



Motion Studio User's Guide

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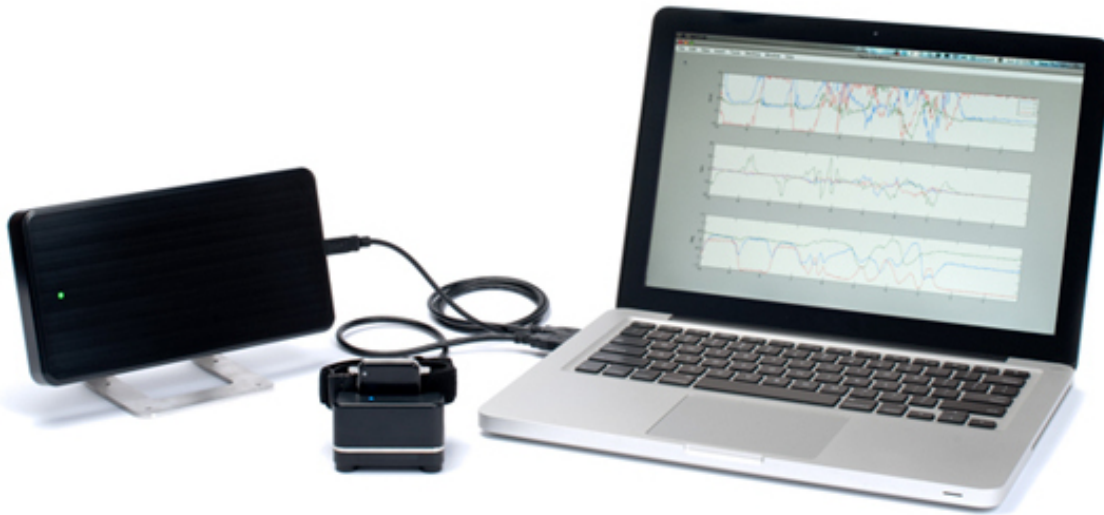
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1 Welcome

Congratulations on your purchase! APDM movement monitors are the most advanced in the world, and provide a complete feature set in a small, attractive, and unobtrusive package.

Motion Studio provides an easy to use software interface to our movement monitors and supporting hardware, and will enable you to:

- Configure your monitor's settings and features
- Use your hardware for synchronized, wireless streaming of data (Opals only)
- Use your hardware for synchronized logging of data (Opals and Emeralds only)
- Use your hardware for long duration, non-synchronized logging of data (Opals, Emeralds, and Sapphires)
- Recalibrate you monitors
- Organize and view your recorded data
- Keep your hardware up-to-date with firmware updates

2 Quick Start

The following steps are required to get up and running:

1. Turn on your computer and wait for it to boot up.
2. Download Motion Studio. See the [Downloading Motion Studio](#) section of this document for details.
3. Install Motion Studio. See the [Installing Motion Studio](#) section of this document for details.
4. Plug the access point(s) into your computer.



5. If multiple docking stations are chained together, you must plug the external power adapter into the docking station. You should see the the lights on each docking station turn yellow when power is applied.
6. Grab a USB cable with a micro (small, flat) connector and plug it into your docking station. If you are using a USB hub, make sure that it is a USB 2.0 High Speed hub and that it has external power. The LEDs on the docking station(s) should turn to solid green when they are recognized by the computer. See special notes in [Installing Motion Studio](#) if running Windows XP.



7. Dock the movement monitors into their docking stations. You should see the light on the monitors turn dark blue.



8. Open Motion Studio, and click on the “Configure” button. Choose your desired recording mode, and click “Finish”.
9. Undock the monitors.
10. Wireless streaming mode
 - a) After about 5-15 seconds, you’ll notice that the LED’s on the monitors will blink green in unison, and that the access point will have a blinking green LED, indicating that it is receiving data from the monitors.
 - b) Press the “Stream” button in the toolbar. You can view live data streaming in the real-time chart.
 - c) Press the “Record” button to start recording data.
11. Logging modes
 - a) Undock the monitors from their docking stations. They will start recording within several seconds. If using the synchronized logging mode, the LEDs on the monitors will blink in unison.
 - b) When you are done recording, dock the monitors, and press the “Import Data” button in the toolbar to retrieve the data from the monitors. See [“Import Manager”](#) section of this document for details.



3 System Overview

The APDM movement monitoring system allows the user to record data from multiple monitors; each integrating a suite of sensors. The system can be configured in 3 recording modes allowing for a wide range of applications. Some movement monitors are limited to a subset of these modes allowing for a lower cost solution. The modes of operation are robust synchronized streaming, rapid synchronized streaming, synchronized logging, and low power logging. Regardless of the mode the movement monitor always will record data to its local memory card which can be imported from the monitor for offline analysis.

3.1 Movement Monitors

Movement monitors are the key element of the system and combine a complement of sensors within a single package. Sensors include a 3 axis accelerometer, a 3 axis gyro, a 3 axis magnetometer, and a temperature sensor. The accelerometers can be configured in a high 6G mode, or a low 2G mode depending on the target application. There are a number of options for securing the monitors on subjects using a selection of straps.

3.1.1 The Opal

The Opal is APDM's full featured movement monitor allowing for use of all 4 recording modes.



The Opal movement monitor

3.1.2 The Emerald

The Emerald is an option that supports the synchronized and low power logging modes, but does not support the streaming modes. These monitors are optimized for long duration recordings or recordings where it is not desirable to have a computer at hand to collect streaming data.

3.1.3 The Sapphire

The Sapphire only supports the low power logging mode. This version of the movement monitor has no wireless capabilities and may be the optimal choice for RF sensitive environments or where a single movement monitor is needed without synchronization.



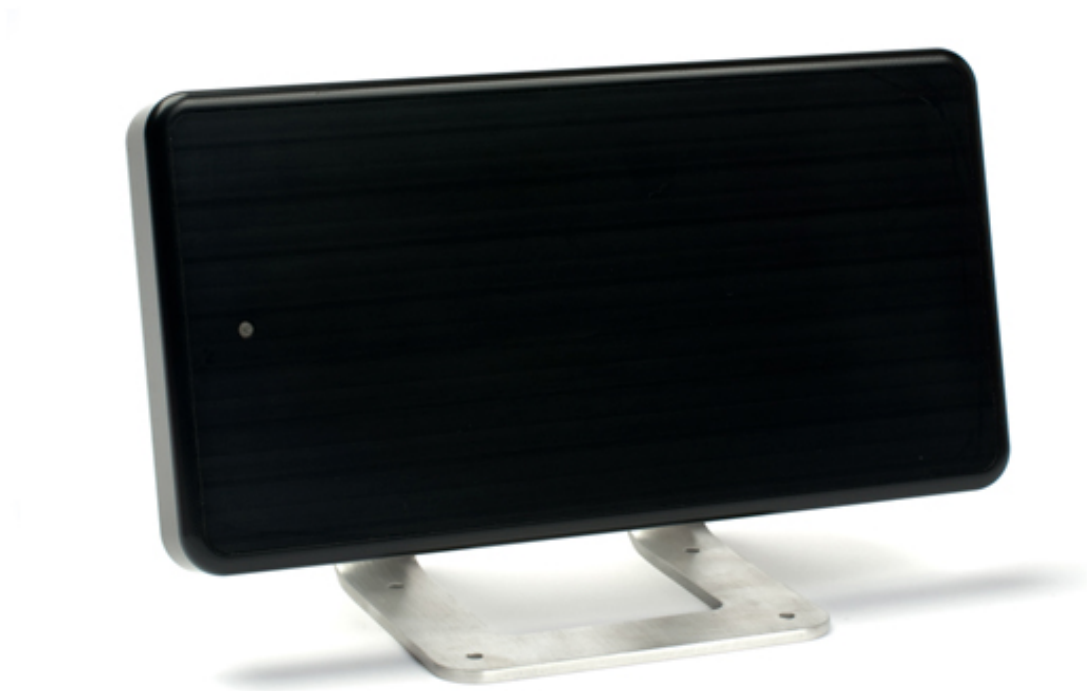
The docking station, for charging, configuring, and downloading data from your movement monitors

3.2 Docking Station

The docking station is used to configure, charge, and download data from the movement monitors.

3.3 Access Point

The wireless access control point (access point for short) allows for wireless communication between the host computer and Opal movement monitors. A single access point can support up to 6 Opals.



The access point, for communicating wirelessly with your movement monitors

3.4 Recording Modes

To suit a range of different recording requirements, a number of different recording modes are possible. Some monitor types do not support all recording modes.

3.4.1 Robust Synchronized Streaming

In the robust synchronized streaming mode, you can stream data from multiple, synchronized monitors directly to your computer. Data is buffered on the monitors, so no data is lost even if there are interruptions in the wireless signal. Only the Opals can be used in this mode.

3.4.2 Rapid Synchronized Streaming

The rapid synchronized streaming mode is similar to the robust synchronized streaming mode, except data is not buffered on the monitors in order to minimize the latency of the streaming data. Latency on Linux and Mac OS is typically in the range of 8ms to 25ms, while latency on Windows is typically in the range of 10ms to 75ms. This recording mode is appropriate for biofeedback applications. In the event of interruptions in the wireless signal, data will be dropped from the stream. Only the Opals can be used in this mode.

3.4.3 Synchronized Logging

In the synchronized logging mode, monitors log recorded data to their on-board flash memory. The monitors are synchronized wirelessly with each other while recording, so the individual logs can easily be synchronized with each other after the data has been imported from your monitor(s). In this mode, up to 32 monitors can be synchronized within a single “mesh”. Only Emeralds and Opals are able to use this mode.

3.4.4 Low Power Logging

All movement monitor products (Opals, Emeralds, and Sapphires) are able to operate in the low power logging mode. In this mode, the monitors’ wireless radios are disabled, decreasing the power required for operation and enabling the monitors to run for longer periods of time. Since the mode does not use any wireless synchronization, each movement monitor will collect data independently and potentially at slightly different rates due to clock drift.

3.5 Motion Studio

Motion Studio is the default software suite bundled with the APDM movement monitor system. It provides an easy way to get up and running collecting data with your movement monitors.

3.6 APDM Software Development Kit

The APDM Software Development Kit (SDK) provides programming tools for software developers. These tools enable developers to write their own software capable of configuring and streaming data from the movement monitors. In addition, it also provides functions for converting the raw data files found on the monitor’s memory card into either a HDF5 (recommended) format or CSV. The SDK provides the same low level interface to the hardware that Motion Studio is built upon.

4 Downloading Motion Studio

Motion Studio is supported on the following platforms:

- Apple Macintosh OSX 64-bit
- Apple Macintosh OSX 32-bit
- Windows 32-bit (XP, Vista, Windows 7)
- Windows 64-bit (Vista, Windows 7)
- Linux 32-bit
- Linux 64-bit

To download the latest version of Motion Studio, visit:

http://share.apdm.com/motion_studio/

and select the version that matches your operating system.

The download includes everything you need to get started, including:

- Drivers
- Firmware
- The Motion Studio desktop application

Note (Windows Only): To simplify the Java configuration on the Windows platform, the 32- and 64- bit versions of Motion Studio come pre-bundled with the appropriate Java Runtime Environment (JRE). This adds about 70 Mb to the download size, but removes a major variable in the installation process.

Note (MacOSX and Linux): Motion Studio requires Java 1.6 to run. Make sure your Java installation is up to date before attempting to launch the application. In order to use the 64-bit version of Motion Studio, you also need to have the 64-bit Java JRE installed.

