Motion Studio User's Guide

Table of Contents

1 Introduction to Motion Studio

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 sensor(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)
- Organize and view your recorded data
- Keep your hardware up-to-date with firmware updates

2 System Overview

Access Point

The access point contains 2.4ghz radios that are used to receive data from the sensors, as well as to synchronized time across all the sensors.

The access point synchronization cable, which daisy-chains from one access point to the next in a multi access point configuration is used to synchronize time among all the access points.

Docking Station

The docking station is used to charge sensors, read data from the SD card on the sensor, send configuration commands to the sensor and read sensor status from the sensor.

Opals

Sensors contain a 3 axis accelerometer, a 3 axis gyro, 3 axis magnetometer and temperature sensor. The accelerometers can be configured in a high, 6G mode, or a low 2G mode depending on the target usage environment.

Technical Specifications

- The accelerometer range is +/- 58.8m/s^2 (6g) (optionally +/- 19.6m/s^2 (2g)).
- Accelerometers have a typical noise density of 1.3 mm/s^2/sqrt(Hz).
- The X and Y gyros are +/- 34.9 rad/s (2000 dps), and Z is +/- 26.8 rad/s (1500 dps).
- The x and y gyros are 0.81 mrad/s/sqrt(Hz), and z is 2.2mrad/s/sqrt(Hz).
- Magnetometers +/- 6 Gauss. The magnetometer is 160 nT/sqrt(Hz).

- Positive X is pointing from the device toward the connector. Positive Y is pointing left of X looking top down at the device. 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.

3 Downloading the Latest Software

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/mobility_lab/

and select the version that matches your operating system.

Unzip the contents of the download into your preferred installation directory.

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

- Drivers
- Firmware
- The Motion Studio desktop application

4 Device Driver Installation

Macintosh OSX (x32/x64)

1. Copy the file found at your installation's “MotionStudio/drivers/libftd2xx.0.1.6.dylib” to your “/usr/local/lib” directory. You will need administration privileges to do so.

Windows XP (x32)

Access Point

1. Plug the access point into your computer.
2. The “Welcome to the Found New Hardware Wizard” dialog will popup
3. Select “No, not this time”
4. Click “Next”
5. Check “Install from a list or specific location”
6. Click “Next”
7. Uncheck “Search removable media”
8. Check “Include this location in the search”
9. Click the “Browse” button and navigate to your installation's “MotionStudio/drivers/apdm_accesspoint_drivers” folder
10. Click “Ok”
11. Click “Next”
12. If Windows prompts you about the driver not being signed, click 'Continue Anyway'
13. Click “Finish”

Sensor Cable

1. Plug the sensor cable into your computer.
2. The “Welcome to the Found New Hardware Wizard” dialog will popup
3. Select “No, not this time”
4. Click “Next”
5. Check “Install from a list or specific location”
6. Click “Next”
7. Uncheck “Search removable media”
8. Check “Include this location in the search”
9. Click the “Browse” button and navigate to the “MotionStudio/drivers/apdm_device_cable_driver” folder
10. Click “Ok”
11. Click “Next”
12. If Windows prompts you about the driver not being signed, click 'Continue Anyway'
13. Click “Finish”

Windows Vista (x32/x64)

Our Windows compatible drivers are currently in the process of being certified by Microsoft, so a few extra steps are necessary:

Access Point

1. Plug the access point into your computer.
2. A “Found New Hardware” dialog will pop-up.
3. Select the “Locate and install driver software” option
4. Select “I don't have the disc. Show me other options”.
5. Select “Browse my computer for driver software”.
6. Click on the “Browse” button and navigate to the “MotionStudio/drivers/apdm_accesspoint_drivers” folder.
7. Check “Include Subfolders”.
8. Click “Next”.

9. A warning message will be presented indicating that “Windows cannot verify the publisher of this driver software”.
10. Click “Install this driver software anyway”.
11. Close the confirmation dialog.

