Gulf Coast Data Concepts

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Human Activity Monitor
(HAM)
User Manual

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1 Introduction

1.1 About This Manual

Thank you for purchasing the Human Activity Monitor (HAM). Gulf Coast Data Concepts spent considerable efforts developing an easy to use data logger for the scientific researcher, student, or hobbyist. This product collects data from three separate sensors types simultaneously to provide an advanced insight into motion analysis. Please read this manual to understand the operation and capabilities of the HAM. If the logger fails to operate as expected, please refer to the troubleshooting guide (page 29).

1.2 Document Conventions

The quick start guide in section 1.7 provides a basic summary of operation to begin using the HAM data logger. This user manual continues into further details of configurations and capabilities starting in section 2. Each section also presents relevant tips and warnings to help the user.

This icon indicates a helpful tip that may enhance the performance of the logger or aide in the application of the logger.

This icon indicates a warning, restriction, or limitation that the user should be aware of regarding the logger operation.

1.3 Product Summary

The HAM is a compact self-recording data logger available with several sensor variants. Data from the digital sensors are time stamped using a real time clock and stored to a microSD card in simple text format. When connected via the USB to a personal computer, the HAM appears as a standard mass storage device containing the comma delimited data files and the user setup file. The HAM includes an internal 250mAh lithium-polymer rechargeable battery, which will recharge using USB power.

1.4 Feature List

Figure 1: HAM Data Logger

1.4.1 General Features

The HAM is available with three sensor configurations. The following features are common to each of the three product types.

- User selectable sample rates
- Accurate time stamped data using Real Time Clock (RTC)
- Data recorded to internal 8GB flash memory
- Easily readable text data files
- Data transfer compatible with Windows or Linux via Universal Serial Bus (USB) interface (no special software required)
- Operates from internal lithium-polymer rechargeable battery
- Weight 0.9oz (25g)
- Size 2.21L x 1.55W x 0.60H inch (56.1x39.4x15.2 mm)

1.4.2 HAM-x16

- 3-axis ±16g accelerometer (Analog Devices ADXL345)
- 16-bit resolution
- Selectable sample rates of 12, 25, 50, 100, 200, 400 Hertz
- Finite Impulse Response filter

1.4.3 HAM-IMU

- 3-axis accelerometer, gyroscope, magnetometer (Invensense MPU-9250)
- Quaternion orientation solutions based on accelerometer and gyroscope data
- Selectable sample rates of 50, 100, 200 Hz

1.4.4 HAM-IMU+Alt

- Same features as the HAM-IMU plus additional high precision barometric pressure sensor (Bosch Sensortec BMP-180)

1.5 Items Included with HAM

1.5.1 Single Unit Purchase

The HAM is packaged with the logger, a fabric mounting strap, a USB extender cable, and a magnetic screwdriver.

Figure 2: HAM and Accessories

1.5.2 5 Unit Kit

A kit includes 5 HAM loggers, 5 mounting straps, a USB extender cable, and a magnetic screwdriver.

Figure 3: 5 Unit kit of Loggers

1.6 Component Names

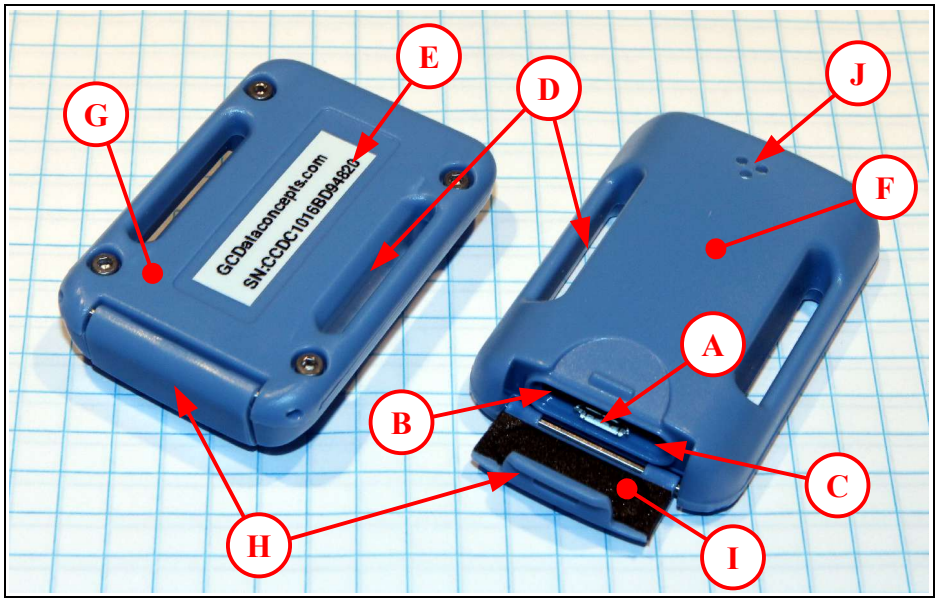


Figure 4: HAM Data Logger Components

A	microB USB connector	F	Enclosure top
B	Blue LED status indicator	G	Enclosure bottom
C	Orange LED data indicator	H	Enclosure cap
D	Mounting slots	I	Cap rubber gasket
E	Serial Number Sticker	J	Air vent (HAM+Alt only)

1.7 Quick Start Guide

The HAM is a simple, economical solution to capture continuous motion data and quickly deliver the information for analysis. The following instructions outline the steps to begin using the HAM. Configuration settings and mounting methods will depend on the particular application.

Step 1: Plug the HAM into a computer and allow the computer operating system to register the device as a Mass Storage Device. Notice that the logger will mount with a drive label using the last digits of the serial number. An orange LED located within the enclosure will indicate the battery is charging. The LED will turn off when the battery is fully charged, which takes about 1 hour.

Figure 5: Connecting to PC

Step 2: Configure the HAM by editing the appropriate tags in the config.txt file using a simple text editor. In Windows, do not use Notepad as the editor does not terminate new lines properly. GCDC recommends Windows Wordpad or Notepad++ to edit the config.txt file. Refer to section 2.6 for a complete list of configuration options.

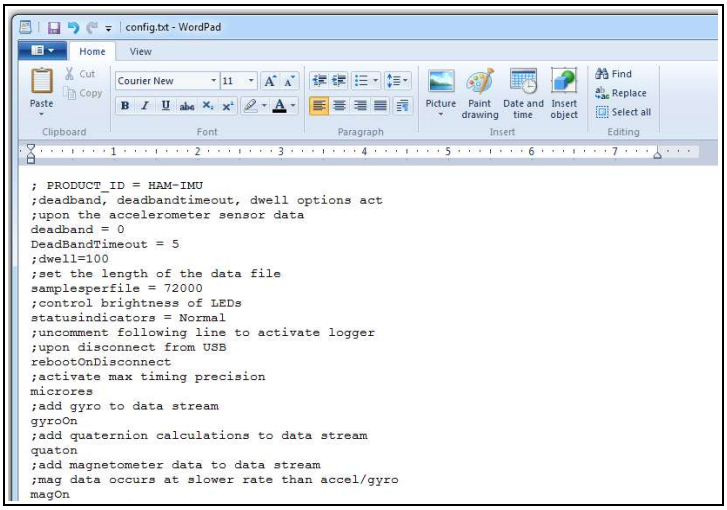


Figure 6: Editing the Config.txt File

Step 3: If necessary, initialize the RTC clock by creating a time.txt file (see section 2.4). Once the time.txt file is saved, immediately unplug the logger to start the initialization process. The logger will load the time.txt file, initialize the clock, and delete the time.txt file. Initializing the RTC ensures the data files include the correct year, month, and day and that the data samples can be correlated to a specific date and time.

Step 4: After removing from the USB port, attach the HAM logger to the target object.

Step 5: Pass a magnet near the top of the HAM enclosure to activate the logger (see Figure 7). The magnetic switch minimizes inadvertent disabling of the logger. Logging will start about 3-5 seconds after activation and orange LED will blink as data is written to the flash memory. If the time.txt file is present, the RTC is initialized with the time written in the file. Then, the blue LED will begin to blink at a 1 second interval indicating the system is operating.

Figure 7: Starting the HAM

Step 6: To stop recording, hold a magnet near the enclosure top for about 3 seconds. The orange and blue LEDs will begin to blink rapidly for 2 seconds and then turn off. Remove the magnet and the HAM turns off.

