TECHNICAL GUIDE

Contents

1 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.

1.1 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.

1.2 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.

1.3 File Structure

1.3.1 Version 5

- **Annotations** Table containing annotations and button events
  - **Time** Annotation time in epoch microseconds
  - **Case ID** A movement monitor case ID associated with the annotation
  - **Annotation** The annotation string
- **Sensors** Group containing sensor data
  - **XI-XXXXXX** Group containing data from the monitor with this case ID. There is one of these groups for each sensor
    - **Accelerometer** Dataset containing accelerometer data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Barometer** Dataset containing barometer data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor

      - **Units** Attribute containing the units used to report the sensor measurements
    - **Gyroscope** Dataset containing gyroscope data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Magnetometer** Dataset containing magnetometer data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Temperature** Dataset containing internal temperature data
      - **Lower Limit** Attribute specifying the lower limit of the sensor
      - **Upper Limit** Attribute specifying the upper limit of the sensor
      - **Name** Attribute containing the name of the sensor
      - **Units** Attribute containing the units used to report the sensor measurements
    - **Time** Dataset containing timestamps in units of microseconds since 0:00 Jan 1, 1970 UTC
      - **Units** Attribute specifying the units used to store the timestamps
    - **Configuration** Group containing attributes that specify the configuration of the sensor
      - **Accelerometer Enabled** 1 for enabled. 0 for disabled
      - **Gyroscope Enabled** 1 for enabled. 0 for disabled
      - **Magnetometer Enabled** 1 for enabled. 0 for disabled
      - **Barometer Enabled** 1 for enabled. 0 for disabled
      - **Button Event 0 =** String configured to represent a button 0 event
      - **Button Event 1 =** String configured to represent a button 1 event
      - **Button Event 2 =** String configured to represent a button 2 event
      - **Button Event 3 =** String configured to represent a button 3 event
      - **Calibration Disabled** 1 to apply only the sensor data sheet typical conversion factors. 0 to use calibration data stored on the device
      - **Label 0** Custom label for this sensor. This is what is displayed on the LCD
      - **Location** Sensor location on the body
      - **Sample Rate** Sensor output data rate
      - **Timezone** Timezone code
      - **Timezone Offset** Timezone offset in units of hours from UTC
      - **Wireless Channel** Wireless channel
      - **Wireless Protocol** 0 for wireless disabled, 1 for synchronized logging, 2 for wireless streaming
      - **Wireless Latency (ms)** Configured maximum acceptable wireless latency
      - **Wireless rate divider** Data is streamed at the sample rate divided by this factor
    - **Metrics** Group containing information on the status of the sensor

- **Processed** Group containing derived signals from the sensor data
  - **XI-XXXXXX** Group containing derived signals from the sensor with this case ID
    - Orientation Dataset containing quaternions which can be used to rotate sensor data from the sensor frame to a local NWU reference frame

1.3.2 Versions 3 and 4

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaseIdList
- **CaseIdList 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 CaseIdList, with the name equal to the case ID
  - **FilteredDataPopulated (version 4)** Attribute indicating the present of the filtered data group
  - **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 (version 3)** 1 for populated, 0 for unpopulated
  - **CalibratedData (version 4)** Calibration data for the monitor
  - **LocalTimeOffset** Time in microseconds 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/s^2)
      - **Range** Attribute containing the range setting for the accelerometer (2g or 6g)
      - **Gravity (version 4)** Attribute indicating the gravity constant used in orientation estimation
    - **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 (°C)
        · **EarthFieldMagnitude (version 4)** The field constant used in orientation estimation
    * **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**
  - **Filtered (version 4)** Filtered data set. This set is intended for post-processed data. Currently the gyro biases are removed from the gyroscope signals. In the future, additional filtering may be implemented.
    * **Accelerometers**
    * **Gyroscopes**
    * **Magnetometers**

1.3.3 Version 3

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaseIdList
- **CaseIdList 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 CaseIdList, 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/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 ($^\circ$C)
  - **TemperatureDerivative** Dataset containing the temperature derivative (Nx1)
    - **Units** Attribute string containing the temperature derivative units ($^\circ$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**

1.3.4 Version 2

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaseIdList
- **CaseIdList 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 CaseIdList, 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 ($^\circ$C)
  - **TemperatureDerivative** Dataset containing the temperature derivative (Nx1)
    - **Units** Attribute string containing the temperature derivative units ($^\circ$C/s)
- **Raw** Group containing raw data if selected during import
  - **Accelerometers**
  - **Gyroscopes**
  - **Magnetometers**
  - **DataFlags**
  - **OptData**
  - **Temperature**
  - **TemperatureDerivative**

1.3.5 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/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 (°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 ($Nx3$)
  - **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 ($Nx1$)

1.4 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.