Sensor Cable

1. Plug the access point into your computer.
2. A “Found New Hardware” dialog will pop-up.
3. Select the “Locate and install driver software” option
4. Select “I don't have the disc. Show me other options”.
5. Select “Browse my computer for driver software”.
6. Click on the “Browse” button and navigate to the “MotionStudio/drivers/apdm_device_cable_driver” folder.
7. Check “Include Subfolders”.
8. Click “Next”.
9. A warning message will be presented indicating that “Windows cannot verify the publisher of this driver software”.
10. Click “Install this driver software anyway”.
11. Close the confirmation dialog.

Windows 7 (x32/x64)

Our Windows compatible drivers are currently in the process of being certified by Microsoft, so a few extra steps are necessary:

Access Point

1. Plug the access point into your computer.
2. There may be an notification that the device driver could not be installed.
3. Click on the Windows “Start” button
4. Right-click on the “Computer” button and select “Manage”
5. Select the “Device Manager”
6. Under “Other Devices” there should be an entry for “AccessPoint” with a yellow exclamation point next to it.
7. Right-click on the “AccessPoint” entry and select “Update Driver Software...”

8. Select “Browse my computer for driver software”
9. Click on the “Browse” button and navigate to the “MotionStudio/drivers/apdm_accesspoint_drivers” folder.
10. Check “Include Subfolders”
11. Click “Next”
12. A warning message will be presented indicating that “Windows cannot verify the publisher of this driver software”.
13. Click “Install this driver software anyway”.
14. Close the confirmation dialog.

Sensor Cable

1. Plug the sensor cable into your computer.
2. There may be an notification that the device driver could not be installed.
3. Click on the Windows “Start” button
4. Right-click on the “Computer” button and select “Manage”
5. Select the “Device Manager”
6. Under “Other Devices” there should be an entry for “TTL232R-3V3” with a yellow exclamation point next to it.
7. Right-click on the “TTL232R-3V3” entry and select “Update Driver Software...”
8. Select “Browse my computer for driver software”
9. Click on the “Browse” button and navigate to the “MotionStudio/drivers/apdm_device_cable_driver” folder.
10. Check “Include Subfolders”
11. Click “Next”
12. A warning message will be presented indicating that “Windows cannot verify the publisher of this driver software”.
13. Click “Install this driver software anyway”.
14. Close the confirmation dialog.

Linux (x32/x64)

The user running the APDM software libraries will need to have appropriate permissions to interface with particular USB 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

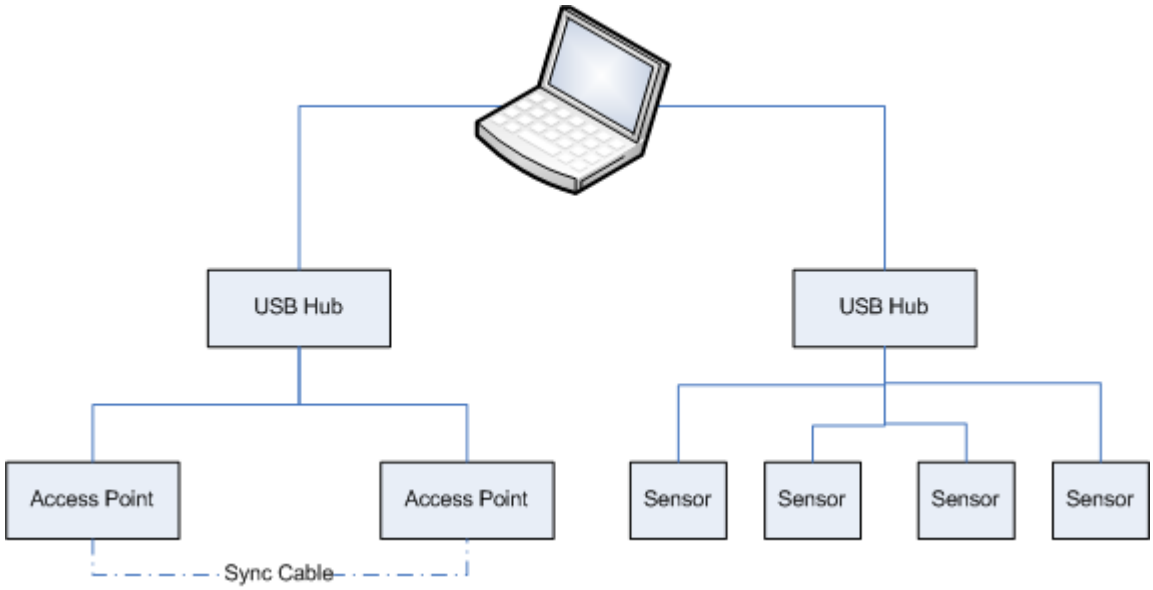
Docking Station: VID: 0x224F PID: 0x0002