Step 7: Plug the logger into a PC and allow the logger to mount as a USB drive. The data files will appear in the "GCDC" directory.

Step 8: The raw data recorded in the files requires conversion to engineering units. The conversion method depends on the sensor type and configuration. See section 3.3 for a complete discussion of data conversion.

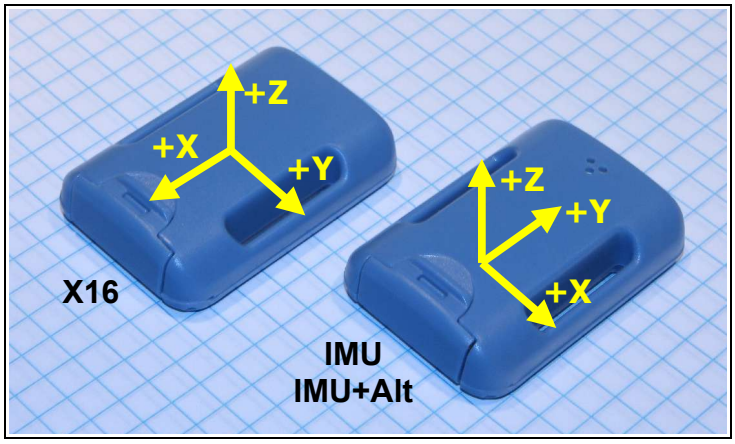


Figure 8: Sensor Orientation

The HAM-x16 follows the same sensor orientation used with other GCDC accelerometer products. However, the IMU and IMU+Alt implements a different sensor orientation to maintain consistency with the calculated quaternion solutions.

2 Operation

2.1 USB Interface

The HAM connects to a PC using a standard micro-B USB connector and supports the USB mass storage device interface for file access and file transfers. Nearly all computer operating systems recognize the HAM as a typical USB external memory drive. Therefore, the HAM will allow file transfers to the internal flash memory like a common USB flash drive. When connected to a PC, the HAM deactivates logging and operates only as a USB interface to the flash memory. Note that some tablet operating systems block access to USB mass storage devices and will not recognize the HAM.

2.2 Memory Card

The HAM stores data to an internal microSD flash memory card. The memory card is not user accessible. The included 8GB card is sufficient for most applications so the card does not need to be removed or upgraded.

The logger needs only the config.txt file to operate. The HAM will use default configuration settings if the config.txt is not present. The "config.txt" and "time.txt" files must occur in the root directory (see section 2.6 and section 2.4). The HAM will create a folder called "GCDC", if not already present, to place the data files.

Interrupting the power to the logger can result in corruption of the microSD card. For example, removing the logger from the USB port during file transfers to the PC or removing the battery during logging activity. Reformat the card if it becomes corrupted (FAT32 file structure). If data transfers to/from the card become slow, consider formatting the card using "SD Card Formatter" software provided by the SD Association (www.sdcard.org).

2.3 Battery

The HAM is powered by an internal 250mAh lithium-polymer rechargeable battery pack. The internal battery management system recharges the battery when the HAM is plugged into a USB port or attached to a USB 5v power adapter. The orange charge indicator LED turns on (see Section 2.5) when the battery is charging and off when the battery reaches full charge.

Figure 10 illustrates the expected battery life for each sensor configuration and sample rate.

The RTC continues to operate from the battery when the device is "off". The RTC should be reinitialized (see Section 2.4) if the battery is completely depleted, which may occur after several months of shelf-time.

A 5v supply via the USB connector provides extended operation of the device independent of the internal battery. Common USB power adapters or USB battery packs for consumer electronics can provide the required 5v supply. The logger does not implement power saving features when connected to an external power supply so power consumption will be higher than using the internal battery.

The data logger may draw up to 250mA from the USB supply to recharge the battery. Plugging multiple data loggers into a USB hub can exceed the power capacity of the hub. This can cause "brown-outs" of the logger and possibly damage the microSD card.

The logger is always "on" maintaining the real time clock and will eventually discharge the battery completely after several months. The HAM may require an additional hour of charging from a completely discharged state. Keep in a cool (20°C/ 68°F) dry environment to avoid damage of the battery pack.

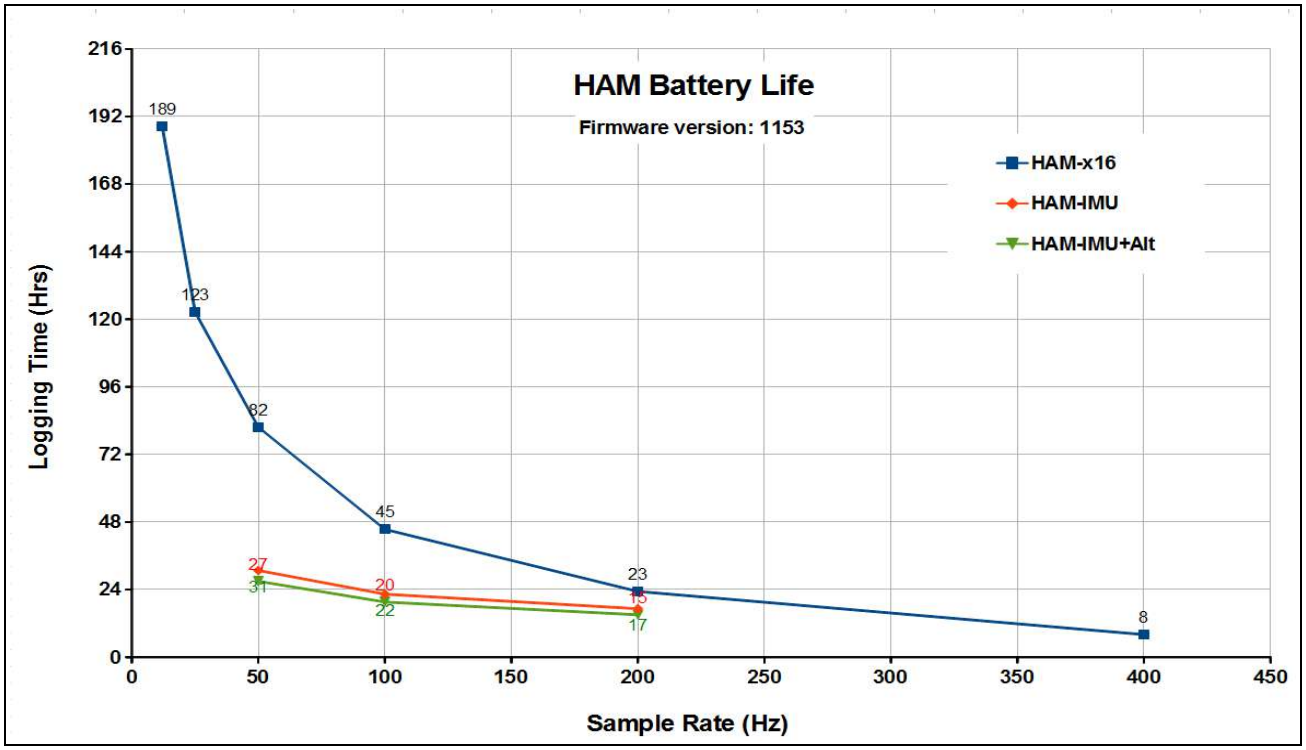


Figure 9: Expected Battery Life

2.4 Setting The RTC

A real time clock (RTC) integrated into the HAM determines the time for each line of data recorded. The RTC is initialized using a user-created text file named "time.txt" located in the root directory of the microSD card. This is a separate file from the config.txt file and it is needed only when initializing the RTC. The system looks for the time.txt file upon booting. If the file exists, the time stored in the file is loaded to the RTC and the time.txt file is deleted. The time information in the time.txt file must be in the exact "yyyy-MM-dd HH:mm:ss" 24-hour format, occur on the first line, and end with a newline character. Figure 10 provides an example time.txt file that will initialize the RTC to 2:26:30 pm June 16, 2014.

The time file method of setting the RTC does not require special communication drivers so it can be implemented using a simple text editor. Direct initialization of the RTC is possible but requires specific device drivers and software from Gulf Coast Data Concepts.

The RTC maintains ±50ppm accuracy (-40°C to +85°C), which means that the accuracy may drift about 4 seconds every day. The RTC is powered by the battery at all times, even when the logger is "off".