1.5 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);
```

1.6 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 Mobility Lab'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`

2 Working With Video

Mobility Lab comes with the functionality to collect video that is synchronized with your inertial recordings. In other words, when you start/strop a recording in Mobility Lab, the connected video camera(s) will start/stop at the same time. Currently, Apple iDevices (iPhone, iPad, and iPod) devices running the Videography app are supported.

2.1 Using Videography and Apple iDevices

The iDevices solution makes use of an app available on the Apple Store named Videography (http://appologics.com/videography). This software must be purchased and installed on each iDevice that you wish to use. Videography must be the open, running application on the iDevice in order for it to be triggerable.

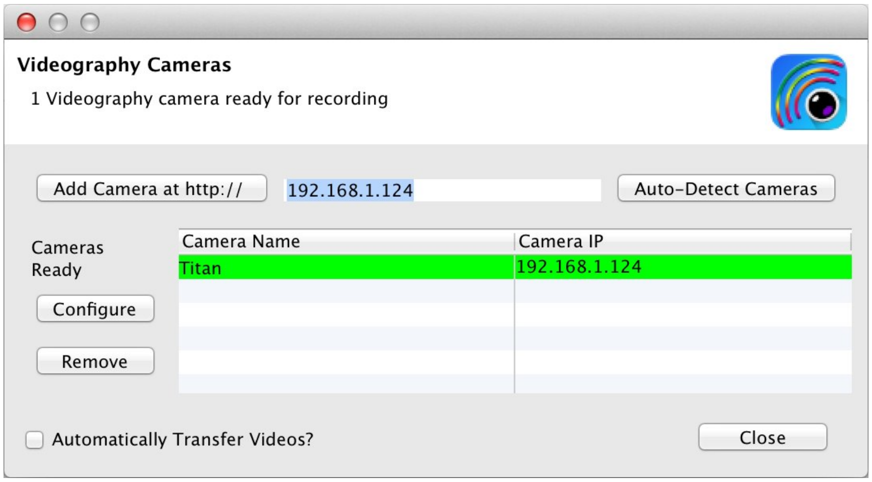
2.1.1 Network Setup

The Videography cameras and the computer running Mobility Lab need to be mutually reachable on the network. There are three possible configurations:

- **Common Local network:** In this configuration, your computer and the Videography cameras are all connected to the same local Wi-Fi network. Typically, this means that these devices are all on the same subnet, meaning that the first 3 octets of the 4-octet IP addresses are the same on your computer and all connected iDevices. For example, your computer may have the IP address 192.168.1.10 and your cameras may have IP addresses 192.168.1.11 and 192.168.1.12. This is the easiest setup to use, as your devices maintain internet access to the outside world through the standard internet connection.
- **Ad-hoc network:** In this configuration, you create an ad-hoc network on your computer running Mobility Lab and connect each Videography camera to this network individually. In this mode, your computer running Mobility Lab and the Videography cameras may not have access to the internet, unless you configure your computer to use a different network connection while its Wi-Fi adapter is being used for the ad-hoc network (e.g., you can use Ethernet for your internet connection and the ad-hoc Wi-Fi network for camera control). This option is useful when no other Wi-Fi network is available.
- **Different Wi-Fi networks:** Even if the laptop and your Videography cameras are on different networks, such as two different Wi-Fi access points within one clinic or two computers in different cities, it may still be possible to remotely control them. The key requirement is that the IP address of the Videography cameras is reachable on port 80 (the standard web port). This may, however, require some advanced networking practices, such as port forwarding.

2.1.2 Camera Configuration

- Enable the use of Videography cameras:
  - Click View→Options in the File Menu.
  - Select ”Enable Videography video integration”
  - Click ”Done” and restart the application



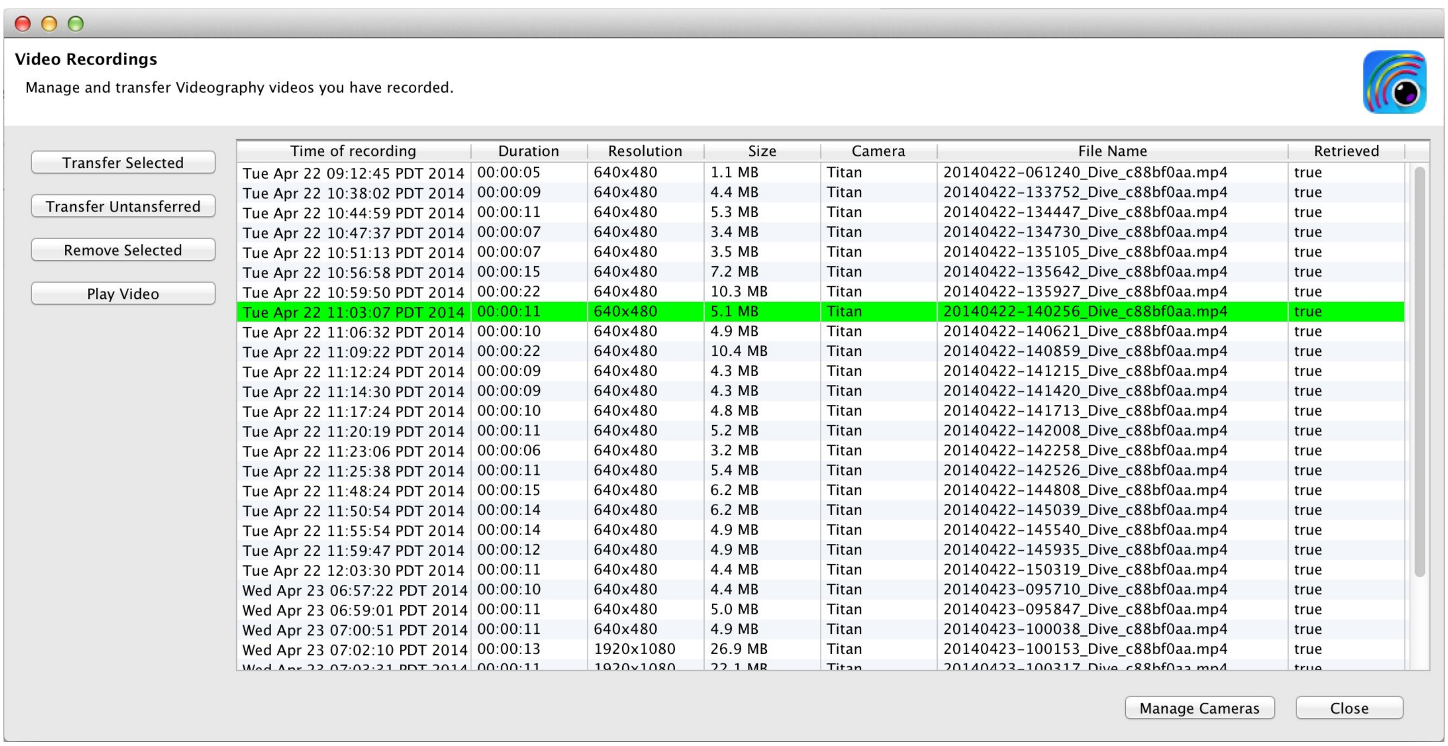
The Videography Camera Configuration Dialog

- Click Video→”Manage Videography Cameras”. You will see a configuration dialog similar to the one above.
- If your computer and all Videography cameras are on the same Wi-Fi network, you can use the **Auto-Detect Cameras** feature to automatically find and add your Videography cameras. Please note that this takes 20s or so. Alternately, you can add the IP address of each camera individually in the text field at the top and clicking on the ”Add Camera at http://” button. Note: You can determine the IP address of the Videography camera by clicking on Settings→”Remote Control” and looking at the Wi-Fi address field.
- If you wish to configure your camera, select it in the dropdown list and click the **Configure** button. Note: You can access the same configuration dialog through a web browser by entering the camera’s IP address into the browser’s address field or by using the software’s configuration options directly through the iDevice.
- You can select the **Automatically Transfer Video** option if you want video to be transferred back to your computer immediately following the video capture. Due to the potentially large size of the video files, you may want to avoid this if you are collecting long video segments with brief periods of inactivity between them or if your network speeds are slow, as active video transfers may interfere with an active recording session. Videos can easily be transferred using the video management tool at a later time.
