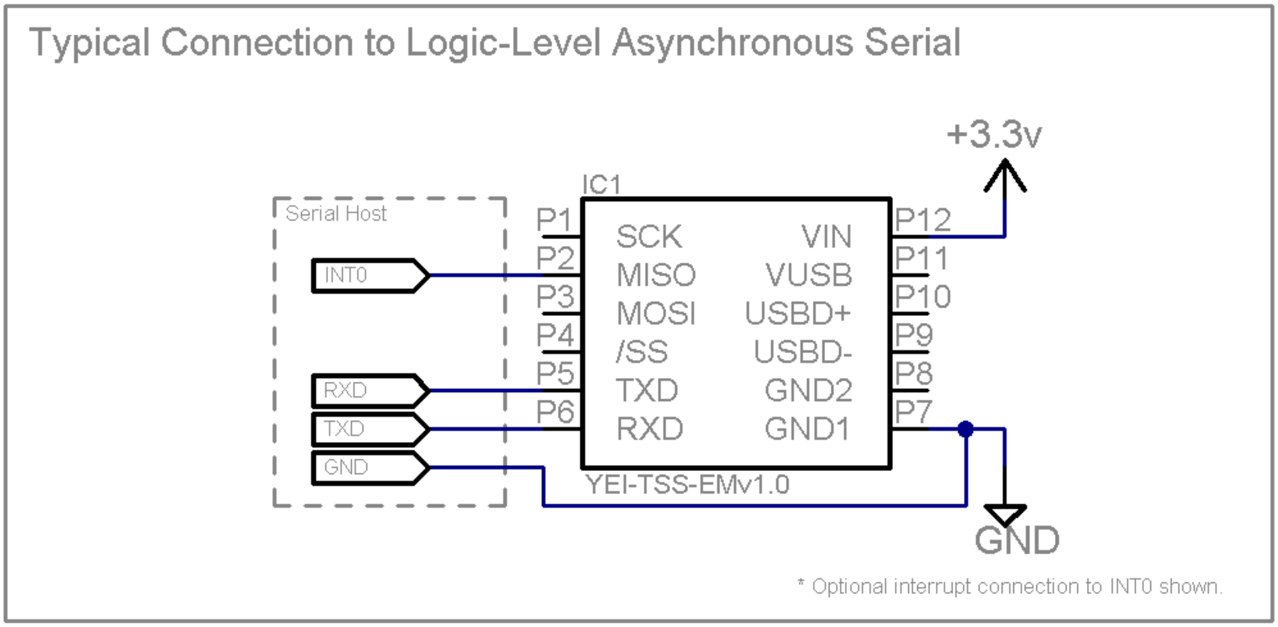
The asynchronous serial interface of the 3-Space Sensor Embedded requires the connection of signals as follows:

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.

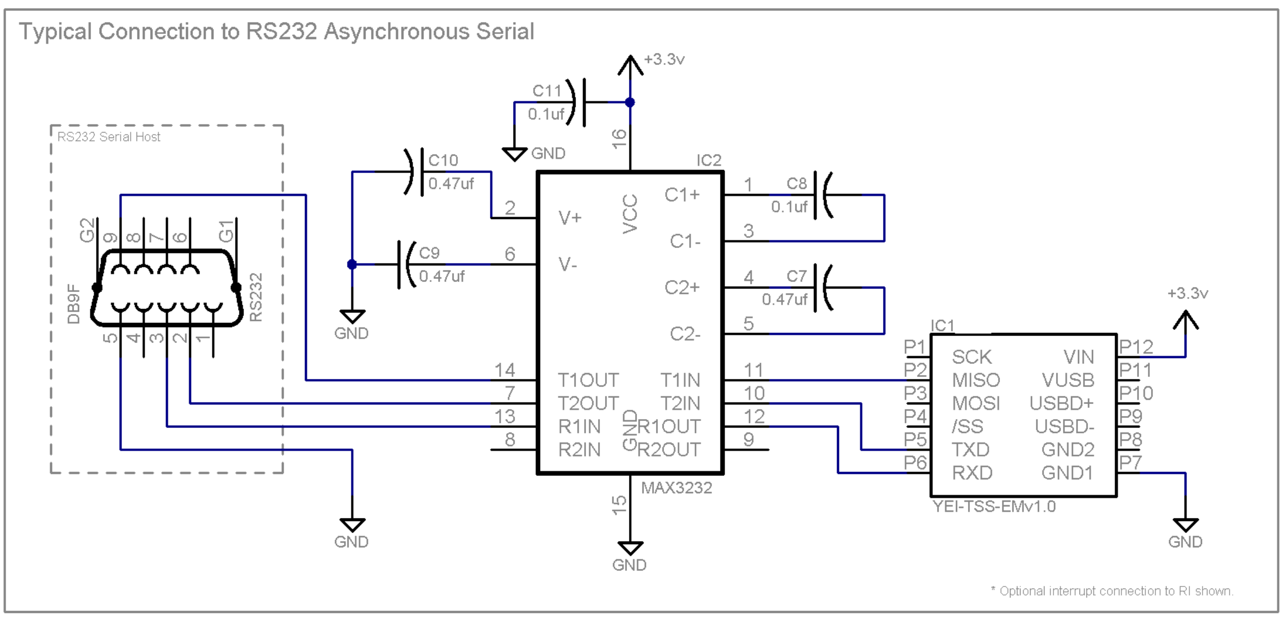
Additionally, the following optional interrupt pin may be configured for use during asynchronous serial mode:

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

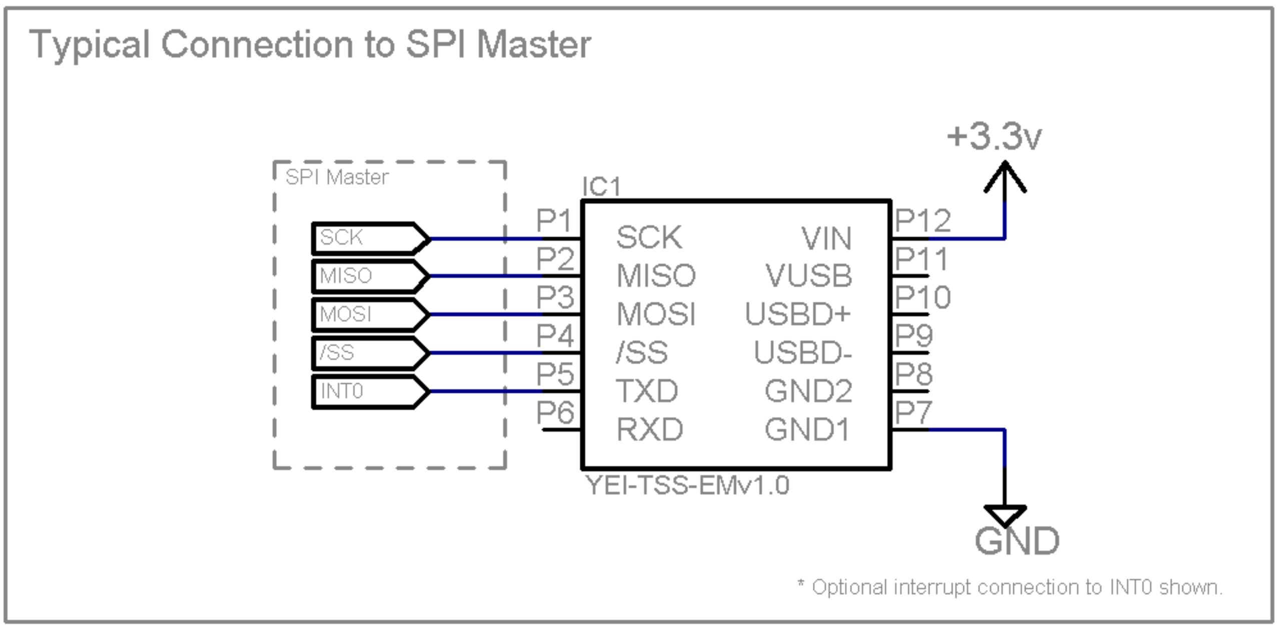
The Serial Peripheral Interface (SPI) of the 3-Space Sensor Embedded requires the connection of signals as follows:

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 18). 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 interrupt pin and mode, see command 16.

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.