Opal Cable: VID: 0x0404 PID: 0x9D37

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

```
ACTION=="add", ATTRS{idVendor}=="224f", ATTRS{idProduct}=="0001", MODE:="0666"
ACTION=="add", ATTRS{idVendor}=="224f", ATTRS{idProduct}=="0002", MODE:="0666"
ACTION=="add", ATTRS{idVendor}=="0403", ATTRS{idProduct}=="9d37", MODE:="0666"
```

5 Hardware Setup



Wireless Streaming Mode

- Attach an access point to the host computer if you are going to use the wireless streaming mode (Opals only) . A minimum of one Access Point is necessary. More can be added to support backup wireless transmission channels or to support additional Opals. A single Access Point can receive data for up to 6 Opals. If multiple Access Points are used, connect them using the 1/8” sync cable.

All Modes

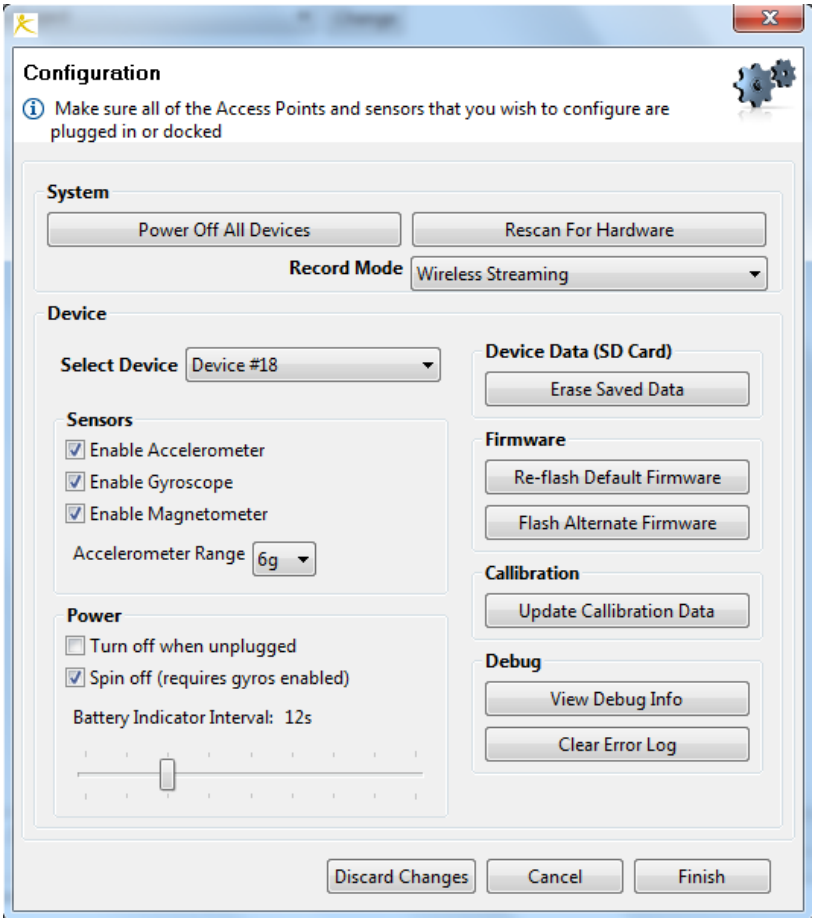
- Attach the Docking Station(s) to the host computer. If you run out of USB ports on your computer, you can use a USB 2.0 high speed hub.