- If a Videography camera is listed here that you no longer wish to trigger, select it and click the **Remove** button.

2.1.3 Triggering The Camera

- When you open up the recording dialog, a Videography widget will be visible among the recording controls. This widget will indicate how many cameras are configured for recording. Communication with each configured camera is checked when the recording dialog is opened, so it is possible that one or more expected cameras do not appear on this list if they are experiencing network issues, have shut down, have switched to another application, etc. If the list doesn't match up with your expectations, click on the Videography icon within this widget to re-open the configuration dialog.
- When you start an inertial recording from within Mobility Lab, the camera(s) will start recording (each camera will display on its own screen that it is recording). When you hit stop, the camera will stop recording.
- If you have the "Automatically Transfer Videos?" option set, the video will be transferred to the computer running Mobility Lab. If not, you can use the Video Manager to transfer and view these files at a later time.

2.1.4 Managing Videography Videos



The Video Management Tool

All recorded Videography videos will be logged in the **Video Management Tool**. This tool will help you keep track of when the recordings were made, which inertial recordings they are associated with, properties of each video (e.g., resolution, size), and whether the video has been transferred from the camera to your computer yet.

- The videos will end up in the following folder:
  INSTALL_FOLDER\Mobility Lab\workspace\CURRENT_PROJECT_FOLDER\videos
  If you are using Mobility Lab, the CURRENT_PROJECT_FOLDER is named ”MobilityLabProject”
- Video Properties:
  - **Time of Recording:** The time when both the inertial and video recording were initiated.
  - **Duration:** The duration of the recording
  - **Resolution:** The video resolution
  - **Size:** The disk size of the video recording
  - **Camera:** The name of the iDevice running Videography.
  - **File name:** The name of the video file after it has been transferred. This matches the name of the recorded inertial file, with an addition to identify the source camera (needed if multiple cameras are used for simultaneous video).
  - **Retrieved:** Whether the video has been transferred from the remote camera to your computer yet.
- Actions
  - **Transfer Selected:** Transfer any selected videos from the remote camera to your computer. The iDevices that you are transferring the videos from must all be running Videography and must be connected through the use of the Camera Configuration Dialog. You can click on the ”Manage Cameras” button on the bottom of the dialog to open up the Camera Configuration Dialog.
  - **Transfer Untransferred:** Transfer any videos that have not yet been retrieved.
  - **Remove Selected:** Remove the selected video(s) from the video log.
  - **Play Video:** Play the selected video. This function only works if the video has already been transferred.
- Note: We do not currently have a tool to view raw inertial data along side the video(s), but this is planned for a future release. These videos should be playable on any modern computer. If you have issues with playback, try downloading VLC (http://www.videolan.org/vlc/index.html)

2.1.5 Synchronization Performance

We have measured the following characteristics regarding synchronization between the video and inertial recordings:

- Mean synchronization error : 100ms
- Standard deviation of the synchronization error: 80ms
- Max synchronization error: 250ms

This variability comes from the communication overhead and when the iDevice actually starts recording. This should be sufficient for most types of recordings, but may be slightly inaccurate when looking at very fast or brief actions.

3 Firmware Updates

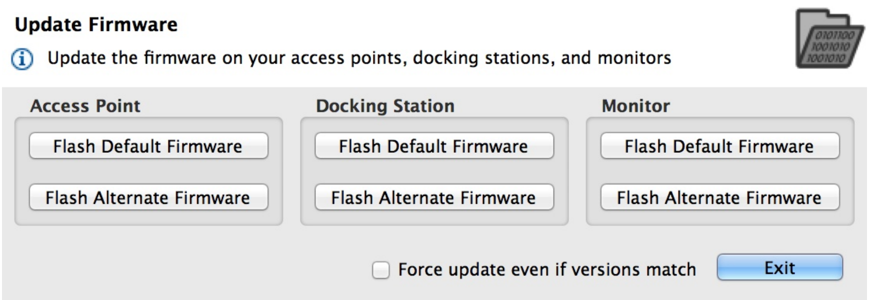
Firmware controls the various hardware components of your APDM product line (monitors, access points, and docking stations). It is important to keep the firmware up to date to ensure that your system gets the latest bug fixes and has access to the latest features. Firmware updates are bundled with updates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

3.1 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.