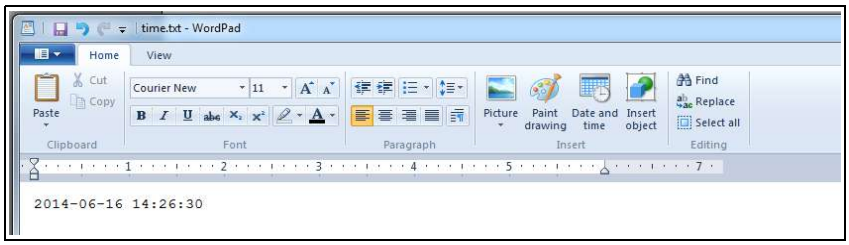


Figure 10: Example Time Entry in time.txt File

Initializing the RTC ensures that the start time and individual time stamps can be correlated to an absolute time – the year, month, day, hour, minute, second, and fractional second. An uninitialized RTC or reset of the RTC will lead to indeterminate start time recorded in the data file header.

After unplugging the logger from the USB port, the logger will load the config.txt file and time.txt file, if present. Therefore, there is a delay between when the time.txt was created and when the logger actually loads the time information. For most applications, this simple method of initializing the clock results in sufficient accuracy.

Initialization of the RTC is limited to +/-1 second. The RTC register that handles the fractional seconds counter is not accessible so the initialization process can not reset the seconds to an even value.

2.5 Status Indicators

System status is indicated by the two LEDs located near the USB connector. The blue LED indicates system operation and blinks once per second to indicate a properly operating system. The blue LED blinks when the HAM is recording data, in standby mode, or is connected to a computer via the USB port. The red LED blinks when data is written or read from the microSD memory card. In data logging mode, the period at which the red LED blinks depends on the sample rate and other configuration settings. The LEDs will flicker during user initiated shutdown. The "statusindicators" tag in the configuration file turns off or changes the brightness of the status indicators (see section 2.6.1.9). The red charge indicator LED is located on the reverse side of the circuit board and

illuminates when charging is in process (see Figure 11). The charge indicator LED will turn off when the battery is fully charged. A fully discharged battery will charge in about 2 hours. A blinking charge indicator LED means there is a problem with the lithium-polymer battery pack.

Figure 11: LED Status Indicators

2.6 System Configuration Options

The HAM is configured using a set of tags and settings stored in a text file named "config.txt", which is located in the root directory of the microSD card. The system reads the configuration file at boot time. Table 1 lists the configuration file tags. A tag is followed by an equal sign ("=") and an applicable tag setting. A line finishes with a newline character. Tags are not case sensitive. Tab and space characters are ignored. Lines starting with a semicolon (";") are treated as comments and ignored by the system. The system will use the default settings listed in Table 1 if the config.txt file is not found.

> *Do not use the Windows Notepad editor because it does not terminate new lines properly. GCDC recommends Windows Wordpad or Notepad++ to edit the config.txt file.*

Table 1: Configuration File Tags and Descriptions

Tag	Product			Valid Settings	Description
	16g	IMU	IMU+Alt		
deadband	✓	✓	✓	An integer between 0 and 16384	Sets the deadband to a range expressed in “counts”. A new sample is recorded if any sensor axis exceeds the previous recorded reading by the deadband value
deadbandtimeout	✓	✓	✓	An integer between 0 and 65535	Specifies the period in seconds when a sample is recorded regardless of the deadband setting. This feature ensures periodic data is recorded during very long periods of inactivity.
dwell	✓	✓	✓	An integer between 0 and 65535	The number of samples recorded after a deadband threshold triggered event
microres	✓	✓	✓	-	The presence of this tag sets the device to record time stamps with 0.1ms effective precision.
rebootondisconnect	✓	✓	✓	-	The presence of this tag causes the system to start recording after disconnect from a USB port.
samplesperfile	✓	✓	✓	An integer greater than 0	The number of lines of data per data file before a new file is created
starttime and stoptime	✓	✓	✓	See section 2.6.1.7	Defines when to start and stop recording
stoponvusb	✓	✓	✓	-	Stops data logging if 5v USB power is present (see section 2.6.1.8)
statusindicators	✓	✓	✓	“Normal”, “High”, “Off”	LED status indicators can be activated with normal brightness (Normal), activated with high brightness (High), or completely deactivated (Off).
samplerate	✓			12, 25, 50, 100, 200, 400	Sets the rate at which data is collected and recorded to the microSD card.
gyroOn		✓	✓	-	Adds gyro samples to data stream
quatOn		✓	✓	-	Adds quaternion solutions to data stream
magOn		✓	✓	-	Adds magnetometer samples to data stream
mpu_sampleRate		✓	✓	-	Sets the recorded sample rate of IMU data
compassSampleRate		✓	✓	Integer between 1 to 100	Sets the recorded sample rate of the magnetometer
mpu_accelFsr		✓	✓	2, 4, 8, 16	Sets the IMU accelerometer sensor range
mpu_gyroFsr		✓	✓	2000, 1000, 500, 250	Sets the IMU gyrscope sensor range
tempOn			✓	-	Adds temperature samples to data stream
pressOn			✓	-	Adds pressure samples to data stream
pressureInterval			✓	Integer between 50 and 32768	Sets the period in milliseconds between pressure samples
interleave			✓	Integer between 1 and 255	Sets the number of pressure samples between temperature samples

2.6.1 Common Configuration Options

2.6.1.1 deadband

“deadband” defines the minimum difference between recorded sensor readings. A new sample from the accelerometer sensor must exceed the previous recorded reading before the logger records the data. The deadband setting is expressed in "counts" units and is applied to the output of each axis. The deadband value can be set to an integer between 0 and 32767. The deadband function is an effective way to reduce the amount of data collected by defining the granularity of the data.

The deadband functions as a event threshold limit when used in conjunction with the “dwell” feature.

Figure 12 illustrates the deadband feature filtering out small changes in acceleration from the recorded data. Only when the deadband limit is exceeded will a new data sample be pushed to the file. Note that this feature will result in samples with inconsistent time periods. Therefore, the data sets should be re-sampled to establish uniform time periods.

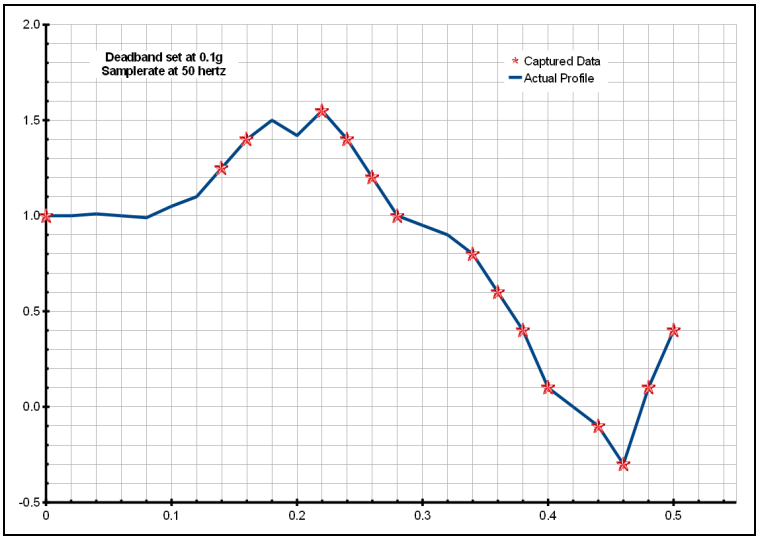


Figure 12: Graphical Illustration of the Deadband Feature

2.6.1.2 deadbandtimeout

“deadbandtimeout” defines the period in seconds when a sample is recorded by the logger regardless of the deadband setting. This feature ensures periodic data is recorded during extended periods of inactivity. A valid setting for the deadbandtimeout is an integer between 0 and 16384.

2.6.1.3 dwell

Use “dwell” together with “deadband” to create an event trigger configuraion. The “dwell” tag defines the number of consecutive samples recorded at the set sample rate after a deadband threshold event. The deadband threshold event occurs when a sensor reading exceeds the last recorded value by the deadband setting. A valid dwell setting is an integer between 0 and 65535. See section 2.7.2 for an example implementation of the deadband/dwell features.