4.2 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

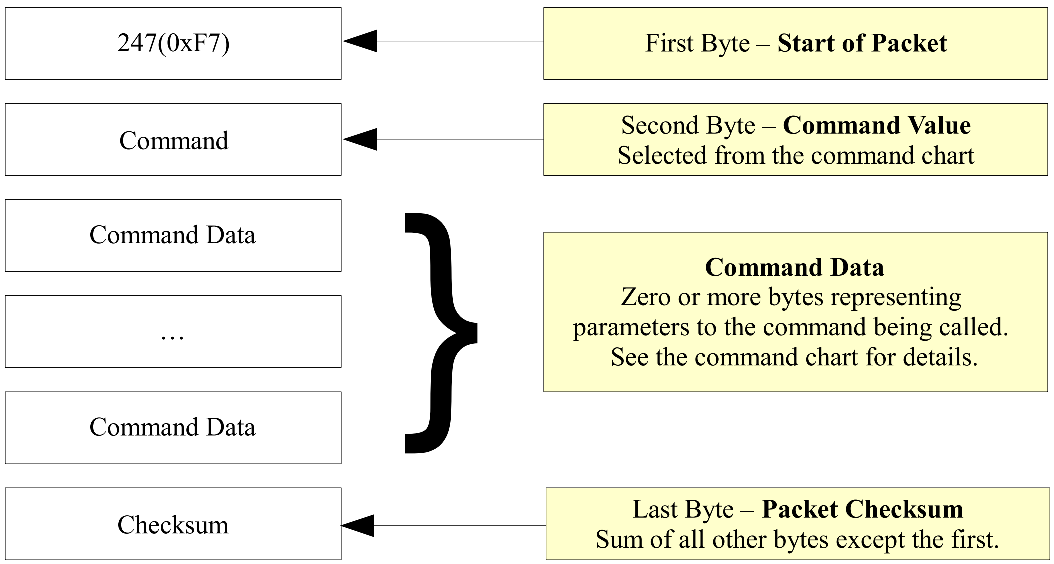


Figure 1 - Typical Binary Command Packet Format

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.

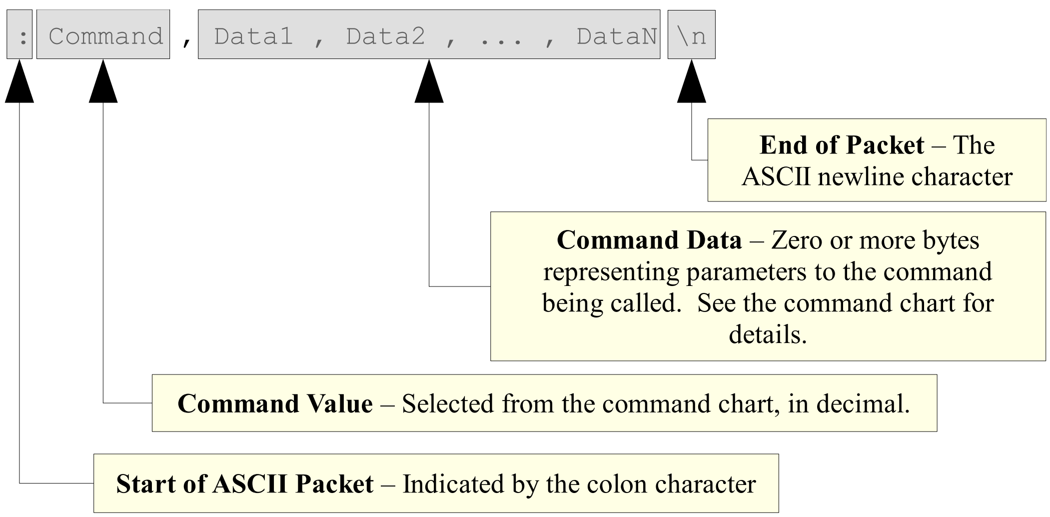


Figure 2 - Typical ASCII Command Packet Format

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 Protocol Packet Format(SPI)

4.3.1 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.