3.2 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

3.2.1 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.

3.2.2 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.

3.2.3 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.

4 Calibration

4.1 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.

4.1.1 Accelerometers

The calibrated accelerometer measurements are calculated as

$$\vec{a}_{cal} = C S_T (\vec{a}_{raw} - \vec{b}_T)$$

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

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

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

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.

4.1.2 Gyroscopes

The calibrated gyroscope measurements are calculated as

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

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

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

$$S_T = \begin{bmatrix} s_x + Ts_{x,T} & 0 & 0 \\ 0 & s_y + Ts_{y,T} & 0 \\ 0 & 0 & s_z + Ts_{z,T} \end{bmatrix}$$

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

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.

4.1.3 Magnetometers

The calibrated magnetometer measurements are calculated as

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

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

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

$$S_T = \begin{bmatrix} s_x + Ts_{x,T} & 0 & 0 \\ 0 & s_y + Ts_{y,T} & 0 \\ 0 & 0 & s_z + Ts_{z,T} \end{bmatrix}$$

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

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.

4.1.4 Temperature

The calibrated temperature measurements are calculated as

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

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.

4.2 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.

4.2.1 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, contact our support team using the contact information provided in Section 10.

4.3 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.

4.3.1 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). The wizard asks that you only undock and collect calibration data 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).

4.3.2 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.

4.3.3 Accelerometer Recalibration

Coming soon!

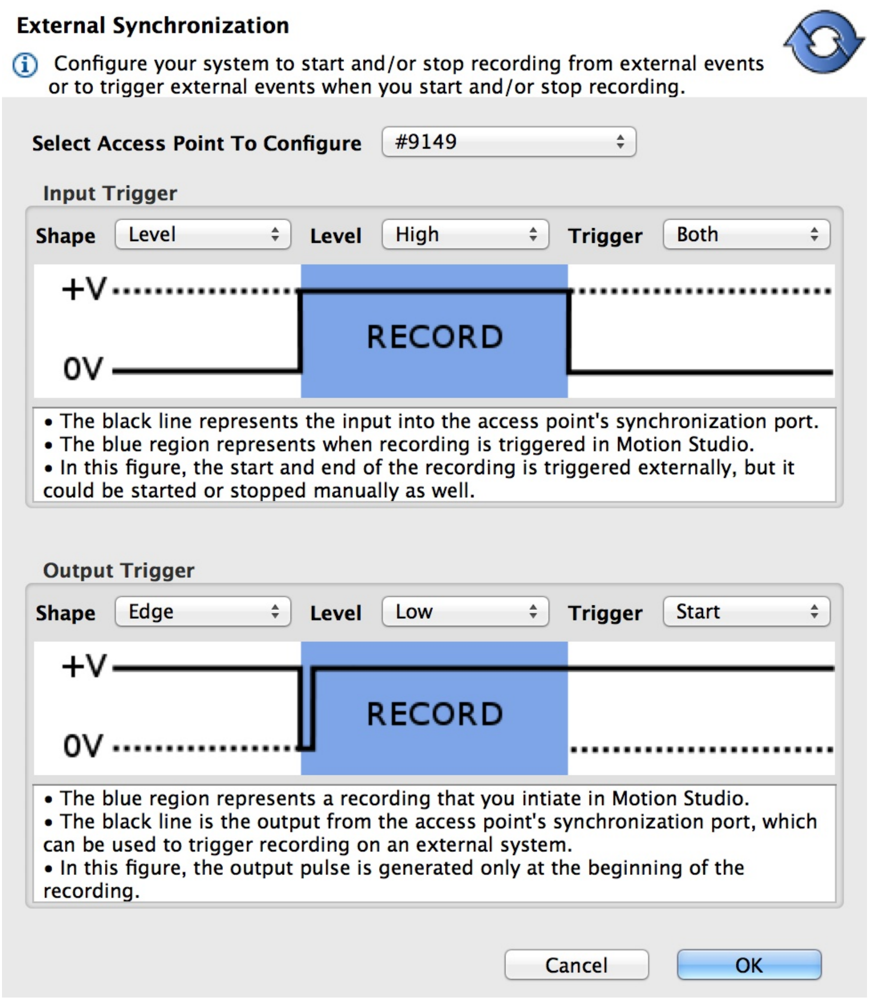
4.4 Clearing User Calibration

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.

5 External Synchronization and I/O

The access point comes with external connectors that enable you to synchronize the recording of data in Mobility Lab with external equipment. This functionality only works when the system is configured in one of the wireless streaming modes and the “Stream” dialog is open. The implementation is adaptable to a number of scenarios. Here are some examples of things you can do:

- Trigger recording in Mobility Lab when external events occur. You can use this functionality to precisely synchronize your inertial recordings with, for example, recordings initiated on a camera based motion capture system.
- Trigger external events when you start and stop recording in Mobility Lab. You can use this functionality to precisely synchronize your inertial recordings initiated in Mobility Lab with, to use another example, a video recording system.
- A combination of the two. For example, hitting the record button on a camera based motion capture system could trigger recording in Mobility Lab which could then trigger a video recording system.

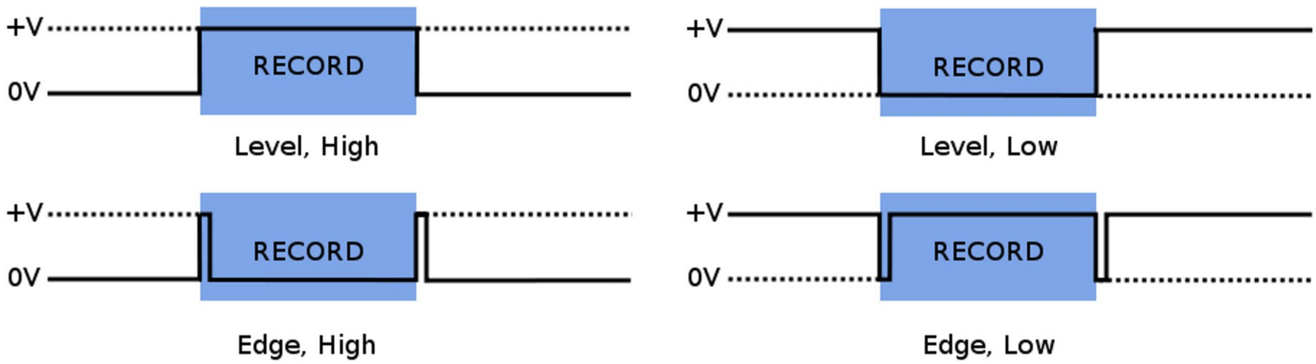


The External Synchronization Configuration Dialog

5.1 Configuration

Specification of external synchronization options is performed through the External Synchronization Configuration dialog. If multiple access points are being used, synchronization options are specified for each access point individually so that you can determine which ones are receiving external signals and/or sending external signals. Each access point can have its input and output triggers specified individually. Input and output triggers can also be disabled through the configuration dialog.

5.2 Input Synchronization



Input synchronization trigger types

5.2.1 Input Trigger Shape