- Insert your sensors into the Docking Stations. You should see the light on the sensors turn blue.

6 System Configuration

APDM Sensors can be configured in a number of ways to match your needs. To open the configuration dialog:

- Make sure your Access Point(s), Sensor Cable(s), and/or Docking Station(s) are plugged into the computer and that your Sensor(s) are connected to the cables.
- Press the “Setup” button in the application tool bar. You will be presented with the dialog pictured below.



The configuration dialog will enable you to configure the settings of your individual devices, in addition to system-wide settings. These options include:

Automatic Firmware Updates

- Before the configuration dialog is presented, your hardware is first checked to ensure that the latest firmware installed. If not, you will be prompted to automatically update your hardware to the latest versions of the firmware bundled with Motion Studio.

System-Wide Configuration

- **Power Off All Devices.** This is a convenient way to power down all of your devices. They will power down after being disconnected from their cables or docking stations. This is particularly useful if the “Spin off” feature is disabled for any of your devices.
- **Rescan for Devices.** If you plug in a device after the dialog has already been opened, pressing this button will rescan for attached devices.
- Record Mode. Use this option to specify how you wish to record data from your devices:
  - **Wireless Streaming** (Opals only). Use this mode to stream data from one or more synchronized devices wirelessly to your computer.
  - **Synchronized Logging** (Opals and Emeralds only). Use this mode to log data from more than one synchronized device to their on-board flash memory. The devices are synchronized wirelessly with each other.
  - **Low Power Logging** (Opals, Emeralds, and Sapphires). Use this mode to log device data to their on-board flash memory. Wireless radios are turned off to save power. Multiple devices will not be synchronized, and some level of clock drift will occur for long recordings.

Device Configuration

- Use the “Select Device” combo box to specify the device you wish to individually configure.

Sensors

- **Enable or disable sensor types.** 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.
- **Accelerometer Range.** Specifies whether the range of the accelerometer is ±2g or ±6g. This is approximately equal to ±20 or ±60 m/s^2. If your application does not need the full ±6g range, using the ±2g range will improve the signal to noise ration (SNR) of your accelerometer readings.

Power

- **Turn Off When Unplugged.** If set, your device will power down when it is uplugged from the cable. This is useful if you wish to power down a single device and the "Spin off" feature is disabled.
- **Spin off.** When this feature is enabled, the device will power down when spun clockwise or counterclockwise about it's z-axis. For example, spinning the device when it is lying flat on a table.
- **Battery Indicator Interval.** Specifies how often the LED sequence indicating the current battery level is generated. This can be set from a value of 3s to 768s.

Device Data (SD Card)

- **Erase Saved Data.** Pressing this button will delete all of the recorded data on the specified device. This does not include configuration data.

Firmware

- **Re-flash Default Firmware.** Each version of Motion Studio comes bundled with the latest version of the firmware at the time of release. Pressing this button will re-flash this version of the firmware onto the specified device.
- **Flash Alternate Firmware.** For testing purposes or to address a bug in a timely fashion, it may be necessary to flash a device with a version of the firmware that is different than the bundled version. You will have to provide the alternate firmware file to use with this option.

Calibration

- **Update Calibration Data.** Use this option in the event that your device needs to

be recalibrated. You will have to provide a calibration file to use.

Debug

- **View Debug Info.** This option allows you to print out detailed information about the device 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 console view.
- **Clear Error Log.** Use this option to clear the error log on the device. This is useful when debugging to ensure that error log entries are not historical.