5 Installing Motion Studio

5.1 Macintosh OSX (x32/x64)

- Unzip the contents of the downloaded zip file into the directory of your choice. No further steps are required.

5.2 Windows

- Double click on the downloaded Mobility Lab setup file. This will guide you through the installation process.

Note: When the setup utility is installing the hardware drivers, you may have be prompted with a warning that the drivers are not digitally signed. This is expected and it is OK to proceed.

Note: Due to read/write permission restrictions (UAC) in Vista and Windows 7 on the “Program Files” and “Program Files (x86)” directories, Motion Studio is installed to “C:/MotionStudio”.

Note: If you have an NEC/Renesas USB 3.0 controller, you must upgrade to the latest driver version, available at <http://www.station-drivers.com/page/nec.htm> You can check this using device manager, under the “Universal Serial Bus Controllers” section. You will see an “Renesas Electronics USB 3.0 Host Controller” or a “Renesas Electronics USB 3.0 Root Hub”.

5.2.1 Windows XP

Windows XP will prompt you with the “Found New Hardware” wizard every time you plug an access point or docking station into a USB port for the first time. This happens even if you have already installed it on a different port, and may even happen if you have already installed it on the same port. This is a “feature” of Windows XP and not an issue in Vista or Windows 7. If you have a chain of multiple docking stations, you will be prompted for each one.

When you are prompted with the “Found New Hardware” wizard:

- Select the “No, not this time” option and click “Next”
- Select the “Install the software automatically” option and click “Next”.

5.3 Linux (x32/x64)

- Unzip the contents of the downloaded zip file into the directory of your choice.

The appropriate permissions have to be set to interface with the hardware devices. This can be configured via the udev system. The user will need access to devices with the following vendor ID (VID) and product ID (PID):

Access Point: **VID:** 0x224F **PID:** 0x0001

Docking Station: **VID:** 0x224F **PID:** 0x0002

An example set of udev rules for the access point and docking station are as follows:

```
ACTION=="add", ATTRS{idVendor}=="224f", ATTRS{idProduct}=="0001", MODE:="0666"
```

```
ACTION=="add", ATTRS{idVendor}=="224f", ATTRS{idProduct}=="0002", MODE:="0666"
```


6 Motion Studio

Motion Studio is the default software suite bundled with the APDM movement monitor system. It provides an easy way to get up and running collecting data with your movement monitors. It also provides advanced configuration, recording, calibration, and data management features that enable you to take full advantage of the APDM movement monitor system.



The Motion Studio workspace

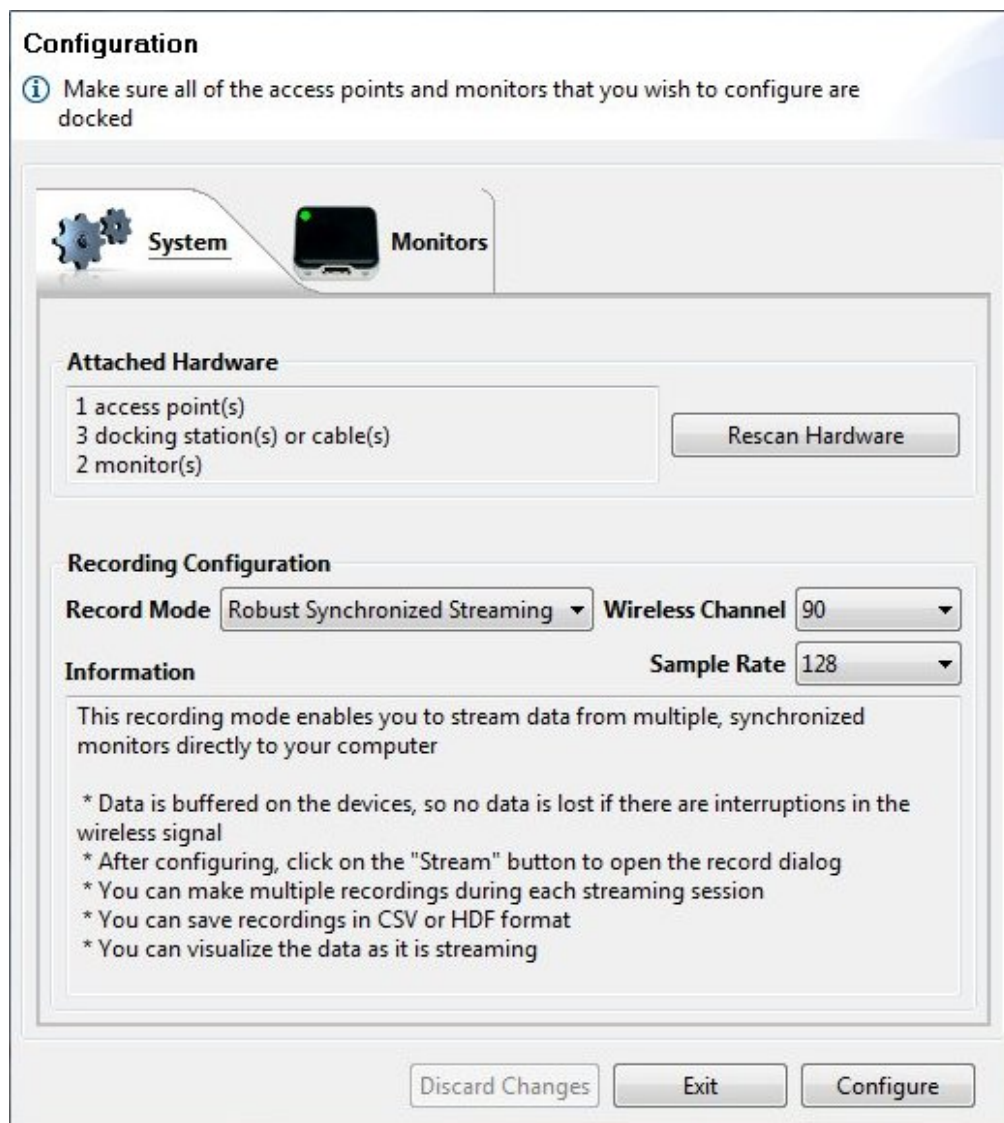
7 Configuration

APDM movement monitors can be configured in a number of ways to match your recording needs. To open the configuration dialog, make sure your access points and docking stations are plugged into the computer and that your monitors are inserted into their docks. Press the “Configure” button in the application tool bar.



The “Configure” button in the toolbar

The configuration dialog will enable you to configure the settings of your individual monitors, in addition to system-wide settings.



The system configuration options of the configuration dialog

7.1 Automatic Firmware Updates

Whenever you press the “Configure” button, your hardware is first checked to ensure that the latest firmware is installed. If not, you will be prompted to automatically update your hardware to the latest versions of the firmware bundled with Motion Studio.

7.2 System Configuration

7.2.1 Attached Hardware

This window displays the APDM hardware that is detected on your computer. If this list does not accurately specify the hardware that you have attached, you should press the “Rescan Hardware” button (see the next topic) to initiate the scan again.

7.2.2 Rescan Hardware

This option will search for APDM hardware attached to your computer and refresh the configuration dialog.

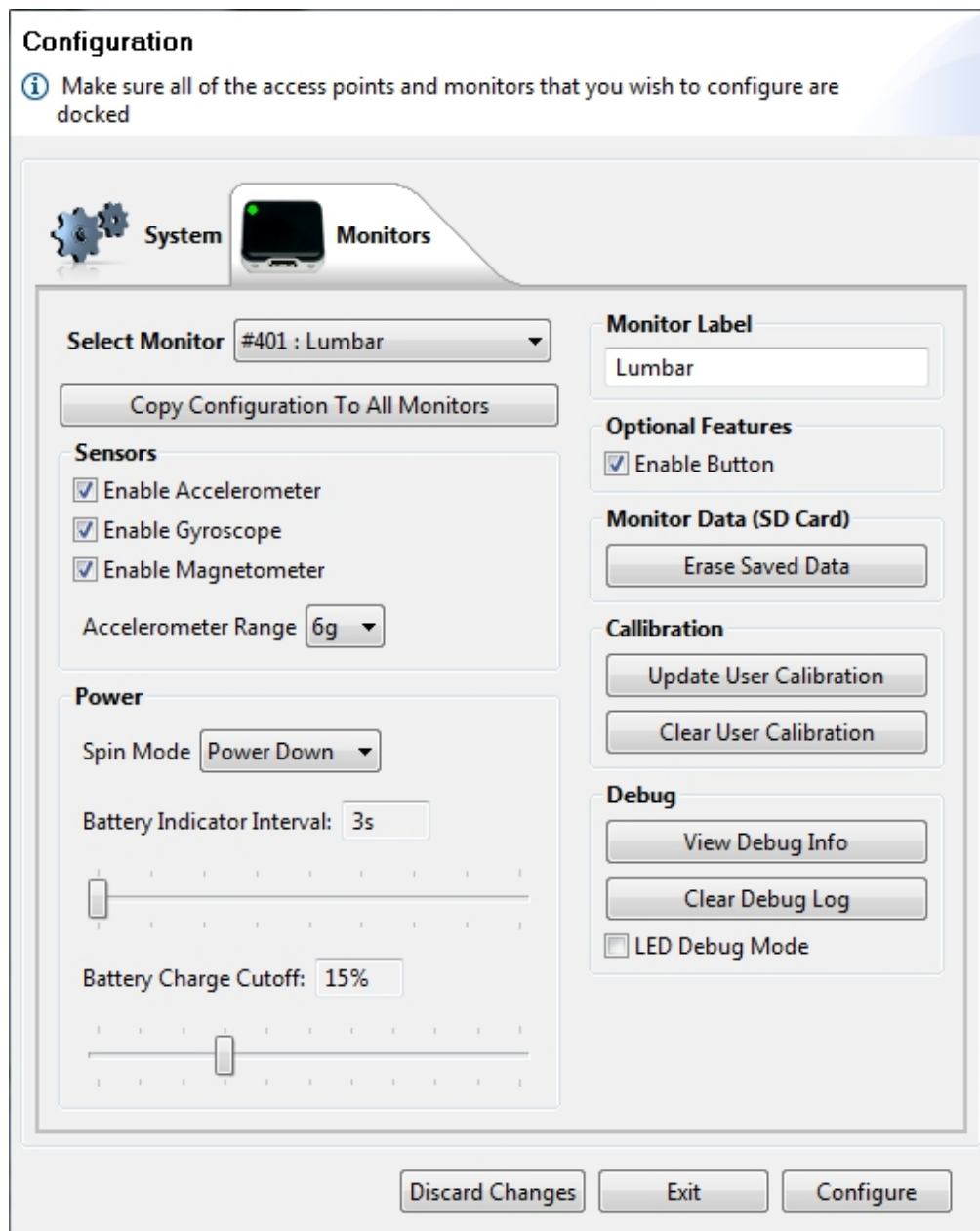
7.2.3 Record Mode

Use this option to specify how you wish to record data from your monitors:

- Robust Synchronized Streaming (Opals only)
- Rapid Synchronized Streaming (Opals only)
- Synchronized Logging (Opals and Emeralds only)
- Low Power Logging (Opals, Emeralds, and Sapphires)

7.3 Wireless Channel

Monitors configured for wireless streaming or synchronized logging transmit data in the 2.4 ghz wireless spectrum range. Channel zero corresponds to roughly 2.40 ghz, and channel 90 corresponds to roughly 2.49 ghz. Many other consumer electronic devices make use of radio frequencies in the 2.4 ghz spectrum, such as WiFi routers, cordless phones, and blue-tooth devices. Because of this, it's important to choose a channel that is not heavily in use by another device or you may experience wireless issues. If you experience wireless issues, the most common source of interference is from WiFi routers. You can determine the channel that your WiFi router is running on and determine its corresponding frequency from the following URL: http://en.wikipedia.org/wiki/IEEE_802.11.