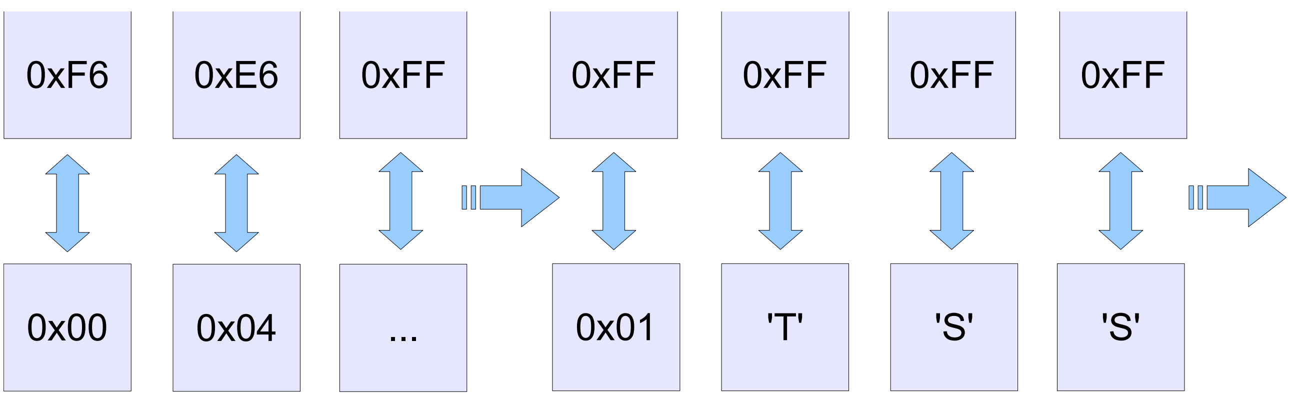


Figure 3 – Sample SPI Communication

4.4 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.

4.3.1 Orientation Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
0(0x00)	Read tared orientation as quaternion	Returns the filtered, tared orientation estimate in quaternion form.	16	Quaternion (float x4)	0	
1(0x01)	Read tared orientation as euler angles	Returns the filtered, tared orientation estimate in euler angle form	12	Euler Angles (float x3)	0	
2(0x02)	Read tared orientation as rotation matrix	Returns the filtered, tared orientation estimate in rotation matrix form	36	Rotation Matrix (float x9)	0	
3(0x03)	Read tared orientation as axis angle	Returns the filtered, tared orientation estimate in axis-angle form	16	Axis (float x3), Angle (float)	0	
4 (0x04	Read 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)	Read difference quaternion	Returns the difference between the measured orientation from last frame and this frame.	16	Quaternion (float x4)	0	
6(0x06)	Read untared orientation as quaternion	Returns the filtered, untared orientation estimate in quaternion form.	16	Quaternion (float x4)	0	
7(0x07)	Read untared orientation as euler angles	Returns the filtered, untared orientation estimate in euler angle form	16	Euler Angles (float x3)	0	
8(0x08)	Read untared orientation as rotation matrix	Returns the filtered, untared orientation estimate in rotation matrix form	36	Rotation Matrix (float x9)	0	
9(0x09)	Read untared orientation as axis angle	Returns the filtered, untared orientation estimate in axis-angle form	16	Axis (float x3), Angle (float)	0	
10(0x0A)	Read 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)	Read 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)	Read untared 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	North Vector (float x3), Gravity Vector (float x3)	0	

4.3.2 Embedded Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
29(0x1D)	Set interrupt type	Sets the interrupt mode of the sensor. First parameter is mode, which can be 0 for off, 1 for pulse mode, 2 for level, 3 for SPI pulse. Second parameter is pin, which can be 0 for TXD or 1 for MISO.	0		2	Mode (Byte), Pin (Byte)
30(0x1E)	Read interrupt type	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. Second parameter is pin, which will be 0 for TXD or 1 for MISO.	2	Mode (Byte), Pin (Byte)	0	
31(0x1F)	Read 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	

4.3.3 Normalized Data Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
32(0x20)	Read 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 (Vector x3), Gravity Direction (Vector x3), North Direction (Vector x3)	0	
33(0x21)	Read normalized gyro rate	Returns the normalized gyro rate vector, which is in units of radians/sec.	12	Gyro Rate (Vector x3)	0	
34(0x22)	Read 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)	Read 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	

4.3.4 Other Data Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
36(0x24)	Read temperature C	Returns the temperature of the sensor in Celsius.	4	Temperature (float)	0	
37(0x25)	Read temperature F	Returns the temperature of the sensor in Fahrenheit	4	Temperature (float)	0	
38(0x26)	Read 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	

4.3.5 Corrected Data Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
39(0x27)	Read corrected accelerometer	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)	Read corrected compass	Returns the compass vector in units of gauss.	12	Compass Vector in units of gauss (float x3)	0	

4.3.6 Raw Data Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
64(0x40)	Read 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)	Read 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)	Read 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)	Read 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	