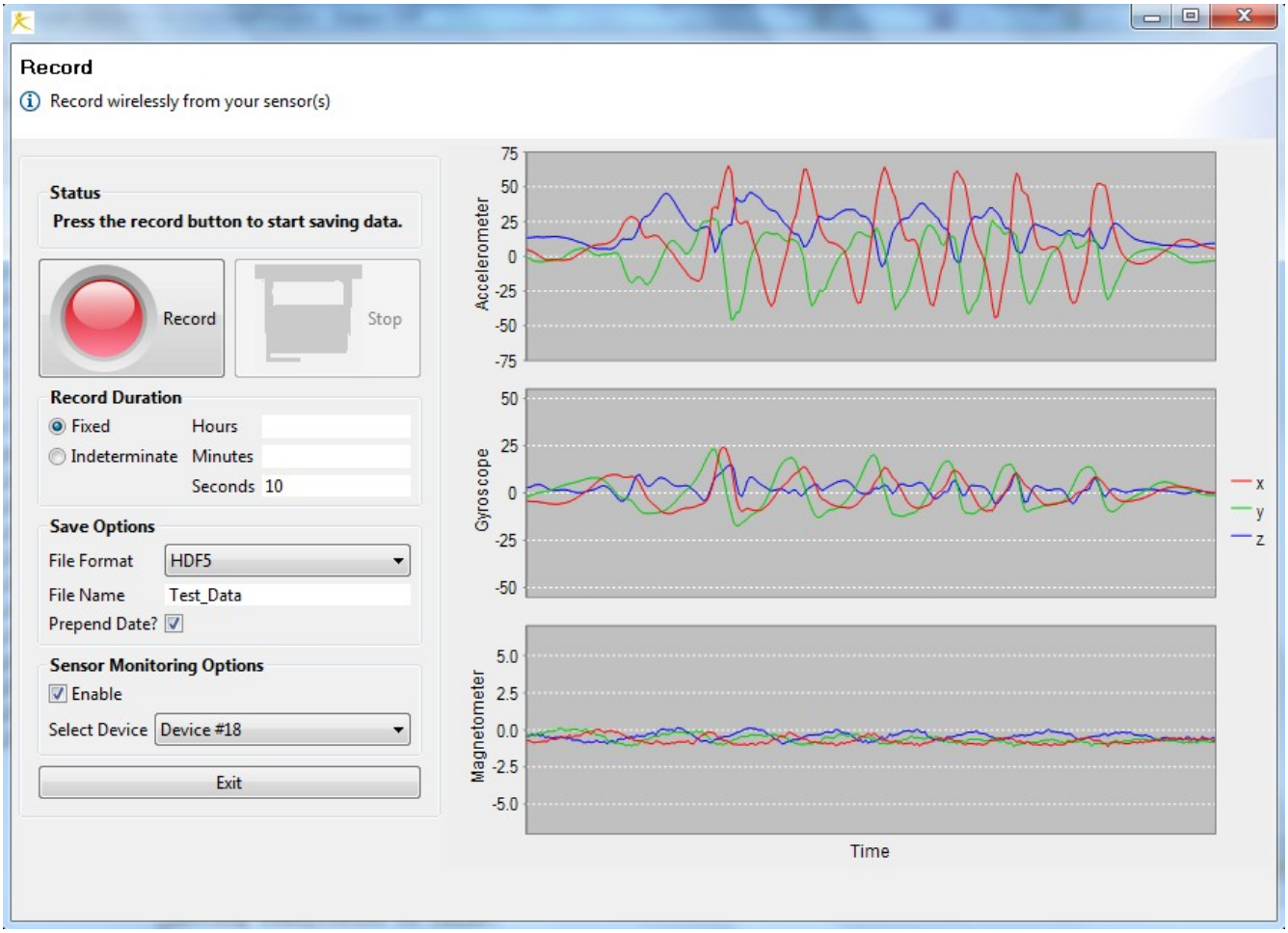
When you are done configuring your system

- Press the "Finished" button to complete the configuration.
- When the configuration progress dialog completes, unplug your sensors from the cables.

7 Wireless Streaming Mode

If wireless streaming mode is selected in the configuration dialog (Opals only), you can stream data from multiple, synchronized devices directly to your computer.