The monitor configuration options of the configuration dialog

7.4 Monitor Configuration

Use the “Select Monitor” combo box to specify the monitor you wish to individually configure.

7.4.1 Copy Configuration to All Monitors

When this button is pushed, the configuration for the currently selected monitor will be copied to all currently docked monitors, with the exception of the “Monitor Label” configuration option.

7.4.2 Sensors

Enable or disable on-board sensors. If your application does not require data from a particular sensor type, turning them off can reduce file sizes and improve battery life. The gyroscopes in particular use a significant amount of battery power.

7.4.3 Accelerometer Range

Specifies whether the range of the accelerometer is ± 2 g or ± 6 g. This is approximately equal to ± 20 or ± 60 m/s², although some sensors may have a slightly larger range before saturating. If your application does not need the full ± 6 g range, using the ± 2 g range will slightly improve the signal to noise ratio (SNR) of your accelerometer readings.

7.4.4 Power

Spin mode. You can optionally assign an action to occur when the monitor is spun clockwise or counterclockwise about its z-axis. For example, spinning the monitor when it is lying flat on a table. Gyroscopes need to be enabled on the monitor in order to make use of this feature. The following spin modes are available:

- Do Nothing.
- Power Down. When this setting is used, the monitor will power down completely when spun rapidly. The monitor will need to be reconfigured before the next use in order to reset the clock. This mode is appropriate for short to long term storage.
- Standby. When this setting is used, all components except the clock are powered down. This mode is appropriate for short term storage (a few days). The monitor will start recording again the next time it is docked and undocked. If it has been stored long enough for the battery to completely run out, reconfiguring or pressing the “Power On” button while it is docked will reset the clock.

Battery Indicator Interval. Specifies how often the LED sequence indicating the current battery level is displayed. This can be set from a value of 3 s to 768 s. The battery level is indicated by the number of blinks, ranging from 1 blink (low battery) to 4 blinks (full battery). The battery indicators on synchronized monitors will also be synchronized.

Battery Charge Cutoff. Specifies the charge level at which the monitor goes into standby mode. This is particularly useful for application where the monitors will not be re-configured between uses and it is desired to keep the clocks running. For example, daily monitoring of a subject that is planning on charging overnight via a charging cable, but not planning on reconfiguring in the morning. If the cutoff level is set to 0%, the battery will completely drain before powering down. If the cutoff level is set to 50%, the monitor will enter standby mode when 50% of the charge is left. This extreme provides for two or more days of operation in

standby mode before the battery is dead and the clock is reset. It will also, however, impact the running time of the monitor.

7.4.5 Monitor Label

By specifying a label for a monitor, this label will be persisted along with the data in both the CSV and HDF file types. Example labels are “Right Arm” and “Jane Doe”. This is often easier than associating data with a monitor ID (e.g., “56”). There is a 15 character limit for the label.

7.4.6 Enable Button

If selected, the monitor will process events triggered by an external button. See Section 11 for details. If unselected, button events will not be processed, even in the presence of an external button.

7.4.7 Monitor Data (SD Card)

Erase Saved Data Pressing this button will delete all of the recorded data on the specified monitor. This does not include configuration data. The data is deleted the next time the monitor is undocked.

7.4.8 Calibration

Update Calibration Data Use this option in the event that your monitor needs to have its calibration data updated. You will have to specify the calibration file to use.

7.4.9 Debug

View Debug Info. This option allows you to print out detailed information about the monitor configuration and a log of any errors that have been encountered during its operation. The output is placed into a special page in the console view of the main application. Use the “Display Selected Console” button to select the appropriate console view.

Clear Error Log. Use this option to clear the error log on the monitor. This is useful when debugging to ensure that error log entries are not historical.

LED Debug Mode. When this option is selected, the monitor’s LED will display debug information while recording, instead of blinking in unison with the rest of the monitors. See [Monitor Reference](#) for details on the LED modes.

7.5 When you are done configuring your system

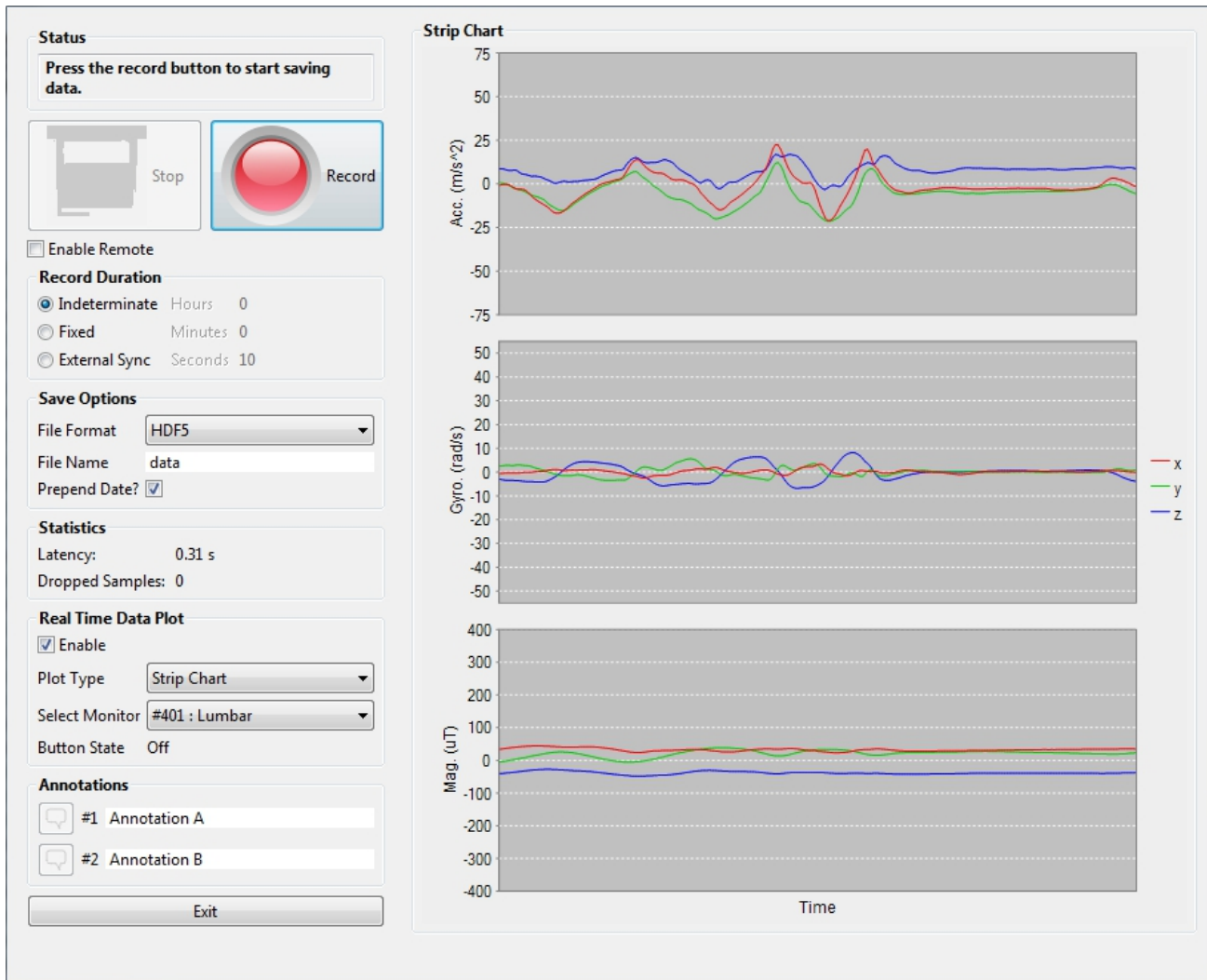
Press the “Configure” button to complete the configuration. When the configuration progress dialog completes, unplug your monitors from their docking stations.

7.6 Re-configuration

Wireless streaming configuration data is stored on the access points. Re-configuration is required whenever the access points are unplugged from the host computer or the host computer is rebooted. Re-configuration is not required if Motion Studio is shut down and restarted, or if one of the logging modes are currently configured.

8 Synchronized Streaming Modes

If one of the synchronized streaming modes (robust or rapid) is selected in the configuration dialog (Opals only), you can stream data from multiple, synchronized monitors directly to your computer.



The synchronized streaming dialog

8.1 Starting a Streaming Session

To start a streaming session, press the “Stream” button in the application tool bar to bring up the recording dialog.



The “Stream” button in the toolbar

The stream dialog will enable you to configure how you view and record streaming data from your Opals.

Note: If you notice excessive latency or a very slow frame rate, consider unchecking the “Enable” checkbox, which will stop the real time plotting of data and free up more processing power on your computer.

8.2 Record Duration

You can select between fixed and indeterminate recording durations:

Fixed duration. You can specify the number of hours, minutes, and seconds for each recording. You can press the “Stop” button to stop your recording before the specified duration has lapsed.

Indeterminate duration. Your recording will continue until you press the “Stop” button.

8.3 Save Options

8.3.1 File Format

You can record to either the HDF5 (<http://www.hdfgroup.org/>) or the CSV file format.

HDF5 is an open format for storing structured, binary data. Files are more compact than their CSV counterparts and can be opened directly in a number of analysis software packages, including Matlab. See the chapter on “Working with HDF5 Files” in this document for more information.

CSV is a plain-text format that can be opened in spreadsheet software applications, such as Excel or OpenOffice, in addition to most analysis software.

8.3.2 File Name

Specify the name of the data file recorded to disk.

8.3.3 Prepend Date

If checked, the date and time of the start of the recording are added to the beginning of the file name.

8.4 Statistics

8.4.1 Latency

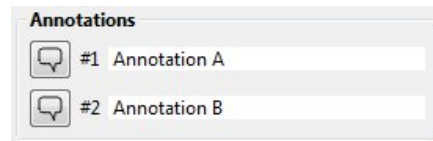
Displays the current latency between the time data is recorded to the time it is received by the computer. Latency may be increased by poor wireless reception or monitors that are occluded from the access point (e.g., against a metal chair back, around a corner, etc.). Additional latency will be incurred by the plotting of the data to the screen.

8.4.2 Dropped Samples

Displays the number of samples dropped since the current streaming session was started. There are only a few extreme cases where samples will be dropped when using the robust streaming mode. In the event that data is dropped, all of the recorded data will be present on the monitor's on-board memory and can be recovered manually using the Import Manager after the monitor is docked.

8.5 Annotations

You can use the annotation buttons to add annotations to an ongoing recording. When the button is clicked, a timestamped marker will be added to the recorded file (HDF only). If you add text to the text box on the right side of either button, the text will be added to the annotation. See Section 6 for details about the HDF format and the location of the annotations. You can also use a remote to annotate your data from a distance (see Section 8.8 for details).