The input trigger shape indicates the type of signal that will be input into the specified access point and how you want Mobility Lab to respond when using the “Stream” dialog. In the figure above, the four basic trigger shapes are shown. The solid black line represents the external synchronization signal being sent to the access point. The blue shaded region represents the period that will be recorded in Mobility Lab. Input triggers are only processed when the “External Sync” option is specified in the “Record Duration” panel of the “Stream” dialog.

5.2.2 Input Trigger Level

Input triggers can be either low or high, depending on the nature of the signal generated by your external synchronization source.

5.2.3 Input Trigger

There are three input trigger options available:

- Start: The external trigger will only be used to start recording in Mobility Lab.
- End: The external trigger will only be used to stop recording in Mobility Lab.
- Both: The external trigger will be used to start and stop recording in Mobility Lab.

5.2.4 Sample Selection with External Input Trigger Events

The time of the external input trigger events may not align exactly with the time of an individual samples being collected in Mobility Lab due to the discreet sampling interval. If the start trigger event time does happen to align exactly with a sample captured in Mobility Lab, the first sample recorded will correspond exactly to the time of the start trigger event. If these do not align exactly (as will generally be the case) the sample preceding the start trigger event will be the first sample recorded. Similarly, if the stop trigger event aligns exactly with a sample captured in Mobility Lab, the last sample recorded will correspond exactly to the time of the stop trigger event. If these do not align exactly, the sample following the start trigger event will be the last sample recorded. This way, we guarantee that the recording captured in Mobility Lab fully spans the time period between the external input start and stop events, but no more.

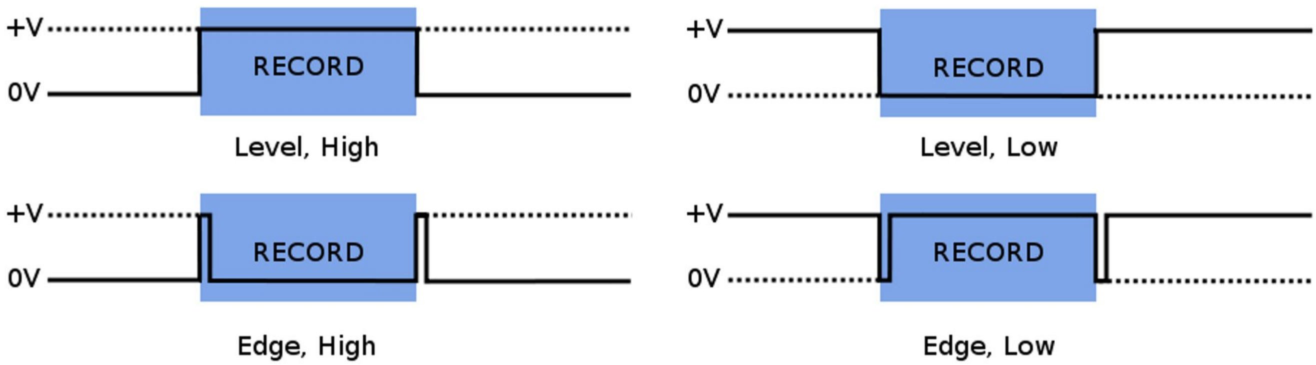
5.2.5 Annotation of Externally Triggered Recordings

Note: Annotations are implemented for the HDF file format only. When an external “Start” trigger event is detected, an annotation is added to the recording that indicates the name of the event (in this case “External trigger start time”) along with the timestamp of the event in epoch microseconds. Similarly, when an external “Stop” trigger event is detected, a timestamped annotation is added to the recording (in this case labeled as the “External trigger stop time”). These annotations allow you to align the recording captured in Mobility Lab with your external events in the case where the external trigger event times do not exactly align with the samples captured in your HDF file.

5.3 Output Synchronization

5.3.1 Output Trigger Shape

The output trigger shape indicates the type of signal that will be generated by the specified access point when recording is started and stopped through the streaming dialog in Mobility Lab. The output trigger shapes are identical to the input trigger shapes, but in this case the solid black line in the figure above represents the signal being output by the configured access point. The blue shaded region represents the



Output synchronization trigger types

period being recorded in Mobility Lab, initiated either through user selection of the start/stop buttons in the "Stream" dialog, use of the wireless remote, or an external synchronization event. Unlike input triggers, output triggers are processed even if the "External Sync" option is not specified in the "Record Duration" panel of the "Stream" dialog.

5.3.2 Output Trigger Level

Output triggers can be either low or high, depending on the requirements of the external system receiving the synchronization signal.

5.3.3 Output Trigger

There are three output trigger options available:

- Start: The external signal will only be generated when recording is started in Mobility Lab.
- End: The external signal will only be generated when recording is stopped in Mobility Lab.
- Both: The external signal will be generated when recording is started and stopped in Mobility Lab.
- Note: It is not recommended to use the level trigger shapes in conjunction with the start or end triggers. This is because the output signal will be in an undeterministic state prior to the trigger event.

5.4 Isolated External Interface Details