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



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

- **Real Time Chart.** The real time chart allows you to monitor the data streaming from your devices. Use the "Select Device" combo box to view the streaming data from different devices. Note: even when the sensors are within range of the Access Point and data is streaming freely, there may be as much as 400ms of latency between the time at which data is recorded and when it appears in the real time chart. 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.
- **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.
- **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. 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.
  - 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.
- **File Name.** Specify the name of the data file recorded to disk.
- **Prepend Date:** If checked, the date and time of the start of the recording are added to the beginning of the file name.
- **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.

8 Synchronized Logging Mode

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

To start recording, simply disconnect the devices from their cables or Docking Stations. 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. To create an additional recording in a separate file, connect and disconnect the devices from their their cables or Docking Stations. No re-configuration is necessary.

To import recorded data, first plug the device into a Docking Station. Use the “Tools” option from the menu and select “Import Raw Data”. Browse to the device, which will show up on your file system as an external storage device. Select the file that you wish to import. It will show up as an HDF5 file in your current working directory.

9 Low Power Logging Mode

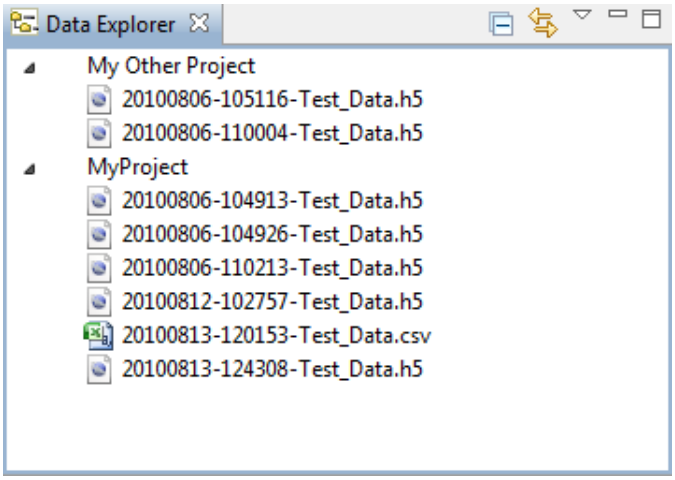
If your devices are configured for low power logging (Opals, Emeralds, and Sapphires), you can log data from more than one device at a time to their on-board flash memory. Wireless radios are turned off to save power. Multiple devices will not be synchronized, and some level of clock drift will occur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

To start recording, simply disconnect the devices from their cables or Docking Stations. After a few moments to initialize, they will start recording to their flash memory. To create an additional recording in a separate file, connect and disconnect the devices from their their cables or Docking Stations. No re-configuration is necessary.

To import recorded data, first plug the device into a Docking Station. Use the “Tools” option from the menu and select “Import Raw Data”. Browse to the device, which will show up on your file system as an external storage device. Select the file that you wish to import. It will show up as an HDF5 file in your current working directory.

10 Managing Your Data

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



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.

To **create a new folder or project**, right-click in the Data Explorer and select “New”.

Whenever you record data through wirelessly streaming or import logged data from your devices, the data will appear in your current **Working Directory**.

Your current Working Directory 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.

To plot a recorded file, right-click on the file and select the “Plot” option.

11 Working with HDF5 Files

HDF 5 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 document will cover the organization of the APDM Movement Monitor data and the basics of reading HDF 5 files in MATLAB.

APDM Data Organization

The HDF 5 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.

File Structure for File_Format_Version 1:

- /
  - 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 it's time set since turning on (1: yes, 0: no)
    - 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/s^2”)
        - 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 (“deg C”)
        - Temperature_Derivative – Dataset containing the rate of change of temperature
            - Units – Attribute string containing the temperature derivative units (“deg 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 epoch microseconds
    - ...
    - Opal_zzz/

Additional fields present when raw data is also stored:

- /
    - Opal_xxx/
        - 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 (Nx3)
        - Gyroscopes_Raw – Dataset containing raw gyroscope data (Nx3)
        - Magnetometers_Raw – Dataset containing raw magnetometer data (Nx3)
        - 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 (Nx1)

Working with HDF 5 in MATLAB

MATLAB contains two high level functions for working with HDF 5 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 HDF 5 file.