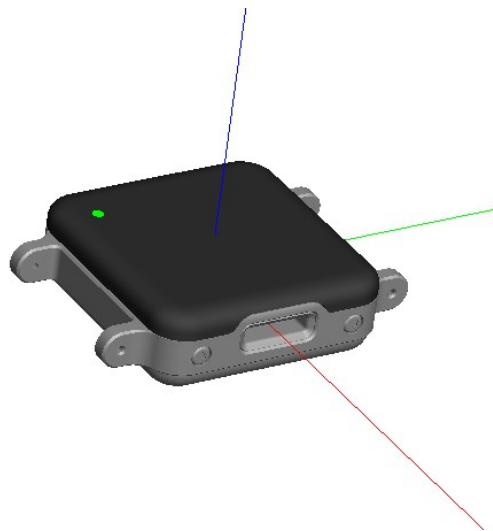
The annotations panel in the stream dialog

8.6 Real Time Chart

Use the "Select Monitor" combo box to view the real-time data from different monitors (subject to wireless and plotting latency). You can view the state of the external button (if enabled and attached) in the "Button State" field. A value of '1' indicates the button is pressed, while a value of '0' indicates that it is not.

The real time chart allows you to view the data streaming from your monitors. There are a number of visualizations currently implemented:

- **Strip Chart.** This shows the calibrated data from all activated sensors for the selected monitor with the most recent streamed data appearing on the right of the chart and moving to the left. There is a 2 second window.
- **Orientation.** This shows the estimated orientation of the monitor as a rendered 3D model. To initialize the visualization, hold your monitor such that the port is facing you and press on the “Center” button. Note: the orientation calculations are dependent, in part, on measurements from the magnetometers. If you are in a location with non-uniform magnetic fields (as is common around metal objects or other ferrous material), the orientation estimates may be compromised.
- **2-D.** This shows one of the axes of an individual accelerometer or gyroscope versus one of the other axes. For example, “Y vs. Z Accelerometer” or “X vs. Y Gyroscope”.



The Orientation Visualization

8.7 Starting and stopping

When you are ready to record press the “Record” button in the stream dialog.

To stop your recording press the “Stop Button”. Your data will be saved to your current working directory and the recording will be plotted on the screen.

The record dialog will then prepare for additional recordings.

8.8 Remote Control

Motion Studio supports the use of a remote control to aid while recording in the Synchronized Streaming mode. This functionality makes it possible to start and stop recording at a distance from your computer.

8.8.1 Supported Remotes

Motion Studio has been designed to use a standard presentation remote intended for navigating a slide presentation in Power Point or similar software. Our preferred remote is the Logitech R400, but other presentation remotes will most likely work out of the box because the buttons are often standardized.

8.8.2 Enabling the Remote

Enabling and disabling the remote can be performed in the streaming dialog by clicking on the "Enable Remote" checkbox below the Stop and Record buttons. When the remote is enabled, on-screen buttons that are mapped to remote functionality will have their standard icons either overlaid or replaced by special remote icons. These icons are modeled after those on the Logitech R400 remote to make the mapping clear. Currently, the start and stop buttons are mapped to the "Next" and "Previous" slide buttons on the remote. The annotation buttons are mapped to the "Start" and "Stop" presentation buttons on the remote.



Examples of Motion Studio button icons that map to remote control buttons

9 Synchronized Logging Mode

If the synchronized logging mode is selected in the configuration dialog (Opals and Emeralds only), you can log data from more than one monitor to their on-board flash memory and the monitors are synchronized wirelessly with each other.

9.1 To start recording

Disconnect the monitors from their docking stations after configuration. After a few seconds to initialize, they will start recording to their flash memory. When within wireless contact with one-another, they will synchronize their clocks. To start an additional recording in a separate file, connect and disconnect the monitors from their cables or docking stations. No re-configuration is necessary.

9.2 To import recorded data

Plug the monitor into a docking station. Click on the "Import Data" button in the toolbar. See [Section 12](#) for information about using the Import Manager.

10 Low Power Logging Mode

If your monitors are configured for low power logging (Opals, Emeralds, and Sapphires), you can log data from one or more monitors at a time to their on-board flash memory. Wireless radios are turned off to save power. Multiple monitors will not be synchronized, and some level of clock drift will occur during long recordings.

10.1 To start recording

Disconnect the monitors from their cables or docking stations after configuration. After a few moments to initialize, they will start recording to their flash memory. When within wireless contact with one-another, they will synchronize their clocks. The monitors will stop recording once they are docked again. No re-configuration is necessary.

10.2 To import recorded data

Plug the monitor into a docking station. Click on the "Import Data" button in the toolbar. See [Section 12](#) for information about using the Import Manager.

11 External Button Event Handling

APDM offers an optional button that fits into the data port of an undocked monitor. This button allows for additional functionality while recording including:

- Inserting event markers into the data stream
- Stopping and starting recording

11.1 Enabling the button

The button is enabled via the Monitor tab in the configuration dialog box. See Section [7.4.6](#) for details. After undocking a monitor with button handling enabled, you must insert the button into the data port on the monitor. The button must be removed again before the monitor can be docked.

11.2 Event Markers

Often it is desirable to record the time of external events directly into the data stream for offline analysis. The external button provides a mechanism for doing this. Note: when streaming data, you may find that annotations provide a nice solution to this problem (HDF file format only). See Section [8.5](#) for more details about annotations.

Pressing the button will insert the button state (up/down) into the data stream of the monitor the button is connected to. A maximum of one button transition (on→off or off→on) can be recorded every 10ms. The button state is stored on a sample-by-sample basis (much like the sensor data) in the output file. Both CSV and HDF file formats support the storage of the button state. A value of '1' indicates that the button is pressed, while a value of '0' indicates that the button is not pressed. If you are using one of the streaming modes, the current button state is indicated in the "Button State" field in the Stream Dialog (make sure you have selected the correct monitor in the "Select Monitor" drop-down when viewing the button state). This is a good way to test that the functionality is working.

11.3 Starting and Stopping Recordings

If the button is held down for at least 3 seconds the monitor will transition into a "hold" mode where recording is halted. The led will indicate this mode by a slow blue blink pattern. If the button is released and held for another 3 seconds while halted, the monitor will start running again and a new recording will be started. Please note the following:

- When you halt a monitor using the external button, any other monitors currently in use will continue to

record. We plan on improving this functionality in the future so that the button can be configured to halt all monitors when in the synchronized streaming mode.

- When in the hold state, the sensors remain powered up. Because of this, it is not intended to be used as a mechanism to significantly improve battery life. Instead, it is intended to be a mechanism to partition your recordings when using one of the logging modes.
- Because of these current limitations, the button is best used for stopping/starting recordings when using a single monitor in the low power logging mode.

12 Import Manager

The Import Manager enables you to import the data saved on the monitors, and to convert it to a format that can be read by a number of software analysis packages. Click on the “Import” button in the toolbar to open the Import Manager.



The Import button in the toolbar

When you open the import manager, the data from all currently docked monitors are moved to an import directory on your PC. These raw data files are displayed in the table at the top of the import directory.

Import Manager

Import and convert raw data from your movement monitors

Raw data ready for conversion

Monitor ID	Monitor Label	Start Date	Duration (s)
<input checked="" type="checkbox"/> 32	Right Leg	Mon Dec 27 15:39:52 PST 2010	6 m, 52 s
<input checked="" type="checkbox"/> 20	Left Leg	Mon Dec 27 15:39:51 PST 2010	6 m, 59 s
<input checked="" type="checkbox"/> 32	Right Arm	Mon Dec 27 15:37:59 PST 2010	56 s
<input checked="" type="checkbox"/> 20	Left Arm	Mon Dec 27 15:37:58 PST 2010	1 m, 1 s
<input type="checkbox"/> 32	Right Arm	Mon Dec 27 15:34:11 PST 2010	3 m, 23 s
<input type="checkbox"/> 20	Left Arm	Mon Dec 27 15:34:08 PST 2010	3 m, 30 s
<input type="checkbox"/> 20		Mon Dec 27 15:32:00 PST 2010	53 s
<input type="checkbox"/> 32	Lumbar	Mon Dec 27 15:31:50 PST 2010	1 m, 8 s
<input type="checkbox"/> 20		Mon Dec 27 15:27:00 PST 2010	3 m, 53 s
<input type="checkbox"/> 32	Lumbar	Sat Dec 25 19:02:55 PST 2010	1 m, 50 s
<input type="checkbox"/> 32	Lumbar	Sat Dec 25 18:56:37 PST 2010	5 m, 30 s
<input type="checkbox"/> 20		Sat Dec 25 18:56:35 PST 2010	8 m, 12 s
<input type="checkbox"/> 32	Lumbar	Sat Dec 25 14:11:58 PST 2010	11 m, 32 s
<input type="checkbox"/> 32	Right Leg	Sat Dec 25 14:08:02 PST 2010	2 m, 55 s

Click on a file, and all other files with overlapping recording times will be highlighted

Conversion Options

File Format: Include Raw Data ☐

Compress Data ☒ Delete Data After Import ☒

File Naming Options

Base File Name: Include Monitor ID ☒

Include Monitor Label ☒ Prepend Date? ☒

The Import Manager dialog window

12.0.1 Selecting Data For Import

In the table at the top of the Import Manager, you can select data for importing by clicking in the checkboxes on the left.

When you select a file in the table by clicking anywhere on the row, any other files that have overlapping recording times will be highlighted. This functionality aids in finding and merging of data that was recorded on multiple monitors synchronously.

12.0.2 Conversion Options

File Format. You can record to either the HDF5 (<http://www.hdfgroup.org/>) or the CSV file format. HDF5 is an open format for storing structured, binary data. Files are more compact than their CSV counterparts and can be opened directly in a number of analysis software packages, including Matlab. See the chapter on “Working with HDF5 Files” in this document for more information. CSV is a plain-text format that can be opened in spreadsheet software applications, such as Excel or OpenOffice, in addition to most analysis software.

Include Raw Data. Select this option if you want to include the raw sensor data in the import file. This is the raw sensor data, and has not been processed or converted to SI units.

Compress Data. When importing data into an HDF5 file, you can choose to compress the data. The resulting file will be significantly smaller, but it will take longer to perform the import. **Note:** Matlab versions before 2009a cannot read compressed HDF5 data.

Delete Data After Import. When selected, the raw data will be deleted after import.

12.0.3 File Naming Options

Base File Name. Specify the base name of the data file the data is being imported into.

Include Monitor ID. If selected, the case ID of the monitor being imported from will be embedded in the file name.

Include Monitor Label. If selected, the label of the monitor being imported from will be embedded in the file name.

Prepend Date. If checked, the date and time of the start of the recording are added to the beginning of the file name.

12.0.4 Import Options

Merge Selections Into One File. If clicked, all selections will be merged into a single HDF file after conversion. Multiple selections from the same monitor cannot be merged into a single HDF file.

Convert Selections Into Seperate Files. If clicked, each selection will be imported into a seperate file after conversion.

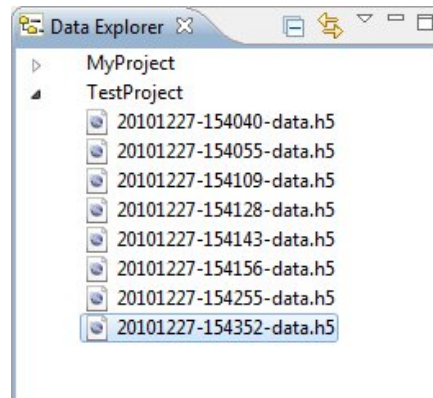
12.0.5 After Import

Imported data will show up in your current working directory. Right click on it and select "Plot" to plot the data to the screen.

13 Managing Your Data

13.1 The Data Explorer

The Data Explorer can be used to help you organize and view your data.