2.6.1.4 microres

The "microres" option sets the device to record time stamps with 0.1ms precision. In micro-resolution mode, the time stamps are recorded as XX.YYYYZZ where XX are seconds, YYYY are 0.1 milliseconds, and ZZ are spurious digits beyond the precision capability. The micro-resolution option should be implemented at sample rates greater than 200 hertz to provide the best timing precision.

Micro-resolution is best suited for applications requiring precise timing, such as vibration analysis, and is recommended for sample rates above 200 Hz. The standard timing precision (default) of 1 milli-second is suitable for most general applications, such as monitoring human motion.

2.6.1.5 rebootondisconnect

The HAM incorporates an on/off button for initiating and terminating the data recording process. Data recording is automatically started upon disconnect from a computer USB port if the tag word "rebootondisconnect" is included in the configuration file.

2.6.1.6 samplesperfile

"samplesperfile" defines the number of data lines each file can have before a new file is created. This tag controls the size of the data files into easily manageable lengths for later processing. This setting is loaded as a signed 32-bit integer, which can translate into very large data files. The user should exercise caution before setting large files and test the end-user software application for data limitations.

2.6.1.7 starttime and stoptime

The HAM starts and stops data recording based on the times defined using the "starttime" and "stoptime" tags. The times must be in "MM HH DD" 24-hr format with the three entries separated by a space. Entries marked with "*" operate as a wild card. The HAM continues to record after the start time unless defined otherwise by the stoptime tag. Note that the configuration option does not include the month. Example timing configurations:

Example 1: On the 15th day, start recording at 12:30pm and stop recording at 6:00pm.

starttime = 30 12 15
stoptime = 00 18 15

Example 2: Start recording at the beginning of every hour and stop recording 45 minutes later.

starttime = 00 *
stoptime = 45 *

2.6.1.8 stoponvusb

The “stoponvusb” tag stops data logging operations when a 5v supply is detected on the USB connector. Without the stoponvusb option (default), the device switches power from the internal battery to the USB 5v and continues to log data.

2.6.1.9 statusindicators

The brightness intensity of the LED status indicators is defined using the “statusindicators” tag and valid settings of “normal”, “high”, and “off”.

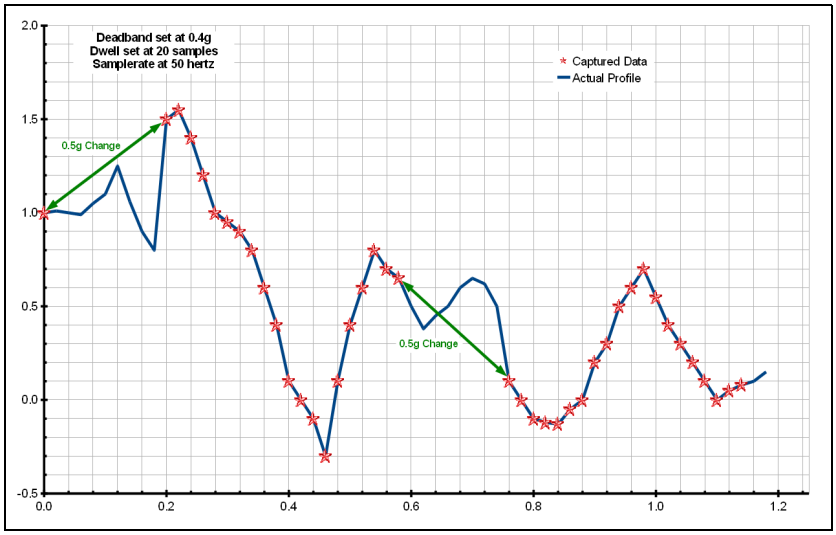


Figure 13: Graphical Illustration of the Dwell Feature

2.6.2 HAM-16g Options

2.6.2.1 samplerate

The “samplerate” tag defines the data rate in Hertz, or samples per second. Valid sample rate settings are 12, 25, 50, 100, 200, and 400 Hz. See section 4.1 for special features regarding the sample rates.

2.6.3 IMU Options

The IMU configuration supports all the features listed in section 2.6.1 with the additional 9-axis MPU-9250 sensor options listed below.

The accelerometer and gyroscope sensors are synchronized and the time stamps are applied to this data from the RTC. The magnetometer, pressure, and temperature samples are collected at sub-intervals to the accelerometer/gyroscope sample rate and stored with the previous accelerometer/gyroscope sample. Therefore, the magnetometer, pressure, and temperature samples will not have occurred at the exact point represented by the time stamp.

2.6.3.1 gyroOn

Add “gyroOn” to the configuration file and the gyroscope data will be added to the data stream. Remove the “gyroOn” term and the data is hidden but the sensor is not deactivated.

2.6.3.2 quatOn

The “quatOn” term in the configuration file adds the quaternion solutions to the data stream as calculated by the MPU-9250 digital motion processing (DMP) engine. The quaternions are based data from the accelerometer and gyroscope sensors and the solutions will occur with each accelerometer/gyroscope sample. Remove “quatOn” or comment the term (“;”) and the quaternions are hidden from the data stream but the DMP continues to operate.

2.6.3.3 magOn

“magOn” adds the magnetometer output to the data stream. Removing “magOn” or comment the term (“;”) to hide the magnetometer data.

Removing the gyroscope, magnetometer, or quaternion solutions from the data stream does not de-activate the sensors or the digital motion processing engine. Therefore, there are no significant power savings achieved with these options. However, removing the particular data streams does simplify the data file for certain applications.

2.6.3.4 mpu_sampleRate

The IMU always samples at 200Hz internally but “mpu_sampleRate” sets the rate at which accelerometer and gyroscope data is recorded to the microSD. Valid settings are 50, 100, and 200 Hz. mpu_sampleRate sets a sub-sampling frequency but data is not smoothed or interpolated.

2.6.3.5 compassSampleRate

The magnetometer detects the Earth's magnetic fields so it can be considered a “compass”. The sample rate of the magnetometer is set with the compassSampleRate term with valid settings between 1 and 100 Hz. The compassSampleRate must be less than the mpu_sampleRate. As magnetometer data becomes available, the data is appended to the previous gyroscope data entry.

2.6.3.6 mpu_accelFsr

“mpu_accelFsr” sets the IMU accelerometer full scale range to ±2g, ±4g, ±8g, or ±16g. In each case, the full range is represented by a 16-bit value or 65536 discreet counts. Raw data is converted to g's by determining the g/count sensitivity factor. See section 3 for a detailed discussion about converting the raw data.

2.6.3.7 mpu_gyroFsr

“mpu_gyroFsr” sets the gyroscope sensor full scale range to ±250 °/sec, ±500 °/sec, ±1000 °/sec, or ±2000 °/sec. The full scale range is represented by a 16-bit value. See section 3 for a detailed discussion about converting the raw data.

2.6.4 IMU+Alt Options

The IMU+Alt configurations supports all the features listed in 2.6.1 and 2.6.3 plus the additional barometric pressure sensor options.

2.6.4.1 tempOn

The BMP180 pressure sensor includes a temperature sensor used for temperature compensation of the pressure measurements. "tempOn" adds the temperature values to the data stream. Remove "tempOn" or comment the term (";") to hide the temperature data but the compensation algorithm will continue to operate.

2.6.4.2 interleave

The temperature samples are collected at sub-intervals of the pressure readings. "interval" defines the number of pressure samples taken before a temperature sample is collected. The temperature data is used in the temperature compensation algorithm.

2.6.4.3 pressureInterval

"pressureInterval" defines the time period, in milliseconds, between pressure samples. The data logger will support intervals between 50 milliseconds (20 Hz) and 32678 milliseconds (9 hr interval). The pressure and temperature data is added to the previously available accelerometer/gyroscope sample stored in the cache. Therefore, the rate at which pressure data is collected and when it appears in the data stream will be different. This is rarely a problem in post-process analysis since pressure changes much slower than accelerometer data.

2.6.4.4 pressOn

"pressOn" adds the temperature compensated pressure readings from the BMP180 to the data stream.