4.3.7 Configuration Write Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
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 rho mode	Determines how trusted the accelerometer contribution is to the overall orientation estimation. Higher values mean that the accelerometer is less trusted.	0		4	Accelerometer rho value (float)
100(0x64)	Set confidence accelerometer rho mode	Determines how trusted the accelerometer contribution is to the overall orientation estimation. Instead of using a single value, uses a minimum and maximum value. Rho values will be changed within 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 rho value (float), Maximum accelerometer rho value (float)
101(0x65)	Set static compass rho mode	Determines how trusted the accelerometer contribution is to the overall orientation estimation. Higher values mean that the compass is less trusted.	0		4	Compass rho value (float)
102(0x66)	Set confidence compass rho mode	Determines how trusted the compass contribution is to the overall orientation estimation. Instead of using a single value, uses a minimum and maximum value. Rho values will be changed within this range depending on the confidence factor. This can have the effect of reducing the compass's effect on the overall orientation estimation and thus reducing magnetically-induced interference.	0		8	Minimum compass rho value (float), Maximum compass rho 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	

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
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), Pin (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 performance. 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 10. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		1	Samples Per Iteration (Byte)
107(0x6B)	Enable/disable gyroscope	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	Mode (Byte)
108(0x6C)	Enable/disable accelerometer	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	Mode (Byte)
109(0x6D)	Enable/disable compass	Enable or disable compass readings as inputs to the orientation estimation. Note that compass readings are still accessible via commands. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		1	Mode (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 mulfi-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)

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
116(0x74)	Set axis directions	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 which axis each of the natural axes will be read as: 000: XYZ (standard operation) 001: XZY 002: YXZ 003: YZX 004: ZXY 005: ZYX (For example, using XZY means that whatever value appears as Y on the natural axes will now be the Z component of any new data and vice-versa.) 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). Bit 4: Positive/Negative Z (Third resulting component) Bit 5: Positive/Negative Y (Second resulting component) Bit 6: Positive/Negative X (First resulting component)	0		1	Axis Direction Byte (byte)
117(0x75)	Set running average percent	Sets what percentage of running average to use on the sensor's orientation. This is computed as follows: total_orient = total_orient * percent total_orient = total_orient + current_orient * (1 – percent) current_orient = total_orient If the percentage is 0, the running average will be shut off completely. Maximum value is 97%. This setting can be saved to non-volatile flash memory using the Commit Settings command.	0		4	Running Average 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(0x7c)	Reset Kalman filter	Resets Kalman filter's state and covariance matrices.	0		0	
121(0x79)	Set accelerometer range	Only parameter is the new accelerometer range, which can be 0 for ±2g (Default range), which can be 1 for ±4g, or 2 for ±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, and a 3 places the sensor into Complementary 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)

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
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 ±0.88G, 1 for ±1.3G (Default range), 2 for ±1.9G, 3 for ±2.5G, 4 for ±4.0G, 5 for ±4.7G, 6 for ±5.6G, or 7 for ±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)

4.3.8 Configuration Read Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
128(0x80)	Read tare orientation as quaternion	Returns the current tare orientation as a quaternion.	16	Quaternion (float x4)	0	
129(0x81)	Read tare orientation as rotation matrix	Returns the current tare orientation as a rotation matrix.	36	Rotation Matrix (float x9)	0	
130(0x82)	Read accelerometer rho value	Returns the current accelerometer rho mode as well as the value. If this mode is set to 0 (static), this will return the rho mode, the static rho value, and then a dummy value of 0. If this mode is set to 1, this will return the rho mode, and the minimum and maximum rho values.	9	Accelerometer rho mode (byte), Accelerometer rho values (float x2)	0	
131(0x83)	Read compass rho value	Returns the current compass rho mode as well as the value. If this mode is set to 0 (static), this will return the rho mode, the static rho value, and then a dummy value of 0. If this mode is set to 1, this will return the rho mode, and the minimum and maximum rho values.	9	Compass rho mode (byte), Compass rho values (float x2)	0	
132(0x84)	Read 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)	Read 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)	Read 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)	Read 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)		
136(0x88)	Read 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)	Read 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)	Read 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)	Read 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)	Read 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)	Read 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)	Read 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	