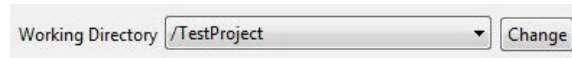


The Data Explorer view

The Data Explorer shows a hierarchical view of your projects and folders. Projects are the top level containers in the Data Explorer, and can hold any number of folders. Folders hold other folders or data files.

13.1.1 Working Directory

Your current Working Directory Tool is displayed in the application's toolbar. You can change your Working Directory by clicking on the "Change" button and selecting a different project or folder.



The Working Directory Tool in the toolbar

Whenever you record data through wirelessly streaming or import logged data from your monitor(s), the data will appear in your current Working Directory.

13.1.2 Creating new projects

1. Right-click in the Data Explorer and select "New → Project..."
2. Select the "Project" option from the New Project Wizard
3. Specify the project name
4. By default, the project and all contained files will be placed in Motion Studio's workspace directory, which is indicated in the console when Motion Studio is launched. If you wish to specify a different

location on your hard drive to create the project, uncheck the “Use default location” checkbox and choose the location of the new directory.

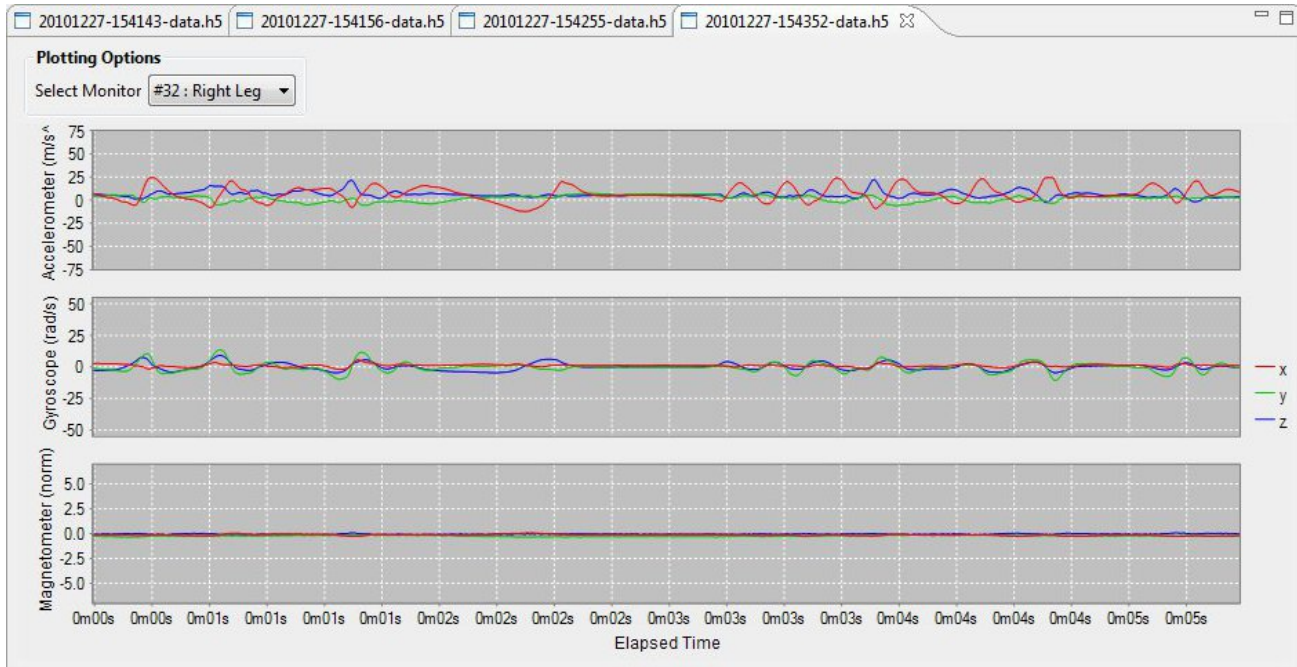
5. Click “Finish”
6. To make this your current working directory, click on the “Change” button in the Working Directory Tool and choose the new project.

13.1.3 Creating new folders in projects

1. Right-click in the Data Explorer and select “New → Folder”
2. Select the parent project or folder for the folder you wish to create
3. Specify the folder name
4. By default, the folder will be created in the project’s directory structure on your hard drive. It is possible, however, to associate the folder with a project but to store the data in a different location. If you wish to specify a different location on your hard drive to create the folder, click the “Advanced” button, select the “Link to alternate location(Linked Folder)” option, and specify the folder on your hard drive that you wish to store this folder’s data in.
5. Click “Finish”
6. To make this your current working directory, click on the “Change” button in the Working Directory Tool and choose the new folder.

13.2 Plotting

To plot a recorded file, either double-click on the file in the Data Explorer, or right-click on the file and select the “Plot” option. The plot dialog enables you to specify the monitor to plot.



The data plot view

14 Working with HDF5 Files

HDF5 is the preferred format for storing APDM movement monitor data. It is a standard format for scientific data that is efficient and widely supported. It uses less space than CSV, is faster to load, and supports more structured data. This section will cover the organization of the APDM movement monitor data and the basics of reading HDF5 files in MATLAB.

14.1 HDFView

A free program called HDFView (<http://www.hdfgroup.org/hdf-java-html/hdfview/>) can be used to explore, plot, and export this data into other formats. A variety of free open source tools for working with HDF files are also available at <http://www.hdfgroup.org/HDF5/release/obtain5.html>.

14.2 Data Organization

HDF5 files are organized like a file structure. The root of the file contains two attributes. One is a list of monitor IDs that have data stored in this file. The other is a version number for the organization of the HDF 5 file.

14.3 File Structure

14.3.1 Version 3

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaselIdList
- **CaselIdList** Attribute containing an array of monitor case IDs in the same order as the MonitorLabelList
- **FileFormatVersion** Attribute containing the file format version (3)
- **Annotations** Table containing annotations
 - **Time** Annotation time in epoch microseconds
 - **Case ID** A movement monitor case ID associated with the annotation
 - **Annotation** The annotation string
- **AA-XXXXXX** A group is included in the file for each monitor in the CaselIdList, with the name equal to the case ID
 - **SampleRate** Attribute containing the output data rate for the monitor
 - **DecimationFactor** Decimation factor for the monitor's internal processing
 - **ModuleID** The module ID for the monitor
 - **TimeGood** Flag indicating whether the time has been set on the monitor since it powered on
 - **RecordingMode** One of: "Wireless streaming", "Synchronized logging", or "Unsynchronized logging"
 - **DataMode** Indicates whether the data was retrieved wirelessly or copied from the monitor's internal storage while docked. One of: "Streamed wirelessly" or "Logged to monitor"
 - **AccelerometersEnabled** 1 for enabled, 0 for disabled

- **GyroscopesEnabled** 1 for enabled, 0 for disabled
- **MagnetometersEnabled** 1 for enabled, 0 for disabled
- **DecimationBypass** Internal use, deprecated
- **CalibrationVersion** Version of the calibration data used to convert from raw samples to calibrated SI units
- **VersionString1** Firmware version string 1
- **VersionString2** Firmware version string 2
- **VersionString3** Firmware version string 3
- **CalibratedDataPopulated** 1 for populated, 0 for unpopulated
- **LocalTimeOffset** Time in milliseconds to add to UTC to convert to local time
- **SyncValue** Dataset containing the internal sync value for each sample
 - * **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
- **Time** Dataset containing a timestamp for each sample
 - * **Units** Attribute string containing the units (microseconds since 0:00 Jan 1, 1970 UTC)
- **ButtonStatus** Dataset containing the button status for each sample (1==pressed, 0==unpressed)
- **Calibrated** Group containing calibrated data
 - * **Accelerometers** Dataset containing accelerometer data (Nx3)
 - **Units** Attribute string containing the accelerometer units (m/s²)
 - **Range** Attribute containing the range setting for the accelerometer (2g or 6g)
 - * **Gyroscopes** Dataset containing gyroscope data (Nx3)
 - **Units** Attribute string containing the gyroscope units (rad/s)
 - * **Magnetometers** Dataset containing magnetometer data (Nx3)
 - **Units** Attribute string containing the magnetometer units (μ T)
 - * **Temperature** Dataset containing the temperature (Nx1)
 - **Units** Attribute string containing the temperature units (°C)
 - * **TemperatureDerivative** Dataset containing the temperature derivative (Nx1)
 - **Units** Attribute string containing the temperature derivative units (°C/s)
 - * **Orientation** Dataset containing the orientation quaternion (Nx4). The orientation is relative to a (magnetic) north, west, up reference frame. The scalar component of the quaternion is the first element.
- **Raw** Group containing raw data if selected during import
 - * **Accelerometers**
 - * **Gyroscopes**
 - * **Magnetometers**
 - * **DataFlags**
 - * **OptData**
 - * **Temperature**
 - * **TemperatureDerivative**

14.3.2 Version 2

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaseldList
- **CaseldList** Attribute containing an array of monitor case IDs in the same order as the MonitorLabelList
- **FileFormatVersion** Attribute containing the file format version (2)
- **Annotations** Table containing annotations

- **Time** Annotation time in epoch microseconds
- **Case ID** A movement monitor case ID associated with the annotation
- **Annotation** The annotation string
- **AA-XXXXXX** A group is included in the file for each monitor in the CaseldList, with the name equal to the case ID
 - **SampleRate** Attribute containing the output data rate for the monitor
 - **DecimationFactor** Decimation factor for the monitor's internal processing
 - **ModuleID** The module ID for the monitor
 - **TimeGood** Flag indicating whether the time has been set on the monitor since it powered on
 - **RecordingMode** One of: "Wireless streaming", "Synchronized logging", or "Unsynchronized logging"
 - **DataMode** Indicates whether the data was retrieved wirelessly or copied from the monitor's internal storage while docked. One of: "Streamed wirelessly" or "Logged to monitor"
 - **AccelerometersEnabled** 1 for enabled, 0 for disabled
 - **GyroscopesEnabled** 1 for enabled, 0 for disabled
 - **MagnetometersEnabled** 1 for enabled, 0 for disabled
 - **DecimationBypass** Internal use, deprecated
 - **CalibrationVersion** Version of the calibration data used to convert from raw samples to calibrated SI units
 - **VersionString1** Firmware version string 1
 - **VersionString2** Firmware version string 2
 - **VersionString3** Firmware version string 3
 - **CalibratedDataPopulated** 1 for populated, 0 for unpopulated
 - **LocalTimeOffset** Time in milliseconds to add to UTC to convert to local time
 - **SyncValue** Dataset containing the internal sync value for each sample
 - * **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
 - **Time** Dataset containing a timestamp for each sample
 - * **Units** Attribute string containing the units (microseconds since 0:00 Jan 1, 1970 UTC)
 - **Calibrated** Group containing calibrated data
 - * **Accelerometers** Dataset containing accelerometer data (Nx3)
 - **Units** Attribute string containing the accelerometer units (m/s^2)
 - **Range** Attribute containing the range setting for the accelerometer (2g or 6g)
 - * **Gyroscopes** Dataset containing gyroscope data (Nx3)
 - **Units** Attribute string containing the gyroscope units (rad/s)
 - * **Magnetometers** Dataset containing magnetometer data (Nx3)
 - **Units** Attribute string containing the magnetometer units (μT)
 - * **Temperature** Dataset containing the temperature (Nx1)
 - **Units** Attribute string containing the temperature units ($^{\circ}\text{C}$)
 - * **TemperatureDerivative** Dataset containing the temperature derivative (Nx1)
 - **Units** Attribute string containing the temperature derivative units ($^{\circ}\text{C/s}$)
 - **Raw** Group containing raw data if selected during import
 - * **Accelerometers**
 - * **Gyroscopes**
 - * **Magnetometers**
 - * **DataFlags**
 - * **OptData**

- * **Temperature**
- * **TemperatureDerivative**

14.3.3 Version 1

This version is deprecated. All new files created will use the most recent version.