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

- `hdf5readslab` reads a portion of a dataset from the HDF 5 file.

Below is simple example of loading acceleration data from a APDM Movement Monitor HDF5 file in MATLAB.

```
idList = hdf5read('example.h5', '/Device_List');
groupName = ['/Opal_' idList(1)]; %Get data from the first monitor
accPath = [groupName '/Acceleration'];
fs = hdf5read(['/' groupName '/Sample_Rate']);
acc = hdf5read('example.h5', 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 HDF 5 to load and process only part of a dataset. This can be useful when the dataset is too large to fit into memory. Care is taken not to attempt to read beyond the end of the file.

```
info = hdf5info('example.h5');
idList = hdf5read('example.h5', '/Device_List');
groupName = ['/Opal_' idList(1)];
accPath = [groupName '/Acceleration'];
fs = hdf5read(['/' groupName '/Sample_Rate']);
nSamples = 0;
for cGroup = 1:length(info.GroupHierarchy.Groups)
      if strcmp(info.GroupHierarchy.Groups(cGroup).Name, groupName)
            group = info.GroupHierarchy.Groups(cGroup);
```

```
            for cDataset = 1:length(group.Datasets)
                  if strcmp(group.Datasets(cDataset).Name, accPath)
                        nSamples = group.Datasets(cDataset).dims(2);
                  end
            end
      end
end
nSamplesRead = min(nSamples, 60*fs); %read at most one minute of data
accSegment = hdf5readslab('examlpe.h5', accPath, [0,0], [nSamplesRead, 3])';
t = (1:nSamplesRead)/fs;
figure;
plot(t,accSegment);
```

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 APDM's HDF 5 files. If you are using one of these older versions, the free h5repack utility available from the HDF Group (http://www.hdfgroup.org/HDF5/release/obtain5.html) can remove the compression.

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

12 LED Reference

Status Codes and LED Colors/Patterns

The LEDs on the Access Points and sensors 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.

Access Point LED Reference

State	Description
Access point receiving data	Blinking Green
Access point receiving data, but buffers on access point are full	Blinking Red, this will occur if there is no application retrieving data data from the access point.

Sensor LED Reference

The sensors contain a RGB LED capable of outputting a wide array of colors to the user to indicate its current state. As of the current version the following colors are used: white ('W'), red ('R'), yellow ('Y'), green ('G'), cyan ('C'), blue ('B'), magenta ('M'), and led off ('_'). In the off state the LED will appear as a non illuminated white dot in the corner of the sensor 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 “Y_Y_” will blink yellow twice and then stay off until the pattern repeats.

State	LED Pattern
Startup (boot loader)	
Startup wait (5 sec)	Y
Failed to load firmware	R
Boot loader mode	W
Firmware	
Reset mode	W_
Docked mode (transition)	B_
Docked mode (charging)	B
Docked mode (full charge)	G_B
Docked mode (bad cable connection)	R_B
Error mode	R_ (note: this may change in the future to a pattern that indicates the type of error)
Card is full	M_
Run mode (transition)	G
Run mode (battery level indication off)	G_
Run mode (battery level 4/4)	G_G_G_G_
Run mode (battery level 3/4)	G_G_G_
Run mode (battery level 2/4)	G_G_
Run mode (battery level 1/4)	G_
Powering off	C_

13 Troubleshooting

Q: When I plug my sensor into its cable or Docking Station, it flashes alternately red and blue.
A: This is an indication of a poor connection. Try to plug your sensor back into its cable or Docking Station and make sure the cable or Docking Station is securely plugged into your computer.

Q: My sensor flashes red, and plugging it back into the cable does not fix the problem
A: If you have any data saved on the device from using it in logging mode, first back up the data using the "Tools->Import Raw Data" feature. Next, from the "Setup" dialog, select the sensor in the "Select Device" combo box and click on the "Re-flash Default Firmware" button. This will reset the sensor to its original state.