APDM's access points come fitted with a 6 pin digital I/O connector and a 4 pin analog I/O connector. To connect an access point to your external equipment, you may have to create a custom cable that can interface with both components. Below we provide the technical specifications necessary to complete this task. Feel free to contact our technical support at support@apdm.com if you require assistance or have additional questions.

The Isolated External Interface for the AP consists of an auxiliary power supply, two GPIO lines (one in, one out), and an inter-AP sync signal. All signals in the isolated external interface section (including power and ground) are isolated from the remainder of the board using an RF solution similar in operation to an opto-isolator. Further, all signals in the isolated external interface are 5V tolerant and ESD protected beyond the 15kV human body model.

The connectors used in the isolated interface consist of one standard female RCA, and one female 6 pin mini-din connector. The RCA connector mates to almost any basic RCA cable similar to those used in audio systems. When choosing an RCA mating connector, choose one that has uncovered bare shield spades to allow the connector to fit fully into the recessed hollow in the AP body.

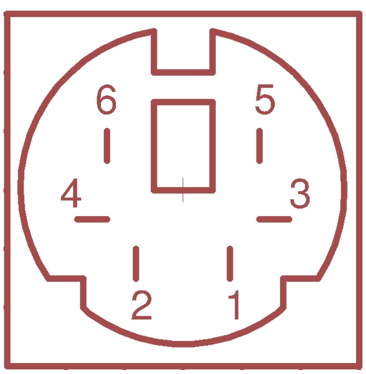
The 6 pin mini-din connector is similar to those used for older style PS/2 keyboards and mice. Choose a connector that is small enough to fit fully inside the recessed hollow in the AP body. Some PS/2 extension cables can be cut into excellent pigtails for this connector.

5.4.1 RCA Inter-AP Sync Connector

- RCA Connector: Digikey Part number RCP-021, CUI INC
- Center Pin: Inter-AP Sync
- Sheild: Isolated Ground

5.4.2 6 Pin Digital Input/Output Connector

- 6 Pin Mating Connector: Digikey part number CP-2060-ND, CUI Inc part number MD-60.
- 6 Pin Mating Pig Tail Cable: Digikey part number 839-1051-ND
- *Note these connectors may need the outer shell trimmed to fit into the AP case, a better solution is often pigtail cables that have over-molded ends and excellent strain relief.*



AP 6 Pin Digital Connector

- Pin 1: Record In

- Pin 2: Output Voltage Select. When connected to positive (pin 6), I/O will be in 5 volt mode. 3.3 volt mode otherwise.
- Pin 3: Isolated Ground (isolated gnd)
- Pin 4: Inter-AP synchronization output signal. 2.56 khz square wave used for synchronizing timing among multiple access points.
- Pin 5: Record Out
- Pin 6: Isolated Vdd, unregulated. 3.3 V or 5 V depending on whether it is connected to pin 2.

The auxiliary power supply is meant to provide for powered external interface solutions, allowing a small circuit to be powered directly from the AP. Accessed via pin 6 of the mini-din connector, the auxiliary power supply is rated for operation up to 250mW at 3.3V or 5V operation. While default operation is at 3.3V, 5V operation can be selected by shorting pin 2 to pin 6 of the 6 pin mini-din connector.

The inter-AP sync signal is a 2.56kHz clock signal used to keep multiple AP configurations in sync with one another. The inter-AP sync signal is available on the RCA connector, as well as pin 4 of the 6 pin mini-din connector next to it. The signal is a square wave pulse that is driven by the 'master' AP (usually the first AP to enumerate) and received by up to seven additional APs (depending on output voltage selection and cable length). In operation the signal is weakly pulled up to the isolated power rail by each AP in the system, and driven directly to ground only by the 'master' AP to produce the pulsed waveform.

Two GPIO lines are available, one input and one output. Both are pulled down by 47.5kΩ resistors, and each have a series resistance of nearly 1.2kΩ due to the methods used to protect the lines from over-voltage/overcurrent conditions. The input signal is available on pin 1 of the 6 pin mini-din connector and is typically used to start/stop data collection by the host PC. Driving the line high to 'record' and low to 'not-record' is the default operation, though this is user selectable in software to allow for other modes of operation. Similar to the input line, the output line is typically used to start/stop data capture on external systems. The line is driven high by the AP when 'start recording' is selected in software, and driven low when recording stops. Opposite high/low operation can be software selected at time of configuration for both input and output signals.

- Note: The pin diagrams below show the interface on the AP and not the cable. The pin layout on the cable is the mirror image of these diagrams.