- **Device_List** Attribute containing a list of monitors present in the file
- **File_Format_Version** Attribute containing the file version
- **Annotations** Table containing annotations
 - **Time** Annotation time in epoch microseconds
 - **Device ID** A movement monitor ID associated with the annotation
 - **Annotation** The annotation string
- **Opal.xxx/** Group containing information about and data from monitor ID xxx
 - **Sample_Rate** Attribute containing the output data rate for the monitor
 - **Decimation_Factor** Decimation factor for the monitor's internal processing
 - **Time_Good** Flag indicating whether the monitor has had its time set since turning on
 - **Decimation_Bypass** Internal use, deprecated
 - **Calibration_Version** Version of the calibration data used to convert from raw samples to calibrated SI units
 - **Version_String1** Firmware version string 1
 - **Version_String2** Firmware version string 2
 - **Version_String3** Firmware version string 3
 - **Acceleration** Dataset containing data from the accelerometers (Nx3)
 - * **Units** Attribute string containing the acceleration units (m/s²)
 - **Angular_Velocity** Dataset containing data from the gyroscopes (Nx3)
 - * **Units** Attribute string containing the angular velocity units (rad/s)
 - **Magnetic_Field** Dataset containing data from the magnetometers (Nx3)
 - * **Units** Attribute string containing the magnetic field units (a.u.)
 - **Temperature** Dataset containing the temperature of the monitor (Nx1)
 - * **Units** Attribute string containing the temperature units (°C)
 - **Temperature_Derivative** Dataset containing the rate of change of temperature
 - * **Units** Attribute string containing the temperature derivative units (°C/s)
 - **Sync_Value** Dataset containing the internal timestamp of each sample
 - * **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
 - * **Time** Dataset containing the time for each sample in microseconds since 0:00 Jan 1, 1970 UTC

Additional fields present when raw data is also stored:

- **Opal.XX/**
 - **Calibration_Data** Attribute containing binary block of calibration data
 - **Raw_File_Version** Attribute containing the version string of the raw file (if this was converted from a .apdm file instead of streamed)

- **Accelerometers_Raw** Dataset containing raw accelerometer data ($N \times 3$)
- **Gyroscopes_Raw** Dataset containing raw gyroscope data ($N \times 3$)
- **Magnetometers_Raw** Dataset containing raw magnetometer data ($N \times 3$)
- **Data.Flags** Dataset containing flags used for processing the raw data
- **Opt_Data** Dataset containing several measurements taken at a low data rate
- **Temperature_Raw** Dataset containing lowpass filtered, but uncalibrated temperature data ($N \times 1$)

14.4 Working with HDF 5 in MATLAB

MATLAB contains two high level functions for working with HDF5 files. Additional help and examples are included in the built in help documentation for these functions.

`hdf5info` reads the structure of the file and all of the attribute values and returns them in an easy to browse MATLAB structure.

`hdf5read` reads a complete dataset or attribute from the HDF5 file.

Additionally, one more high level helper function is included with the APDM movement monitor software. This function also contains built in help documentation and examples.

`hdf5readslab` reads a portion of a dataset from the HDF5 file.

14.5 Examples

Below is simple example of loading acceleration data from an APDM movement monitor HDF5 file (version 2 or later) in MATLAB. For version 1 files, the dataset paths simply need to be changed to match the format listed above.

```
filename = 'example.h5';
try
    vers = hdf5read(filename, '/FileFormatVersion');
catch
    try
        vers = hdf5read(filename, '/File_Format_Version');
    catch
        error('Couldn''t determine file format');
    end
end
if vers < 2
    error('This example only works with version 2 or later of the data file')
end
```

```

caseIdList = hdf5read(filename, '/CaseIdList');
groupName = caseIdList(1).data;
accPath = [groupName '/Calibrated/Accelerometers'];
fs = hdf5read(filename, [groupName '/SampleRate']);
fs = double(fs);
acc = hdf5read(filename, accPath)'; %Transposed to make Nx3 in MATLAB
t = (1:size(acc,1))/fs;
figure;
plot(t,acc);

```

A more complicated example using the flexibility of HDF5 to load and process only part of a data set. This can be useful when the data set is too large to fit into memory. Care is taken not to attempt to read beyond the end of the file.

```

filename = 'example.h5';
try
    vers = hdf5read(filename, '/FileFormatVersion');
catch
    try
        vers = hdf5read(filename, '/File_Format_Version');
    catch
        error('Couldn''t determine file format');
    end
end
if vers < 2
    error('This example only works with version 2 or later of the data file')
end
idList = hdf5read(filename, '/CaseIdList');
groupName = idList(1).data;
accPath = [groupName '/Calibrated/Accelerometers'];
fs = hdf5read(filename, [groupName '/SampleRate']);
fs = double(fs);
fhandle = H5F.open(filename, 'H5F_ACC_RDONLY', 'H5P_DEFAULT');
dset = H5D.open(fhandle, [groupName '/Calibrated/Accelerometers'], 'H5P_DEFAULT');
dspace = H5D.get_space(dset);
[ndims, dims] = H5S.get_simple_extent_dims(dspace);
nSamples = dims(1);
nSamplesRead = min(nSamples, 60*fs); %read at most one minute of data
accSegment = hdf5readslab(filename, accPath, [0,0], [nSamplesRead, 3])';
t = (1:nSamplesRead)/fs;
figure;
plot(t,accSegment);

```

14.6 Notes

- Arrays in MATLAB use the FORTRAN convention of storing them in memory by column then row, instead of the C convention (used by HDF 5) of row then column. This has the effect of making the returned arrays transposed from how this document (and many other interfaces to HDF5) claim they are laid out.
- Older versions of MATLAB (before 2009a) did not support the compression used in Motion Studio's HDF 5 files. If you are using one of these older versions, the free h5repack utility available from the HDF Group can remove the compression. This utility is available at:

<http://www.hdfgroup.org/HDF5/release/obtain5.html>

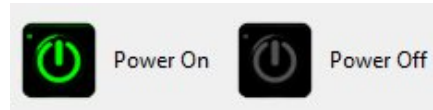
The command to repack the file is:

```
h5repack -f NONE example.h5 example_no_compression.h5
```

15 Powering Your Monitors On and Off

15.1 Docking Monitors

In most situations, it is sufficient to simply dock your monitors when not in use. When docked, monitors stop recording, stop broadcasting, and start charging their batteries. Once fully charged, the batteries will enter a trickle charge mode to keep them topped off.



The power buttons in the toolbar

15.2 Power Off

For transport or storage, it is often desirable to power off all system components. This can be done by docking the monitors and clicking on the “Power Off” button in the toolbar. When this option is chosen, the monitors will power down the next time they are undocked.

Alternately, you can configure your monitor to power down or standby when it is rapidly spun about the z-axis (see Section [7.4.4](#) for details).

15.3 Power On

From a powered off state, the monitors can be powered on either by configuring them through the configuration dialog, or by docking them and pressing the “Power On” button.

Note: Reconfiguration is required for synchronized streaming modes if the access point was also powered down or suspended.

16 Firmware Updates

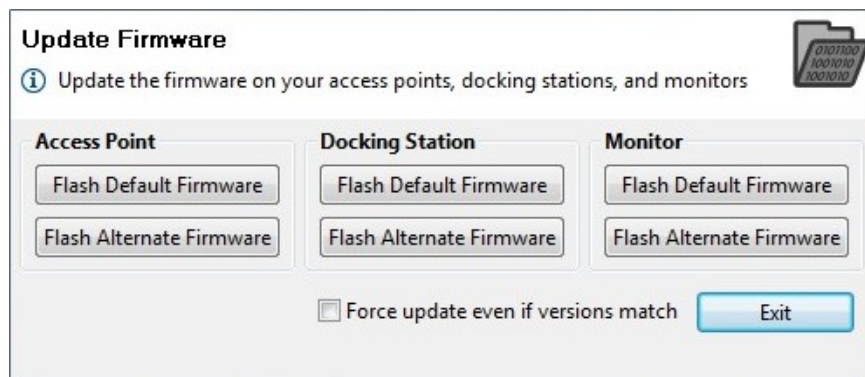
Firmware controls the various hardware components of your APDM product line (monitors, access points, and docking stations). It is important to keep the firmware up to date to ensure that your system gets the latest bug fixes and has access to the latest features. Firmware updates are bundled with updates to Motion Studio. Firmware can be updated either automatically or manually.

16.1 Automatic Firmware Updates

Whenever you configure your system, your hardware is first checked to ensure that the latest firmware is installed. If not, you will be prompted to automatically update your hardware to the latest versions of the firmware bundled with your system.

16.2 Manual Firmware Updates

Firmware can be updated manually as well. This functionality can be used to either flash the default firmware to one of the hardware components, or to flash a different version. To access the “Update Firmware” dialog, click on “Tools→ Update Firmware” in the menu bar.



The manual firmware update tool

16.2.1 Flash Default Firmware

Your system comes bundled with an up to date version of the firmware. Pressing this button will re-flash this version of the firmware onto the specified monitor.

16.2.2 Flash Alternate Firmware

For testing purposes or to address an issue in a timely fashion, it may be necessary to flash a monitor with a version of the firmware that is different than the bundled version. You will have to specify the alternate

firmware file to use with this option.

16.2.3 Force Update

When using either of the options above, if the firmware version on the target device(s) matches the firmware version to be flashed, the device will be skipped. If the “Force update even if versions match” checkbox is selected, however, the firmware will be flashed even if the versions match. This may be necessary in some cases to recover a malfunctioning device.

17 Calibration

17.1 Sensor Error Models

The errors modeled and compensated for by the calibration are: scale factor, cross axis sensitivity, sensor misalignment, and bias. For scale factor, there is a linear temperature model, and for bias, a look up table based temperature model. The notation is reused, but each type of sensor has distinct calibration parameters. For example, the scale factor matrix S_T for the accelerometers is different from the one for the gyroscopes, and from the one used for the magnetometers. APDM factory calibration does not compensate for misalignment between the sensors and the case, only misalignment between the accelerometers and the other two sensors.

17.1.1 Accelerometers

The calibrated accelerometer measurements are calculated as

$$\vec{d}_{cal} = CS_T(\vec{d}_{raw} - \vec{b}_T) \quad (1)$$

$$C = \begin{bmatrix} \cos s_{xy} \cos s_{xz} & \sin s_{xy} & \sin s_{xz} \\ \sin s_{xy} & \cos s_{xy} \cos s_{yz} & \sin s_{yz} \\ \sin s_{xz} & \sin s_{yz} & \cos s_{xz} \cos s_{yz} \end{bmatrix} \quad (2)$$

$$S_T = \begin{bmatrix} s_x + Ts_{x,T} & 0 & 0 \\ 0 & s_y + Ts_{y,T} & 0 \\ 0 & 0 & s_z + Ts_{z,T} \end{bmatrix} \quad \vec{b}_T = \begin{bmatrix} b_{x,T} \\ b_{y,T} \\ b_{z,T} \end{bmatrix} \quad (3)$$

where C is the cross axis sensitivity matrix, S_T is the temperature dependent scale factor matrix, and \vec{b}_T is the temperature dependent bias vector. There is a look up table for the temperature effect on bias for each sensor axis. The bias value for a particular temperature is linearly interpolated from this table.