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
143(0x8f)	Read axis-direction byte	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)	Read oversample rate	Returns a value 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.	1	Oversample rate (byte)	0	
145(0x91)	Read running average percent	Returns a value indicating how heavily the orientation estimate is based upon the estimate from the previous frame. For more information on the meaning of this value, please refer to the Set Running Average Percent command (117).	4	Running average percent (float)	0	
146(0x92)	Read 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	
147(0x93)	Read Kalman filter covariance matrix	Return the current Kalman filter covariance matrix.	36	Covariance matrix (float x9)	0	
148(0x94)	Read 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)	Read multi-reference mode power weight	Read weighting power for multi-reference vector weights. Intended for advanced users.	4	Weight (float)	0	
150(0x96)	Read 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)	Read 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)	Read filter mode	Returns the current filter mode, which can be 0 for IMU mode, 1 for Kalman, 2 for Alternating Kalman or 3 for Complementary. For more information, please refer to the Set Filter Mode command (123).	1	Filter mode (byte)	0	
153(0x99)	Read 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)	Read 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)	Read compass range	Reads the current compass measurement range, which can be 0 for ±0.88G, 1 for ±1.3G, 2 for ±1.9G, 3 for ±2.5G, 4 for ±4.0G, 5 for ±4.7G, 6 for ±5.6G or 7 for ±8.1G.	1	Compass range setting (byte)	0	

4.3.9 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	Bias (float x3), Matrix (float x9)
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	Bias (float x3), Matrix (float x9)
162(0xa2)	Read compass calibration coefficients	Return the current compass calibration parameters.	48	Bias (float x3), Matrix (float x9)		
163(0xa3)	Read accelerometer calibration coefficients	Return the current accelerometer calibration parameters.	48	Bias (float x3), Matrix (float x9)		
164(0xa4)	Read gyroscope calibration coefficients	Return the current gyroscope calibration parameters.	48	Bias (float x3), Matrix (float x9)		
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	Bias (float x3), Matrix (float x9)
169(0xa9)	Set calibration mode	Sets the current calibration mode, which can be 0 for 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)	Read 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)	Read 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	

4.3.10 General Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
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.	1	LED mode (byte)	0	
200(0xc8)	Read LED Mode	Returns the current sensor LED mode, which can be 0 for standard or 1 for static.	0		1	LED mode (byte)
223(0xdf)	Read 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)	Enable watchdog timer	Enables the onboard watchdog timer with the specified timeout rate. If a frame takes more than this amount of time, the sensor will automatically reset.	0		4	Timeout rate in microseconds (int)
228(0xe4)	Disable watchdog timer	Disables the watchdog timer.	0		0	
229(0xe5)	Enter bootloader mode	Places the sensor into a special mode that allows firmware upgrades. This will case 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)	Read 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)	Read 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	
235(0xeb)	Set clock speed	Sets the current processor clock speed. Possible values are 15Mhz, 30 Mhz or 60 Mhz (default). This setting does not need to be committed, but does not take effect until the sensor is reset.	0		4	Clock speed in Hz (int)
236(0xec)	Get clock speed	Returns the current processor clock speed.	4	Clock speed in Hz (int)	0	
237(0xed)	Get serial number	Returns the serial number, which will match the value etched onto the physical sensor.	4	Serial number (int)		
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	

4.3.11 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)	Read joystick enabled	Read whether the sensor is currently streaming joystick HID data.	1	Joystick enabled state (byte)	0	
243(0xf3)	Read mouse enabled	Read whether the sensor is currently streaming mouse HID data.	1	Mouse enabled state (byte)	0	

4.3.12 General HID Commands

Command	Description	Long Description	Return Data Len	Return Data Details	Data Len	Data Details
244(0xf4)	Set control mode	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: Turn off this control: 255 Axes: Global Axis: 0 Screen Point: 1 Buttons: Hardware Button: 0 Orientation Button: 1 Shake Button: 2	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)	Read 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)	Read 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 cause by the buttons causing small shockwaves in the sensor.	0		1	Number of frames (byte)
249(0xf9)	Get button gyro disable lentgh	Returns the current button gyro disable length.	1	Number of frames (byte)	0	
250(0xfa)	Read 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)	Read 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

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

Notes:

Serial Number: ______________________________

YEI Technology
630 Second Street
Portsmouth, Ohio 45662

Toll-Free: 888-395-9029
Phone: 740-355-9029

www.YeiTechnology.com
www.3SpaceSensor.com