2.7 Example Configuration Files

2.7.1 Example A: HAM-x16

The following configuration records data at 100 hertz. Deadband and deadbandtimeout are set to zero so the logger will record constantly at the set sample rate. Each data file is 90,000 lines long, which is 15 minutes of data. The status indicators are set to high brightness. The logger is activates upon removal from the USB port ("rebootondisconnect" is active).

```
;Example HAM-x16 config file
;set sample rate
;available rates 12, 25, 50, 100, 200, 400
samplerate = 100
;record constantly
deadband = 0
deadbandtimeout = 0
;set file size to 15 minutes of data
samplesperfile = 90000
;set status indicator brightness
statusindicators = high
rebootOnDisconnect
;see HAM user manual for other config options
```

Figure 14: Configuration File Example A

2.7.2 Example B: HAM-IMU

The recorded sample rate is set to 50 Hz and the file size is 15 minutes. All three sensors are reported in addition to the quaternion solutions. The accelerometer is set to 16g range and the gyroscope is set to the default 2000 °/sec. The logger will activate using the magnetic on/off switch.

```
; PRODUCT_ID = HAM-IMU
;set mpu sample rate
mpu_SampleRate = 50
;set the length of the data file
samplesperfile = 45000
;control brightness of LEDs
statusindicators = Normal
;uncomment following line to activate logger
;upon disconnect from USB
;rebootOnDisconnect
;activate max timing precision
microres
;add gyro to data stream
gyroOn
;add quaternion calculations to data stream
quaton
;add magnetometer data to data stream
;mag data occurs at slower rate than accel/gyro
magOn
; available accelerometer full scale ranges are 2, 4, 8 and 16g
;(2g is the default)
mpu_accelFsr=16
; available gyro full scale ranges are 250, 500, 1000, and 2000
; (2000 deg/sec is the default)
mpu_gyro_Fsr=2000
```

Figure 15: Configuration File Example B

2.7.3 Example C: HAM-IMU+Alt

Example C sets the logger to record the accelerometer and gyroscope readings at 200 Hz with the microresolution time stamps. The quaternions are not recorded. The pressure data is recorded every 200 milliseconds, or 5 hz. A temperature sample appears once with every 5 pressure samples.

```
; PRODUCT_ID = HAM-IMU+Alt
;set mpu sample rate
mpu_SampleRate = 200
;set the length of the data file
samplesperfile = 120000
;control brightness of LEDs
statusindicators = Normal
;uncomment following line to activate logger
;upon disconnect from USB
rebootOnDisconnect
;activate max timing precision
microres
;add gyro to data stream
gyroOn
;add quaternion calculations to data stream
;quaton
;add magnetometer data to data stream
;mag data occurs at slower rate than accel/gyro
magOn
; available accelerometer full scale ranges are 2, 4, 8 and 16g
;(2g is the default)
mpu_accelFsr=16
; available gyro full scale ranges are 250, 500, 1000, and 2000
; (2000 deg/sec is the default)
mpu_gyro_Fsr=1000
;add temperature to data stream
tempOn
; add pressure to data stream
pressOn
; pressure measurement interval, in milliseconds
pressureInterval = 200
; interleave is the number of samples to skip between temp
interleave = 5
```

Figure 16: Configuration File Example C

3 Data Interpretation

3.1 Data Files

The HAM creates a new data file when the system is booted or when the maximum number of data lines is reached in the previous data file. A system boot condition occurs when the on/off button is pressed, 5v power is restored to the system via the USB connector, or when the HAM is removed from a computer USB port with the "rebootondisconnect" feature enabled. Data files are placed in a folder named "GCDC" and are named data-XXX.csv, where XXX is a sequential number starting with 001. The system will create up to 999 files. At the beginning of each file, a header is written describing the system configuration and the current time when the file was created. Figure 17, Figure 18, and Figure 19 show example data files.

A short gap in data may occur between sequential files as data is purged from the cache and a new file is allocated on the microSD card.

```
;Title, http://www.gcdataconcepts.com, X16-ham, Analog Dev ADXL345
;Version, 1102, Build date, Oct  9 2015,  SN:CCDC1016BD94820
;Start_time, 2016-08-23, 12:56:31.455
;Temperature, -999.00, deg C,  Vbat, 3712, mv
;SampleRate, 100,Hz
;Deadband, 0, counts
;DeadbandTimeout, 5,sec
;Time, Ax, Ay, Az
0.163,10,24,-2054
0.173,21,28,-2063
0.183,17,12,-2090
0.194,3,7,-2097
0.204,30,5,-2061
0.214,24,24,-2061
0.224,17,26,-2082
0.234,44,16,-2063
0.245,19,33,-2072
0.255,-2,26,-2093
0.265,39,3,-2061
```

Figure 17: Example Data File From HAM-x16

```
;Title, http://www.gcdataconcepts.com, X16-MPU-ham, ADXL345, MPU-9250
;Version, 1191, Build date, Nov 15 2016,  SN:CCDC3016BD8E5C6
;Start_time, 2007-01-01, 00:41:40.226
;Temperature, -999.00, deg C,  Vbat, 3784, mv
;MPU SR, 200,Hz,  Accel sens, 2048,counts/g, Gyro sens, 16,counts/dps,  Mag SR, 10,Hz,  Mag sens, 1666,counts/mT
;Deadband, 0, counts
;DeadbandTimeout, 0,sec
;Time, Ax, Ay, Az, Gx, Gy, Gz, Qw, Qx, Qy, Qz, Mx, My, Mz
0.007019,-188,-18,-1972,-9,-67,18,16129.817,-68.053,2797.668,657.930,171,-365,15
0.027008,-163,-54,-1982,-5,-55,-5,16131.427,-72.148,2788.909,655.199,160,-372,17
0.046997,-131,-42,-1968,-30,-19,-28,16132.665,-76.892,2782.077,653.215
0.066986,-151,-41,-1954,3,-39,-12,16132.392,-86.321,2782.562,656.712
0.086975,-140,-46,-1928,43,-71,16,16132.554,-94.275,2780.698,659.512
0.106964,-137,-66,-1980,-14,-38,-9,16134.173,-97.605,2771.813,656.830
0.126984,-134,-82,-1918,-20,-30,-30,16134.342,-104.756,2770.933,655.274,160,-365,17
0.146973,-146,-70,-1973,25,-53,-12,16134.968,-110.056,2766.936,655.897
0.166962,-149,-68,-1963,-16,-33,-4,16136.392,-113.642,2758.305,656.613
0.186951,-122,-66,-1999,-33,-23,-2,16138.000,-117.654,2748.665,656.814
0.206940,-168,-66,-1956,-6,-49,1,16137.845,-125.390,2748.568,659.582
0.226959,-163,-68,-1924,19,-49,4,16138.756,-128.133,2742.852,660.561,170,-362,25
0.246948,-141,-48,-1994,-21,-18,-11,16140.399,-131.693,2733.330,659.181
0.266937,-111,-44,-2001,-27,-36,-11,16142.280,-134.598,2722.567,657.065
0.286926,-145,-47,-1969,-54,-19,-23,16143.165,-141.170,2716.745,658.057
0.306915,-141,-55,-1969,33,-58,6,16142.745,-149.733,2718.176,660.548
0.326904,-165,-62,-1951,16,-54,0,16143.179,-154.226,2715.371,660.432,165,-366,14
0.346924,-160,-42,-1982,6,-26,-14,16144.381,-154.010,2709.083,656.931
0.366913,-155,-76,-1963,-15,14,-24,16144.848,-156.041,2706.791,654.418
0.386902,-153,-80,-1938,29,-42,-8,16144.354,-161.844,2708.726,657.174
0.406891,-163,-39,-1946,23,-31,11,16146.145,-162.608,2697.910,657.484
0.426910,-151,-54,-1956,-68,-4,-14,16149.673,-159.624,2678.638,650.317,156,-357,30
0.446869,-134,-87,-1990,-104,16,-61,16152.328,-159.413,2664.654,641.820
0.466858,-155,-72,-1935,-1,-26,-34,16151.533,-165.850,2668.786,643.031
```