17.1.2 Gyroscopes

The calibrated gyroscope measurements are calculated as

$$\vec{\omega}_{cal} = MCS_T(\vec{\omega}_{raw} - \vec{b}_T) \quad (4)$$

$$M = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta_r & -\sin \theta_r \\ 0 & \sin \theta_r & \cos \theta_r \end{bmatrix} \begin{bmatrix} \cos \theta_p & 0 & \sin \theta_p \\ 0 & 1 & 0 \\ -\sin \theta_p & 0 & \cos \theta_p \end{bmatrix} \begin{bmatrix} \cos \theta_y & \sin \theta_y & 0 \\ -\sin \theta_y & \cos \theta_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (5)$$

$$C = \begin{bmatrix} \cos s_{xy} \cos s_{xz} & \sin s_{xy} & \sin s_{xz} \\ \sin s_{xy} & \cos s_{xy} \cos s_{yz} & \sin s_{yz} \\ \sin s_{xz} & \sin s_{yz} & \cos s_{xz} \cos s_{yz} \end{bmatrix} \quad (6)$$

$$S_T = \begin{bmatrix} s_x + T s_{x,T} & 0 & 0 \\ 0 & s_y + T s_{y,T} & 0 \\ 0 & 0 & s_z + T s_{z,T} \end{bmatrix} \quad (7)$$

$$\vec{b}_T = \begin{bmatrix} b_{x,T} \\ b_{y,T} \\ b_{z,T} \end{bmatrix} \quad (8)$$

where M is the misalignment matrix, C is the cross axis sensitivity matrix, S_T is the temperature dependent scale factor matrix, and \vec{b}_T is the temperature dependent bias vector. There is a look up table for the temperature effect on bias for each sensor axis. The bias value for a particular temperature is linearly interpolated from this table.

17.1.3 Magnetometers

The calibrated magnetometer measurements are calculated as

$$\vec{m}_{cal} = MCS_T(\vec{m}_{raw} - \vec{b}_T) \quad (9)$$

$$M = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos \theta_r & -\sin \theta_r \\ 0 & \sin \theta_r & \cos \theta_r \end{bmatrix} \begin{bmatrix} \cos \theta_p & 0 & \sin \theta_p \\ 0 & 1 & 0 \\ -\sin \theta_p & 0 & \cos \theta_p \end{bmatrix} \begin{bmatrix} \cos \theta_y & \sin \theta_y & 0 \\ -\sin \theta_y & \cos \theta_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (10)$$

$$C = \begin{bmatrix} \cos s_{xy} \cos s_{xz} & \sin s_{xy} & \sin s_{xz} \\ \sin s_{xy} & \cos s_{xy} \cos s_{yz} & \sin s_{yz} \\ \sin s_{xz} & \sin s_{yz} & \cos s_{xz} \cos s_{yz} \end{bmatrix} \quad (11)$$

$$S_T = \begin{bmatrix} s_x + T s_{x,T} & 0 & 0 \\ 0 & s_y + T s_{y,T} & 0 \\ 0 & 0 & s_z + T s_{z,T} \end{bmatrix} \quad \vec{b}_T = \begin{bmatrix} b_{x,T} \\ b_{y,T} \\ b_{z,T} \end{bmatrix} \quad (12)$$

where M is the misalignment matrix, C is the cross axis sensitivity matrix, S_T is the temperature dependent scale factor matrix, and \vec{b}_T is the temperature dependent bias vector. There is a look up table for the temper-

ature effect on bias for each sensor axis. The bias value for a particular temperature is linearly interpolated from this table.

17.1.4 Temperature

The calibrated temperature measurements are calculated as

$$T_c = s(T_r - b_{20}) + 20, \quad (13)$$

where s is the scale factor, T_r is the raw sensor reading, and b_{20} is the raw temperature value at 20 degrees Celsius.

17.2 Factory Calibration

Your monitors come pre-calibrated from APDM. Each monitor is calibrated individually in a procedure that determines optimal scaling factors and offsets for the accelerometers, gyroscopes, and magnetometers across a wide range of orientations and temperatures.

17.2.1 Updating Factory Calibration

There may be rare cases where the factory calibration data is deleted from your monitor(s) due to an issue with the SD card. In these scenarios, it may be necessary to re-flash the factory calibration onto your monitor using the “Flash Factory Calibration” button in the monitor tab of the configuration dialog. If you believe that you have a poorly calibrated monitor and would like to discuss your options,

Please contact us at:

email: info@apdm.com

telephone: 888-988-APDM (2736)

Opal-Users Mailing List: <https://mail.apdm.com/mailman/listinfo/opal-users>

17.3 User Calibration

While the factory calibration is optimal at the time of shipping, all low power sensors like the ones used in APDM's monitor's are subject to small changes over time and may require re-calibration. This is something that can be done by APDM, but we are also dedicated to providing tools to enable end users to recalibrate their own devices.

17.3.1 Magnetometer Recalibration

To perform this task, click on the “Tools”→“Recalibrate Magnetometer” option in the menu bar. This wizard will guide you through the process of recalibrating the magnetometers on your monitor(s). You can only recalibrate one monitor at a time, because they must each be moved independently away from other objects that may disrupt the magnetic field (including other monitors).

17.3.2 Gyroscope Recalibration

To perform this task, click on the “Tools”→“Recalibrate Gyroscopes” option in the menu bar. This wizard will guide you through the process of recalibrating the gyroscopes on your monitor(s). This process can be applied to all of your monitors simultaneously.

17.3.3 Accelerometer Recalibration

Coming soon!

17.4 Clearing User Calibration

If you wish to revert to the factory calibration settings, you can clear any user calibration that you have applied. This can be accomplished through the “Clear User Calibration” button in the monitor tab of the configuration dialog.

18 Monitor Reference

18.1 Charging

A movement monitor charges its internal battery any time it is connected to a docking station. At the optimal charge rate the movement monitors internal battery will complete its bulk charge (80%-90%) within an hour for a fully discharged battery. It is recommended that the movement monitor be charged for up to 3 hours to provide a peak charge to the battery ensuring it has the longest run time and improves battery life.

Warning: Your movement monitor uses a lithium battery. This battery may only be charged over a limited temperature range. Never attempt to dock or charge your Opal when the temperature experienced can be outside the range of 0 to 45 degrees Celsius (32 to 113 degrees Fahrenheit). The recommended charging and docking temperature range is between 5 to 35 degrees Celsius (40 to 95 degrees Fahrenheit).

18.2 Powering Down

If you wish to power down your monitors for storage or travel, dock or plug in the monitors you wish to power down and select the “Tools→Halt All Monitors” option in Motion Studio. After this is selected, all monitors will power down when they are undocked or unplugged.

18.3 Data Storage

The movement monitors utilize a flash card to store data while logging. This data can be downloaded by using a docking station to dock the movement monitor. When the movement monitor is docked it finishes up writing to the internal flash card and then releases it to the docking station. At this time the docking station indicates to the PC that there is a new read only removable drive to be mounted. Using your file browser you can navigate to the removable drive and copy the files off of it. The files are in a proprietary raw format and need to be converted to either a HDF5 or CSV format that will provide data in calibrated SI units. This conversion happens automatically if Motion Studio is used to import the data. Alternately, there are functions in the SDK to do this conversion programmatically.

18.4 Cleaning

Cleaning the movement monitors case should be done by wiping the bottom of the case where it contacts the skin with Rubbing alcohol or other cleaning wipe. If the entire case needs to be cleaned use only an ethyl alcohol or isopropyl alcohol based wipe. Methyl alcohol should be avoided for cleaning the top since it will cause degradation of the plastic over time. The movement monitor should not be submerged in any liquids or

subjected to any high temperatures for cleaning. The straps on the monitor can be cleaned by wiping them down with Rubbing alcohol. Alternatively the straps can be removed and washed separately using mild soap and water.

18.5 Storage

Storage of the movement monitor should be in a dry static free location. An anti-static bag or in the supplied case is recommended. The movement monitor should also not be subjected to any large G forces to prevent damage or changes to the calibration of the sensors in the monitor. It is recommended for the health of the battery to have at least a bulk charge during storage.

18.6 Drivers

Drivers are provided as part of the library distribution and Motion Studio. Instructions for installing drivers are provide in the “Hardware Driver Installation” section of this document.

18.7 Firmware Updates

Updating the movement monitor firmware should be done using the Motion Studio software.

18.8 Technical Specifications

- The accelerometer range is $\pm 58.8 \text{ m/s}^2$ (6 g) (optionally $\pm 19.6 \text{ m/s}^2$ (2 g)).
- Accelerometers have a typical noise density of $1.3 \text{ mm/s}^2 / \sqrt{\text{Hz}}$.
- The X and Y axis gyros have a range of $\pm 34.9 \text{ rad/s}$ (2000 dps)
- The Z axis gyro has a range of $\pm 26.8 \text{ rad/s}$ (1500 dps)
- The X and Y axis gyros have a typical noise density of $0.81 \text{ mrad/s} / \sqrt{\text{Hz}}$
- The Z axis gyro have a typical noise density of $2.2 \text{ mrad/s} / \sqrt{\text{Hz}}$
- Magnetometers have a range of $\pm 6 \text{ Gauss}$
- The magnetometers have a typical noise density is $160 \text{ nT} / \sqrt{\text{Hz}}$
- Positive X is pointing from the monitor toward the connector. Positive Y is pointing left of X looking top down at the monitor. Z is pointing up out of the top of the case. Angular velocity sign is defined according to a right hand rule. A counterclockwise rotation about the Z axis looking from the +Z direction is positive.

18.9 LED Reference

18.9.1 Status Codes and LED Colors/Patterns

The LEDs on the access points and movement monitors provide important information about the operating state of the hardware, including error statuses. The tables below list the LED patterns associated with these states and can be useful in troubleshooting issues encountered with the hardware.

18.9.2 Movement Monitor LED Reference

Movement monitors contain a RGB LED capable of outputting a wide array of colors to the user to indicate its current state. The following colors are used: white (○), red (●), yellow (●), green (●), cyan (●), blue (●), magenta (●), and led off (—). In the off state the LED will appear as a non illuminated white dot in the corner of the monitor opposite the docking connector. All LED patterns are output on a repeating cycle which may vary in period depending on the pattern. In all cases the last color listed will stay constant until the pattern repeats. For example “●—●—” will blink yellow twice and then stay off until the pattern repeats.