- Note: A cable designed to trigger recording in Mobility Lab from an external synchronization event must make use of isolated ground (pin 3) and record in (pin 1). Assuming a voltage range of 3.3V, these are the only pins that need to be implemented. If the voltage range is 5V, pins 2 and 6 must be connected.
- Note: A cable designed to trigger an external system when recording is started or stopped in Mobility Lab must make use of isolated ground (pin 3) and record out (pin 5). Assuming a voltage range of 3.3V, these are the only pins that need to be implemented. If the voltage range is 5V, pins 2 and 6 must be connected.

5.4.3 External Sync Box

The external sync box is meant to allow for easy access to the access point external digital expansion port. A shielded straight-through six conductor cable connects the AP to the sync box, BNC connections outside the box allow for simple connections to remote equipment.

AP External Sync Box

Three external BNC connections:

- AP-AP: This connection should only be connected to another AP, it is used to keep multiple APs in sync and can be used to connect multiple APs in a star or daisy chain configuration (both will work).
- AP In: This input to the AP can be configured via software to allow an external device to begin and stop recordings. Accepts both +3.3V and +5V logic levels.
- AP Out: This AP output can be configured via software to drive low, high, or pulse at record start/stop points allowing synchronization with an external system (such as a camera motion capture system). *Note: the default configuration for AP Out is +3.3V logic levels, though +5V levels can be selected using the voltage select switch located in the top of the box.*

Four LEDs indicators:

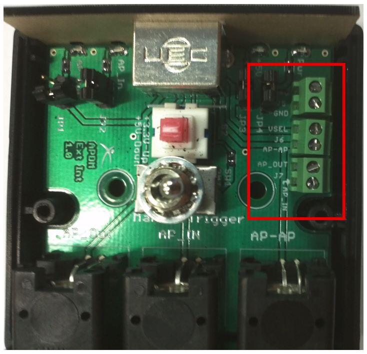
- PWR: Lights when power is applied to the external interface.
- +5V: Lights to indicate that the external interface is configured for 5V operation. Default is 3.3V (Light out)
- AP In: Lights to indicate that the APIIn signal is High
- AP Out: Lights to indicate that the AP Out signal is High

Push-button and Toggle switch:

- Push Button: Up to select 3.3V operation. Down to select 5V operation.
- Toggle: Manually ties the AP In signal to the positive voltage rail allowing for manual triggering of recordings (software configured).

Additional connections and functionality are located inside the box and can be accessed by removal of the box top: JP1 through JP4 can be removed to disconnect the corresponding LED.

Six Euro-style screw terminals can be used to directly connect to the six wires in the AP cable:



AP External Sync Box

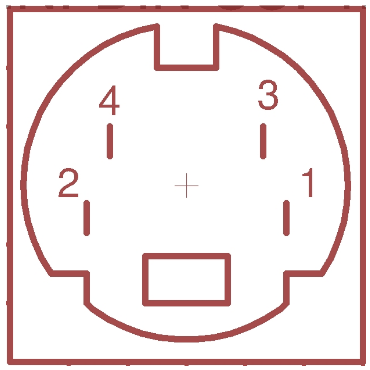
- +V: Positive voltage rail from the isolated supply located inside the AP.
- GND: Ground rail from the isolated supply located inside the AP.
- VSEL: Tie to Ground or leave floating to select output and +V operation at +3.3V, tie to +V to select +5V operation.
- AP-AP: Allows multiple AP configurations, tie only to the same port of another AP.
- AP Out: Digital output from the AP. Default is 0V to +3.3V, but can be configured for 0-5V operation.
- AP In: Digital input to the AP from an external source or the manual trigger toggle switch.

Note: The AP is able to safely source only 50mA on the +V rail.

5.4.4 4 Pin Analog Input/Output Connector

Note: This connector is currently reserved for future expansion.

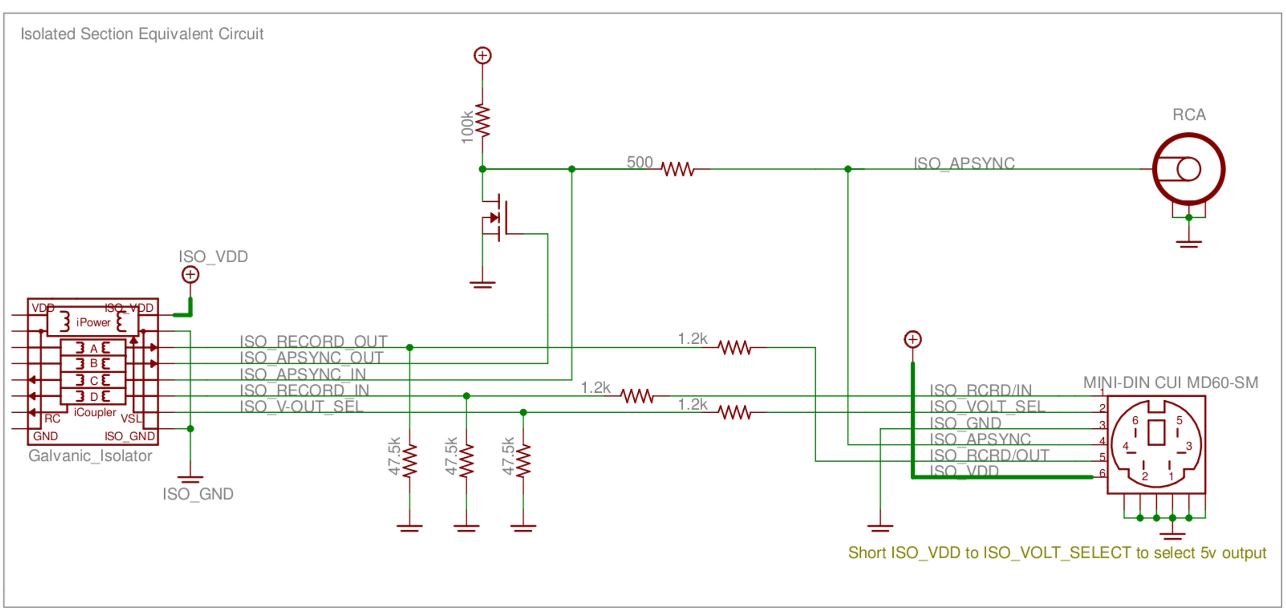
- 4 Pin Mating Connector: Digikey part number CP-2040-ND, CUI Inc part number MD-40
- 4 Pin Mating Pig Tail Cable: Digikey part number 839-1049-ND



AP 4 Pin Analog Connector

- Pin 1: Analog In (0 to 6 volts)
- Pin 2: Analog Out (0 to 5 volts or 0 to 3.3 volts depending on software controled configuration)
- Pin 3: No Connect (reserved for future use, avoid connecting this pin)
- Pin 4: Ground (gnd). This is the same ground as USB, and depending on how your USB hub and/or laptop are designed electrically, may also be the same ground as the hub and laptop. Consideration should be taken for ground loops.

5.4.5 Schematic



6 Movement Monitor Reference

6.1 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).

6.2 Powering Down

If you wish to power down your monitors for storage or travel, dock the monitors you wish to power down and click on the “Power Off” button in Mobility Lab. After this process is complete, these monitors will power down when they are undocked. They can be powered back on by re-applying the saved configuration or re-configuring the system.