Figure 18: Example Data File From HAM-IMU

```
;Title, http://www.gcdataconcepts.com, X16-ham, MPU9250,BMP180
;Version, 1191, Build date, Nov 15 2016,  SN:CCDC401631CF4D7
;Start_time, 2016-12-13, 10:14:06.308
;Temperature, -999.00, deg C,  Vbat, 4160, mv
;MPU SR, 200,Hz,  Accel sens, 2048,counts/g, Gyro sens, 16,counts/dps,  Mag SR, 10,Hz,  Mag sens, 1666,counts/mT
;BMP180 SI, 0.200,s  T interleave, 5
;Deadband, 0, counts
;DeadbandTimeout, 0,sec
;Time, Ax, Ay, Az, Gx, Gy, Gz, Qw, Qx, Qy, Qz, Mx, My, Mz, P, T
0.009278,419,1982,115,-112,14,37,14387.006,-1341.886,-7672.993,879.769,140,42,97,101686,25650
0.029267,414,2006,129,-128,116,25,14376.811,-1319.962,-7693.561,899.752
0.049286,446,2058,125,-76,177,48,14369.909,-1302.481,-7706.366,925.528,134,50,103
0.069306,428,2074,164,-33,142,106,14364.279,-1296.570,-7713.545,960.759
0.089295,399,2059,120,-4,120,192,14360.300,-1302.421,-7714.470,1003.925,134,50,103
0.109284,387,2003,102,38,82,258,14361.509,-1316.590,-7703.624,1050.368
0.129303,407,1996,111,128,57,288,14368.845,-1338.940,-7680.172,1092.660,134,50,103,101682,25638
0.149292,396,2009,170,200,6,280,14378.290,-1363.386,-7652.254,1133.315,135,44,113
0.169312,408,2009,181,203,23,286,14384.694,-1380.768,-7630.017,1179.969
0.189301,399,2021,134,141,88,298,14388.278,-1379.058,-7614.365,1237.956
0.209320,376,2021,93,106,249,295,14394.586,-1351.673,-7595.633,1307.932
0.229340,380,2038,111,130,387,289,14405.235,-1319.689,-7568.595,1378.199
0.249329,415,2073,121,192,353,284,14418.930,-1305.351,-7533.206,1441.094,130,47,97
0.269348,391,2062,134,246,218,307,14431.775,-1316.507,-7495.822,1496.245
0.289368,378,2043,149,260,83,339,14443.939,-1338.380,-7457.575,1549.636,130,47,97,101681
0.309326,398,2033,139,271,71,346,14457.155,-1351.848,-7417.663,1605.270
0.329346,380,2042,156,277,152,324,14473.134,-1347.036,-7373.952,1665.578
0.349335,379,2028,162,295,256,302,14488.651,-1337.392,-7331.448,1725.015,140,35,109
0.369354,394,2030,143,267,229,291,14502.483,-1330.589,-7291.721,1781.505
0.389343,393,2027,164,262,220,282,14516.040,-1323.667,-7252.832,1834.219
0.409363,376,2029,165,260,214,256,14531.896,-1311.036,-7210.387,1884.394
0.429383,367,2030,136,293,249,235,14548.529,-1301.764,-7166.232,1930.352
0.449372,391,2033,164,296,174,225,14563.083,-1306.330,-7125.272,1968.763,158,43,101
0.469391,387,2031,143,282,95,224,14576.423,-1313.095,-7087.070,2003.129
0.489380,359,2013,155,271,103,196,14590.938,-1310.777,-7048.876,2033.509,158,43,101,101681
0.509400,388,2026,123,273,145,148,14604.927,-1303.931,-7013.789,2058.656
0.529389,384,2022,174,243,128,115,14615.980,-1300.249,-6985.708,2077.934
0.549408,379,2021,141,201,86,95,14624.119,-1298.805,-6964.538,2092.582,149,47,91
```

Figure 19: Example Data File From HAM-IMU+Alt

3.2 Data Format

Data is written to files in comma separated text format starting with the file header information and followed by event data entries. The sample rate, sensor scale settings, and deadband configuration is listed in the file header. Each sample contains a time stamp entry followed by the sensor output readings. The time entry is seconds elapsed from the start time recorded in the header. Add the elapsed time to the start time to determine the complete date and time of the sample. The sensor readings are represented in raw digital counts and must be converted into measurement units (see Section 3.3).

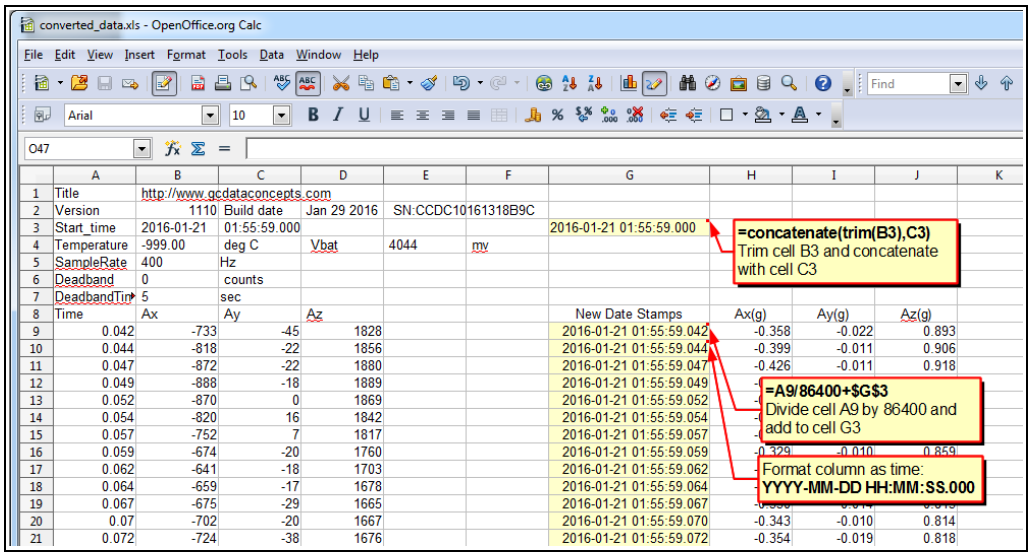
The last line of the final data file records the reason for the termination, such as “shutdown: switched off”, “shutdown: low battery”, “shutdown: max files exceeded”, “shutdown: vbus disconnect”, or “connected to computer”. The line is designated as a comment with a semicolon (“;”).

3.3 Data Conversion

3.3.1 Time Stamps

Each sample starts with a time stamp, which is the seconds elapsed from the start time listed in the file header. Add the time stamp to the start time to determine the complete date/time of each sample.

The time stamp calculation is incorporated easily into a spreadsheet, such as Excel or Calc. First, open the data file in a spreadsheet and parse on the comma (“,”) deliminator. Most spreadsheets will automatically parse the data using the “,” character. The parsing operation will separate the start_time into two cells – date and time. Use the “trim” function to strip the white space around the date cell and use “concatenate” to combine the text into a new start date. The spreadsheet will automatically format the new text into a date. Next, divide the time stamp entry by 86400. This converts the time stamp into a value compatible with the spreadsheet date functions. Finally, add the new time stamp to the new start date and a complete data/time is generated. Format the column as a “time” category and include the trailing “.000” to present the millisecond precision.



	A	B	C	D	E	F	G	H	I	J	K
1	Title	http://www.gcdataconcepts.com									
2	Version	1110	Build date	Jan 29 2016	SN:CCDC10161318B9C						
3	Start_time	2016-01-21	01:55:59.000				2016-01-21 01:55:59.000				
4	Temperature	-999.00	deg C	Vbat	4044	mv					
5	SampleRate	400	Hz								
6	Deadband	0	counts								
7	DeadbandTim	5	sec								
8	Time	Ax	Ay	Az			New Date Stamps	Ax(g)	Ay(g)	Az(g)	
9	0.042	-733	-45	1828			2016-01-21 01:55:59.042	-0.358	-0.022	0.893	
10	0.044	-818	-22	1856			2016-01-21 01:55:59.044	-0.399	-0.011	0.906	
11	0.047	-872	-22	1880			2016-01-21 01:55:59.047	-0.426	-0.011	0.918	
12	0.049	-888	-18	1889			2016-01-21 01:55:59.049				
13	0.052	-870	0	1869			2016-01-21 01:55:59.052				
14	0.054	-820	16	1842			2016-01-21 01:55:59.054				
15	0.057	-752	7	1817			2016-01-21 01:55:59.057				
16	0.059	-674	-20	1760			2016-01-21 01:55:59.059	-0.329	-0.010	0.859	
17	0.062	-641	-18	1703			2016-01-21 01:55:59.062				
18	0.064	-659	-17	1678			2016-01-21 01:55:59.064				
19	0.067	-675	-29	1665			2016-01-21 01:55:59.067				
20	0.07	-702	-20	1667			2016-01-21 01:55:59.070	-0.343	-0.010	0.814	
21	0.072	-724	-38	1676			2016-01-21 01:55:59.072	-0.354	-0.019	0.818	

Figure 20: Time Stamp Conversion Method

The time stamps can be added directly to the start_time entry (no need to divide by 86400) when using Matlab, Octave, or R.