State	LED Pattern
Startup Mode (boot loader)	
Startup wait (5 sec) v1.0, bootloader v1	●
Startup wait (5 sec) v1.1, bootloader v2	●
Failed to load firmware	●
Boot loader mode	○
Firmware Mode	
Docked mode (pre-charging – very low battery)	●●
Docked mode (bulk charging – low battery)	●●(fast)
Docked mode (trickle charging – 80-100% charge)	●●(slow)
Docked mode (full charge)	●
Docked mode (battery error)	●●
Docked mode (wait)	●
Docked mode (error)	●●●●
Reset mode	○_
Transitioning into standby or powering off	●_
Hold mode	●_
Run mode (battery level 4, full)	●●●●_
Run mode (battery level 3)	●●●_
Run mode (battery level 2)	●●_
Run mode (battery level 1, low)	●_
Run mode (battery very low)	●●●_
Run mode (clock unset, battery level 4, full)	●●●●_
Run mode (clock unset, battery level 3)	●●●_
Run mode (clock unset, battery level 2)	●●_
Run mode (clock unset, battery level 1, low)	●_
Run mode (clock unset, battery very low)	●●●●_
Run mode (no sync-lock, battery level 4, full)	●●●●_
Run mode (no sync-lock, battery level 3)	●●●_
Run mode (no sync-lock, battery level 2)	●●_
Run mode (no sync-lock, battery level 1, low)	●_
Run mode (no sync-lock, battery very low)	●●●●_
Run mode (clock unset, no sync-lock, battery level 4, full)	●●●●_
Run mode (clock unset, no sync-lock, battery level 3)	●●●_
Run mode (clock unset, no sync-lock, battery level 2)	●●_
Run mode (clock unset, no sync-lock, battery level 1, low)	●_
Run mode (clock unset, no sync-lock, battery very low)	●●●●_

State	LED Pattern
Error Modes	
Error mode: default	● _ ● _
Error mode: configuration	● _ ● _ ● _
Error mode: system	● _ ● _ ● _ ● _
Error mode: data buffer	● _ ● _ ● _ ● _ ● _
Error mode: SD buffer	● _ ● _ ● _ ● _ ● _ ● _
Error mode: SD I/O	● _ ● _ ● _ ● _ ● _ ● _ ● _
Card is full	● _
Wireless Streaming Debug LED Modes	
Normal	● _
CPU limited	● ● _
Sync bad	● ● _
CPU limited, Sync bad	● ● _
Missed sync > 0	● _
Missed sync > 0, CPU limited	● ● _
Missed sync > 0, Sync bad	● ● _
Missed sync > 0, CPU limited, Sync bad	● ● _

19 Access Point Reference

19.1 Drivers

Drivers are provided as part of the library distribution and Motion Studio. Instructions for installing drivers are provide in the “Hardware Driver Installation” section of this document.

19.2 Firmware Updates

Updating the movement monitor firmware should be done using the Motion Studio software.

19.3 Mounting and Placement

The antennas of the access point are located directly behind the black plastic face of the access point. The access point(s) should be aimed such that this face is in the approximate direction of the area where the movement monitors will be used.

19.4 Single vs. Dual

Access Point Mode With the wide range of wireless environments it is not always possible to provide a reliable channel of communication between any two nodes. Using two access points per set of up to six movement monitors is one method of improving reliability by utilizing spacial diversity. In this mode a movement monitor can hop between access points depending on which one has a better signal path. For large spaces or with spaces that have obstacles that may block wireless signals this mode of operation is recommended. Configuration of a system in this mode is transparent to the user and is automatically selected when there is enough access points available for the given number of movement monitors. Using multiple access points requires them to all have a synchronization cable connected between them.

19.5 LED Reference

Access points contain a RGB LED capable of outputting a wide array of colors to the user to indicate its current state. The following colors are used: white (○), red (●), yellow (●), green (●), cyan (●), blue (●), magenta (●), and led off (●). All LED patterns are output on a repeating cycle which may vary in period depending on the pattern. In all cases the last color listed will stay constant until the pattern repeats. For example “●●●” will blink yellow twice and then stay off until the pattern repeats.

State	LED Pattern
Access point is powered on and is not receiving data from any monitors	●
Access point is receiving data from all monitors and there is no excessive latency for any of the monitors	● _
Access point is receiving data from all monitors but there is excessive latency (>3s) in one or more monitors. The latency is, however, decreasing (improving). This usually indicates that one or more monitors was temporarily obstructed and is now catching up.	● ●
Access point is receiving data from all monitors but there is excessive latency (>3s) in one or more monitors which is increasing (getting worse). This usually indicates that one or more monitors is obstructed and is having trouble transmitting its data.	● ●
Access point is receiving data from one or more, but not all, of the movement monitors	● _
Access point is receiving data from one or more monitors that it is not expecting to receive data (e.g. there is a monitor configured on another computer system streaming data)	● ● or ● ●
Access point is in low power USB suspend mode.	●
Access point firmware error type 3, contact support	● ● ● _
Access point firmware error type 4, contact support	● ● ● ● _
Access point firmware error type 5, contact support	● ● ● ● ● _

20 Docking Station Reference

20.1 Drivers

Drivers are provided as part of the library distribution and Motion Studio. Instructions for installing drivers are provide in the “Hardware Driver Installation” section of this document.

20.2 Power

- If running a single docking station, it can be powered from:
 - a USB cable plugged into a dedicated USB port on your computer
 - a USB cable plugged into a powered USB hub
 - a USB cable plugged into a wall adapter (charging only)
 - the external AC adapter (charging only)
- If running a chain of 2 or more docking stations:
 - For data transfer, both USB and external AC power are required. If a power-related error occurs, then the docking station will blink yellow until external or power is plugged in.
 - if only charging is required, the external AC power must be used

20.3 LED Reference

Docking stations contain a RGB LED capable of outputting a wide array of colors to the user to indicate its current state. The following colors are used: white (○), red (●), yellow (●), green (●), cyan (●), blue (●), magenta (●), and led off (●). All LED patterns are output on a repeating cycle which may vary in period depending on the pattern. In all cases the last color listed will stay constant until the pattern repeats. For example “●●●” will blink yellow twice and then stay off until the pattern repeats.

State	LED Pattern
OK	
Powered off, USB suspended, or bootloader pause	
OK, but USB not enumerated	
Power problem. Need to plug in external power or USB power.	
Docking in progress	
Docked, but SD unavailable to host	
SD Card mounting in progress	
SD Card mounted and available to host	
SD card read-access in progress	
USB error	
Error	
Error: SD card mounting error	
Error: in-dock USB hub problem	
Firmware error type 4, contact support	
Firmware error type 5, contact support	
Firmware error type 6, contact support	
Bootloader mode	
Updating firmware	
Hardware Error - DA	
Hardware Error - GA	
Hardware Error - PA	
Hardware Error - UA	

21 Limited Warranty

This Limited Warranty applies to the APDM equipment and does not apply to related software. All software is covered by the End-User License Agreement. APDM equipment is covered by the one-year parts & labor warranty which is void should the customer open the equipment without written authorization or due to misuse.

1. **Warranty of Title.** APDM Inc. ("APDM") warrants solely to the original purchaser (Customer) that (a) APDM has good title to the Equipment and that, upon Customer's payment of the purchase price to APDM, good title to the Equipment will be transferred to Customer.
2. **Limited Warranty of Condition and Operation.** APDM warrants solely to Customer that when delivered to purchaser and for a period of one (1) year after the date of delivery to Customer, the Equipment, will conform in all materials respects to APDM's published specifications when used as described in APDM's written instructions, be in good working order and free of defects in workmanship and materials. EXCEPT AS OTHERWISE PROVIDED HEREIN, APDM MAKES NO WARRANTY, EXPRESS OR IMPLIED, AS TO ANY MATTER WHATSOEVER, INCLUDING WITHOUT LIMITATION ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE EXCEPT THOSE SET FORTH IN THE DESCRIPTION AND DIRECTIONS ON THE LABELING OF THE EQUIPMENT. UNLESS THE EQUIPMENT IS USED IN ACCORDANCE WITH THE DIRECTIONS ON THE LABELING AND THE INSTRUCTIONS ACCOMPANYING THE EQUIPMENT, THIS LIMITED WARRANTY AND ANY WARRANTIES IN SUCH DESCRIPTION SHALL BE VOID AND OF NO EFFECT.
3. **Customer's Exclusive Remedies.** If within one (1) year from the date of delivery to Customer the Equipment does not comply with the foregoing Limited Warranty of Condition and Operation, APDM will at APDM's option, repair, replace or refund the purchase price of the defective Equipment free of charge to the Customer. Customers requesting repair, replacement or refund are required to ship, the Equipment to APDM at APDM's facilities in Portland, Oregon, or at such other place as APDM designates. As a condition of this warranty, Customers must call APDM's Customer Service Line for instructions on and prior approval of shipment prior to returning any defective Equipment.
4. **Limitation of Liability.** APDM SHALL HAVE NO LIABILITY FOR ANY CONSEQUENTIAL, INCIDENTAL, OR SPECIAL DAMAGES BY REASON OF ANY ACT OR OMISSION OR ARISING OUT OF OR IN CONNECTION WITH THE EQUIPMENT OR ITS RENTAL, DELIVERY, INSTALLATION, MAINTENANCE, OPERATION, PERFORMANCE, OR USE, INCLUDING WITHOUT LIMITATION ANY LOSS OF USE, LOST REVENUE, LOST PROFITS, OR COST ASSOCIATED WITH DOWNTIME. THE OBLIGATIONS CONTAINED IN THIS PARAGRAPH CONTINUE BEYOND THE TERM OF THIS LIMITED WARRANTY.
5. **Limitation of Liability.** This Limited Warranty shall be governed by, and construed and interpreted in accordance with, the local laws of the State of Oregon (without application of its conflicts of laws rules).

22 Troubleshooting

Q: I repeatedly get the error “Error encountered while checking firmware. Please try again.”

A: This is usually an issue with how Windows recognizes the docking stations when they are plugged in.

- One possible cause of this is insufficient power being provided to the docking stations. Make sure that chains of docking stations have external power. Also make sure that docking stations plugged into a USB hub are using a USB 2.0 High Speed hub with external power.
- Another cause is that the system incorrectly initialized the docking stations. Undock any monitors, unplug the power and USB cables from the docking station(s), and carefully follow the steps in [Section 2](#) while plugging the docking stations back in.

Q: After configuring for wireless streaming, the LEDs on my monitors are all flashing green in unison, but the LED on the access point is flashing red, indicating that it is not receiving all of the data.

A: There are a couple of possible explanations for this:

- One of the monitors is obstructed somehow. Make sure that they are all unobstructed and have clear line of sight to the access point.
- There is a rare situation where the radios on the monitors do not start broadcasting after configuration. To recover from this situation, plug the monitors back into their docking stations, and press the “Halt” button in MotionStudio. Unplug the monitors and wait for them to power down. Next, place them back into their docking stations and wait for them to power up. Finally, unplug them from their docking stations (no re-configuration required) and wait for them to power up and start broadcasting. Often, this reset will enable the radios on the malfunctioning monitor.

Q: When I dock my monitor into its station, it flashes alternately red and blue.

A: This is an indication of a poor connection. Remove your monitor from the dock, wait for 5-10 seconds, and re-dock it.

Q: My monitor flashes red (and possibly yellow), and docking/undocking it does not fix the problem

A: If you have any data saved on the monitor from using it in logging mode, first attempt to back up the data using from your operating system’s file explorer or Motion Studio’s Import Manager. Next, from the Configuration dialog, select the monitor in the “Select Monitor” combo box and click on the “Re-flash Default Firmware” button. This will reset the monitor to its original state.

Q: In Windows XP, when I insert my monitors into the docking stations, I do not see all the SD cards show up in explorer.

A: If a network drive has already been mapped to a given drive letter that the monitor would normally use, windows will not properly mount the SD card from the monitor. This can also cause problems for Motion

Studio when it attempts to import/convert data files from the monitor. You should un-map the network drive from the given drive letter. See <http://support.microsoft.com/default.aspx?scid=kb;en-us;297694> for details.

Q: My Windows XP/32 computer blue screens when I plug in APDM hardware.

A: This is due to a known bug in the XP/32 USB subsystem, and can be worked around by installing the 'apdm_usb_serial_number.reg' registry modification in the windows drivers directory used during driver installation.

APDM is pleased to assist you with any questions you may have about our software or about the use of the technology for your application.

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Opal-Users Mailing List: <https://mail.apdm.com/mailman/listinfo/opal-users>