3.3.2 x16 Accelerometer Data

The HAM-x16 records the raw digital data from the accelerometer sensor. This helps reduce processor load, increase sample rate capability, and avoids data errors due to floating point calculations. The 16-bit data, or 65536 discreet counts, covers the full range of the +/-16g sensor. Therefore, the conversion factor is 65536 / 32 = **2048 counts/g**. Divide the raw data by 2048 to determine “g” units.

To determine acceleration in g's, divide the raw data by 2048. A “g” is 32.174 ft/sec^2 or 9.807 m/sec^2.

3.3.3 IMU Accelerometer Data

The Invensesense MPU-9250 reports accelerometer data using a 16-bit value, or 65536 counts. Converting the raw data to "g" units depends on the selected sensor range, as described in Table 2 below. To determine acceleration in "g" units, divide the raw accelerometer data by the appropriate factor listed in the table.

Table 2: IMU Accelerometer Conversion Factors

Accelerometer Sensor Range	Conversion Factor (counts/g)
±2g	16384
±4g	8192
±8g	4096
±16g	2048

3.3.4 IMU Gyroscope Data

The gyroscope sensor has four range settings and the output is represented by a 16-bit value, or 65536 counts. Divide the raw data by the appropriate value listed in Table 3 to convert the raw data into °/sec.

Table 3: IMU Gyroscope Conversion Factors

Accelerometer Sensor Range	Conversion Factor (counts/(°/sec))
±250 °/sec	131.072
±500 °/sec	65.536
±1000 °/sec	32.768
±2000 °/sec	16.384

3.3.5 IMU Magnetometer Data

The magnetometer measures magnetic field lines and reports the ±1200 uT range as a 13-bit value, or 8192 counts. Therefore, divide the raw magnetometer values by 3.413 to determine micro-Tesla (uT). Although, in most cases, the raw value representing North, South, East, West is more important than the actual uT.

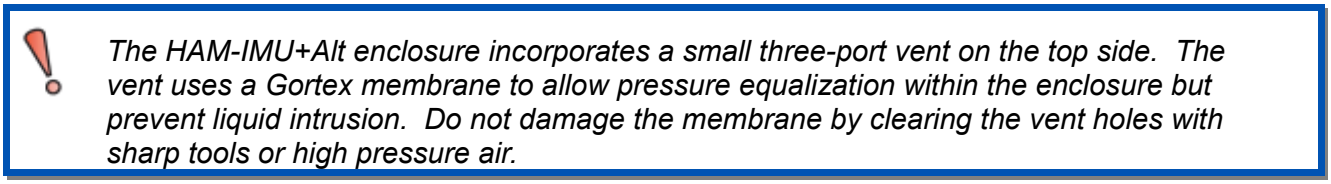
3.3.6 Quaternions Solution (Qw, Qx, Qy, Qz)

Quaternions are a dimensionless representation of orientation. The following wikipedia entries provide detailed discussion of quaternions:
http://en.wikipedia.org/wiki/Quaternion
http://en.wikipedia.org/wiki/Quaternions_and_spatial_rotation
http://en.wikipedia.org/wiki/Conversion_between_quaternions_and_Euler_angles

3.3.7 Pressure and Temperature Data

The logger sets the BMP180 sensor to high-precision mode to provide the most accurate measurement of pressure. Pressure data is recorded to the data file in Pascal units and includes the appropriate compensation based on temperature collected at the pressure sensor. No conversion is necessary to determine pressure in Pascals.

Temperature is recorded in milli-degree Celsius. Divide the temperature value by 1000 to determine degrees Celsius.



3.3.7.1 Converting Pressure to Altitude

Altitude is calculated from the pressure data using the following equation:

$$Altitude = 44330 \times \left(1 - \left(\frac{P}{Po}\right)^{\frac{1}{5.255}}\right)$$

where *Altitude* = meters above baseline altitude
P = pressure in Pascal
Po = pressure in Pascal at the baseline altitude (mean sea level = 101325 Pa)

4 System Details

4.1 Sensors

The sensors "push" data to the logger at selected rates based on a clock internal to the sensor. The sensor's clock precision and drift are undefined. For example, a selected sample rate of 50 Hz may actually push data at 52 Hz. The HAM incorporates a precise real time clock to independently time stamp the data as it leaves the sensor and to ensure that accurate timing is recorded to the data file. Therefore, the time stamps should be used as the reference for determining the actual sample rates of the accelerometer and gyroscope data. In the case of the IMU, the accelerometer and gyroscope data is synchronized within the sensor.

Additional sensor data, such as the magnetometer, pressure, and temperature values, arrive at slower sample rates than the accelerometer and gyroscope data. The logger appends the new data to the last accelerometer/gyroscope entry available in the memory cache. Therefore, the magnetometer, pressure, and temperature values are not synchronized to the particular time stamp. This method was chosen to simplify the data file format and allow easier parsing of the file. In most cases, the magnetometer, pressure, and temperature data change slowly relative to accelerometer and gyroscope data. The entire data sample line can be assumed to be synchronized.

4.1.1 16g Accelerometer

The HAM uses the Analog Devices ADXL345 3-axis digital accelerometer sensor, which is based on micro-electro machined semiconductor technology (MEMS). This accelerometer sensor is similar to those used in cellphones, laptops, hard drives and other consumer electronics. Table 4 lists the basic sensor and logger performance parameters but refer to Analog Devices for detailed sensor specifications.

Table 4: Accelerometer Sensor Characteristics

Parameter	Condition	Min	Typical	Max	Units
Acceleration range			±16.0		g
Sensitivity			2048		count/g
Sensitivity Deviation			±1.0		%
Nonlinearity	X, Y, Z axis		±0.5		%FS
Zero-g Offset Level Accuracy	X, Y axis	-150		+150	mg
	Z axis	-250		+250	mg
Inter-Axis Alignment Error			±0.1		Degrees
Cross-Axis Sensitivity			±1		%

The accelerometer sensor is based on microelectromechanical systems (MEMS) technology and is not affected by magnetic fields. Glue a magnet to the bottom of the plastic enclosure to facilitate easy attachment to iron surfaces.

The HAM-x16 accelerometer sensor will detect the acceleration of gravity, which is a convenient feature for validating the sensor operation. Setting the logger on a flat level surface will result in -2048 counts (-1g) in the z-axis.

4.1.1.1 Special Feature

The HAM implements an 8X over-sample and finite impulse response (FIR) filter algorithm at sample rates up to 400Hz. This means that the digital accelerometer sensor provides 8X the sample rate requested in the config.txt file. For example, “samplerate=400” sets the sensor to stream at 3200 Hz, which is the maximum capability of the ADXL345. The eight samples are averaged and processed through the FIR filter to improve the response characteristics. The oversampling and FIR algorithm increases the sensor's native 13-bit resolution to the 16-bit data recorded in the data file.

The HAM will support sample rates of 800, 1600, and 3200 Hz but the HAM deactivates the oversampling and FIR filter and records the native 13-bit resolution from the sensor. However, these sample rates are not guaranteed and the time stamps may become inaccurate or the logger operation could become unstable. Performance is dependent on the microSD card capability.

Figure 21 shows an example configuration setting the logger to record at 800 Hz. The 13-bit data from the sensor is right padded (LSB) into a 16-bit value to maintain consistency with the oversampled data. Therefore, the conversion factor is still 2048 counts/g.

```
; Example HAM-x16 Config file
; set to 800Hz
samplerate = 800
; record constantly
deadband = 0
deadbandtimeout = 0
; set file length
samplesperfile = 100000
; set status indicators
statusindicators = normal
```

Figure 21: 800Hz sample configuration

4.1.2 IMU

The HAM logger uses the InvenSense MPU-9250 9-axis sensor. This sensor combines a 3-axis accelerometer, 3-axis gyroscope, and 3-axis magnetometer (compass) as well as a Digital Motion Processor (DMP) engine to provide an orientation solution. The DMP uses data from the accelerometer and gyroscope sensors to calculate the quaternion solution for orientation. Table 7 lists the basic sensor and logger performance parameters but refer to the MPU-9250 specification for further details. Sensor orientation is illustrated in Figure 2.

4.1.2.1 IMU-Accelerometer

Table 5: IMU-Accelerometer Sensor Characteristics

Parameter	Condition	Min	Typical	Max	Units
Nonlinearity	X, Y, Z axis		0.5		%FS
Zero-g Offset	X, Y axis	-80		+80	mg
	Z axis	-150		+150	mg
Sensitivity	±2g		16384		counts/g
	±4g		8192		
	±8g		4096		
	±16g		2048		

4.1.2.2 IMU-Gyroscope

Table 6: IMU-Gyroscope Sensor Characteristics

Parameter	Condition	Min	Typical	Max	Units
Nonlinearity	X, Y, Z axis		0.2		%FS
Zero Rate	X, Y, Z axis		±20		°/sec
Sensitivity	±250 °/sec		131.072		counts/°/sec
	±500 °/sec		65.536		
	±1000 °/sec		32.768		
	±2000 °/sec		16.384		
Sensitivity Tolerance	X, Y, Z axis	-3		+3	%
Cross-Axis Sensitivity			±2		%

4.1.2.3 IMU-Magnetometer

Table 7: IMU-Magnetometer Sensor Characteristics

Parameter	Condition	Min	Typical	Max	Units
Full Scale Range	X, Y, Z axis		±1200		uT
Sensitivity		3.175	3.413	3.509	counts/uT
Zero-Field Output		-1000		+1000	counts

The magnetic sensor detects the Earth's magnetic field lines, which is used to help determine orientation. Other magnetic fields, such as from permanent magnets and electromagnetic systems, will affect the sensor output. Therefore, do not use magnets as an attachment method for this logger.

4.1.3 IMU-Pressure

The HAM-IMU+Alt logger uses the Bosch Sensortec BMP180 digital pressure sensor. Table 8 lists the basic sensor characteristics but refer to Bosch for complete sensor details. The sensor is configured to operate in high-precision mode to maximize the measurement accuracy.

Table 8: Pressure Sensor Characteristics

Parameter	Condition	Min	Typical	Max	Units
Operating temperature	Operational			+85	C
	Full Accuracy			+65	°C
Absolute accuracy pressure V_{DD}=3.3 V	70000 - 110000 Pa (0 to +65 °C)	-250	±100	+250	Pa
	30000 - 70000 Pa (0 to +65°C)	-300	±100	+300	Pa
	30000 - 110000 Pa (-20 to 0 °C)	-400	±150	+400	Pa
Resolution of output data	Pressure				Pa
	Temperature				°C
Relative accuracy pressure	70000 – 110000 Pa (@ 25°C)		±20.0		Pa
	0 – 65°C (@ p constant)		±50.0		Pa
Absolute accuracy temperature	@ +25°C	-1.5	0.5	+1.5	°C
	0 - 65°C	-2.0	±1.0	+2.0	°C

4.2 Operating and Storage Conditions

The HAM is protected from normal handling and moderately wet conditions, such as rain, sweat, and splashes. The operating temperature range is limited primarily by the lithium-polymer battery capabilities.

Table 9: Operating and Storage Conditions

Parameter	Value
Temperature Range (Operating)	-5°F ~ 130°F (-20°C ~ 55°C)
Temperature Range (Storage)	-5°F ~ 80°F (-20°C ~ 25°C)
Relative Humidity (Operating and Storage)	<90%

Be careful opening the cap after the logger was exposed to water. Droplets of water will remain around the periphery of the cap and could enter the enclosure. After opening the cap, use a dry cloth to wipe any residual water from the cap and gasket region.

4.3 Dimensions

The overall HAM dimensions are 2.21 inches long (56.1 mm), 1.55 inches wide (39.4 mm), and 0.60 inches high (15.2 mm) and weighs 0.9 ounces (25g). The two slots are designed to allow a 1" wide (25mm) strap to loop around the enclosure.

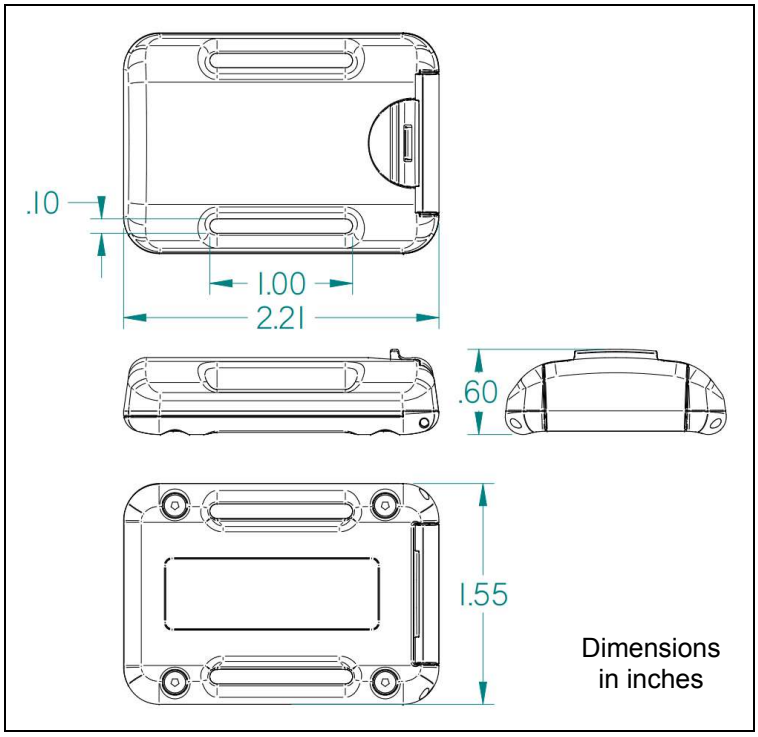


Figure 22: Enclosure Dimensions

5 Troubleshooting

Problem	Resolution
I pass a magnet near the logger but it does not appear to activate and no LEDs blink.	Make sure the battery is charged.
	Some weaker magnets may need to be oriented in a certain way to activate the switch. Rotate the magnet until the switch responds and the logger activates.
	The logger could be operating correctly but the status indicators are turned off. Check the "statusindicator" option in the config.txt file.
The logger turns on, the blue LED blinks once per second but the red LED does not indicate logging.	The deadband setting is set too high and the logger is waiting to detect an event.
	The logger is in standby mode waiting for a start time to occur. Check the config.txt file for the start/stop settings.
The logger records only for a short period of time.	Check that the battery is fully charged.
	The memory is full and data files must be deleted.
I plug the logger into a USB port but the PC does not indicate an external drive present.	The flash memory is corrupted. Plug the logger into a PC and run a disk diagnostic tool to check the memory. Reformat if necessary (FAT32).
	The USB connection could be faulty or the extender cable (if present) could be faulty. Remove the extender cable and plug the logger into another USB port.
The logger seems to ignore the config.txt file and use default settings.	Check that the config.txt file is properly formatted and not corrupted. Each setting should occur on a separate line.
	Some IT organizations implement an automatic encryption of all removable media devices. This will encrypt the config.txt file and the logger will not be able to access the file. Do not allow encryption of the device.
The start time in the data file header is incorrect.	Initialize the RTC.
The time.txt file doesn't load to the RTC	Check that the date/time is correctly formatted and the file name is "time.txt". Windows may hide the file extension so naming the file as "time.txt" may actually be named "time.txt.txt". Check the Windows file explorer options the view of regarding file extensions.

Problem	Resolution
The Z-axis data is missing in the file.	No, it's present but the column headers are shifted in your spreadsheet due to the presence of the “headers” tag.
The logger is stationary but it registers 1g.	This is normal and indicates Earth's gravity is operating correctly.
But the logger actually registers something other than 1g when stationary.	The sensor will exhibit a slight offset error. Add or subtract the appropriate amount to correct the error.
I want to calibrate my logger.	The logger does not have provisions for implementing user-defined calibration coefficients and any corrections must be performed post-process.
	GCDC does not provide calibration services.
What are quaternions and why does my head hurt?	Quaternions are a fancy mathematical notion for representing orientation without the limitation of “gimbal lock” found with Euler angles. Quaternions are used commonly in 3D gaming software engines to render the orientation of objects.

End of User Manual