6.3 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 Mobility Labis used to import the data. Alternately, there are functions in the SDK to do this conversion programmatically.

6.4 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.

6.5 Storage

Storage of the movement monitor should be in a dry static fee 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 to have at least a bulk charge during storage.

6.6 Drivers

Drivers are provided as part of the library distribution and Mobility Lab. The drivers are installed automatically as part of the Mobility Lab installation process.

6.7 Firmware Updates

Updating the movement monitor firmware should be done using the Mobility Lab software. This process is detailed in Section 3 of this document.

6.8 Technical Specifications

- The accelerometer range is $\pm 58.8\,\mathrm{m/s^2}$ (6 g) (optionally $\pm 19.6\,\mathrm{m/s^2}$ (2 g)).
- Accelerometers have a typical noise density of $1.3\,\mathrm{mm/s^2/\sqrt{Hz}}$.
- The X and Y axis gyros have a range of ± 34.9 rad/s (2000 dps)
- The Z axis gyro has a range of ± 26.8 rad/s (1500 dps)
- The X and Y axis gyros have a typical noise density of 0.81 $\mathrm{mrad/s/\sqrt{Hz}}$
- The Z axis gyro have a typical noise density of 2.2 $\mathrm{mrad/s/\sqrt{Hz}}$
- Magnetometers have a range of ± 6 Gauss
- The magnetometers have a typical noise density is 160 $\mathrm{nT/\sqrt{Hz}}$
- Positive X is pointing from the monitor toward the connector. Looking top down at the monitor with positive X pointing away from you, positive Y is pointing left. 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.

6.9 LED Reference

6.9.1 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.

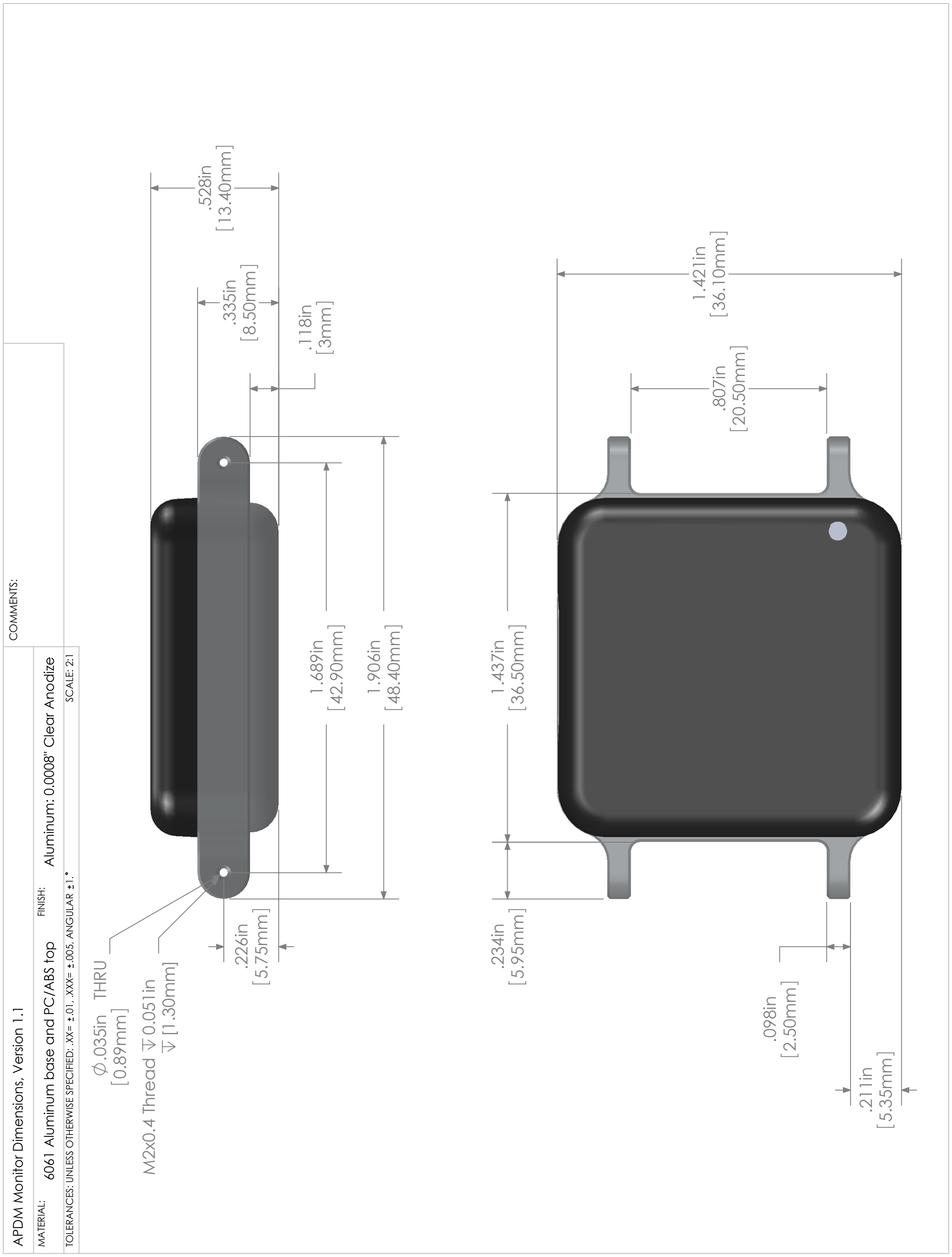
6.9.2 Movement Monitor LED Reference

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

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	🟡🔴_

6.10 Technical Drawing



7 Access Point Reference

7.1 Drivers

Drivers are provided as part of the SDK distribution and Mobility Lab.

7.2 Firmware Updates

Updating the movement monitor firmware should be done using the Mobility Lab software.

7.3 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.

7.4 Using Multiple Access Points

Having multiple access points is useful when redundancy is needed or when recording from more than 6 Opals. To configure multiple access points, you must have them attached to your computer via USB at the time of configuration. Additionally, the access points must be linked via RCA cable (a standard stereo cable). The rest of the configuration is handled automatically.

7.4.1 Redundancy

In some recording environments, it may be difficult to always maintain line of site from your streaming Opals to the access point. For example, you may have a bend in a hallway, or you may be operating in a large open space where you are unlikely to receive a reflected signal if the Opal is pointed away from the access point. In these scenarios, multiple access points can be used to provide better coverage. The streaming Opals will communicate with whichever access point is providing the stronger signal.

7.4.2 Streaming from more than 6 Opals

Each access point can communicate with up to 6 Opals simultaneously. You can therefore stream from up to 12 Opals with 2 access points, or 24 Opals with 4 access points.

7.5 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 (● (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.

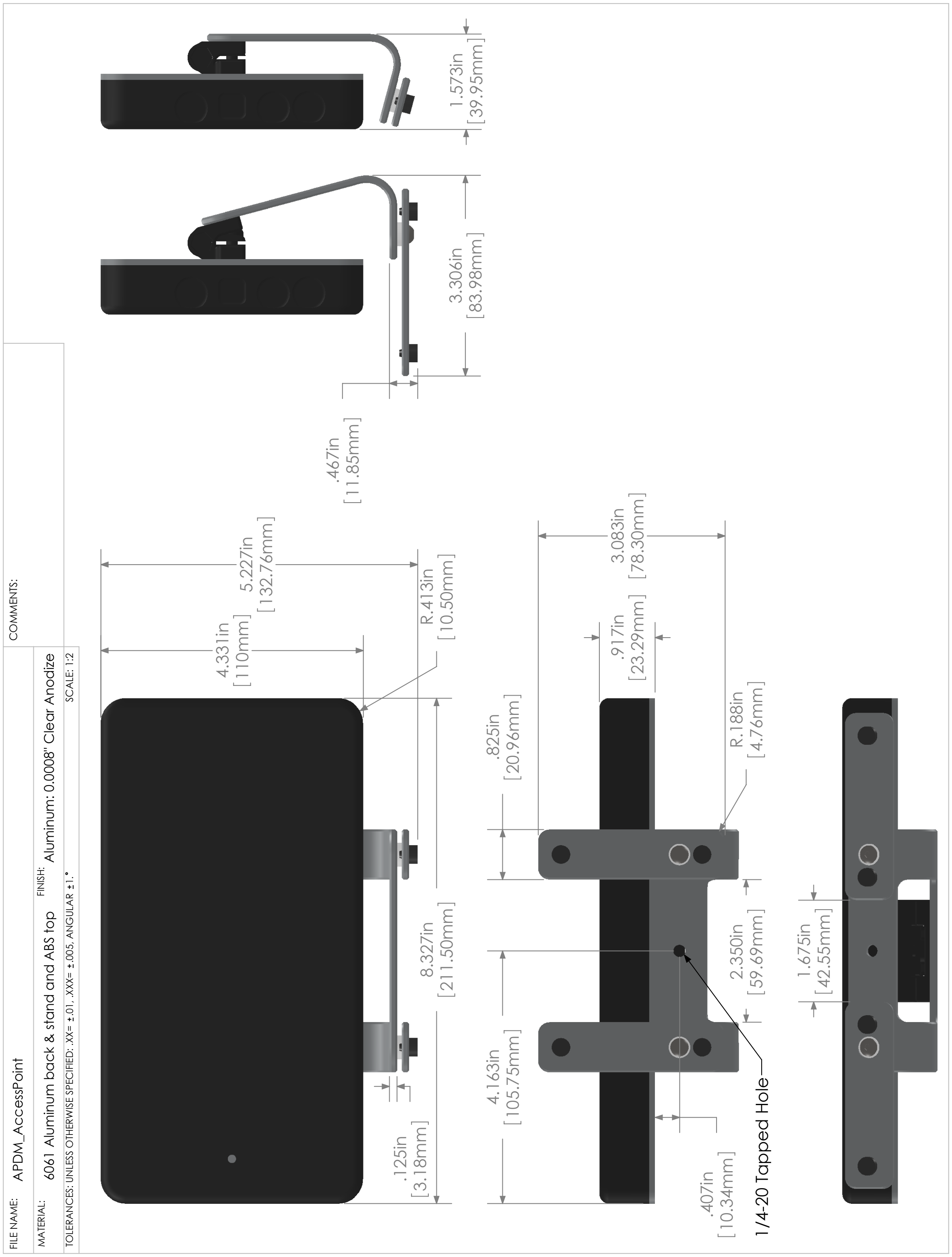
State	LED Pattern
Access point is powered on and is not receiving data from any monitors	🟢
Access point is receiving data from all monitors and there is no excessive latency for any of the monitors	🟢_
Access point is receiving data from all monitors but there is excessive latency (>3s) in one or more 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 Access point SDRAM Memory error, contact support	🔴_🔴_🔴__ 🔴_🔴_🔴_🔴__ 🔴_🔴_🔴_🔴_🔴__ 🔴_🔴_🔴_🔴_🔴_🔴_🔴_🔴__

7.6 Mechanical and Electrical Specifications

Weight: 1.2lbs, (550 grams)

Electrical: 290mA at 5V over USB connection

7.7 Technical Drawing



8 Docking Station Reference

8.1 Drivers

Drivers are provided as part of the SDK distribution and Mobility Lab.

8.2 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 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

8.3 Mechanical and Electrical Specifications

Weight: 0.2 lbs, (90 grams)

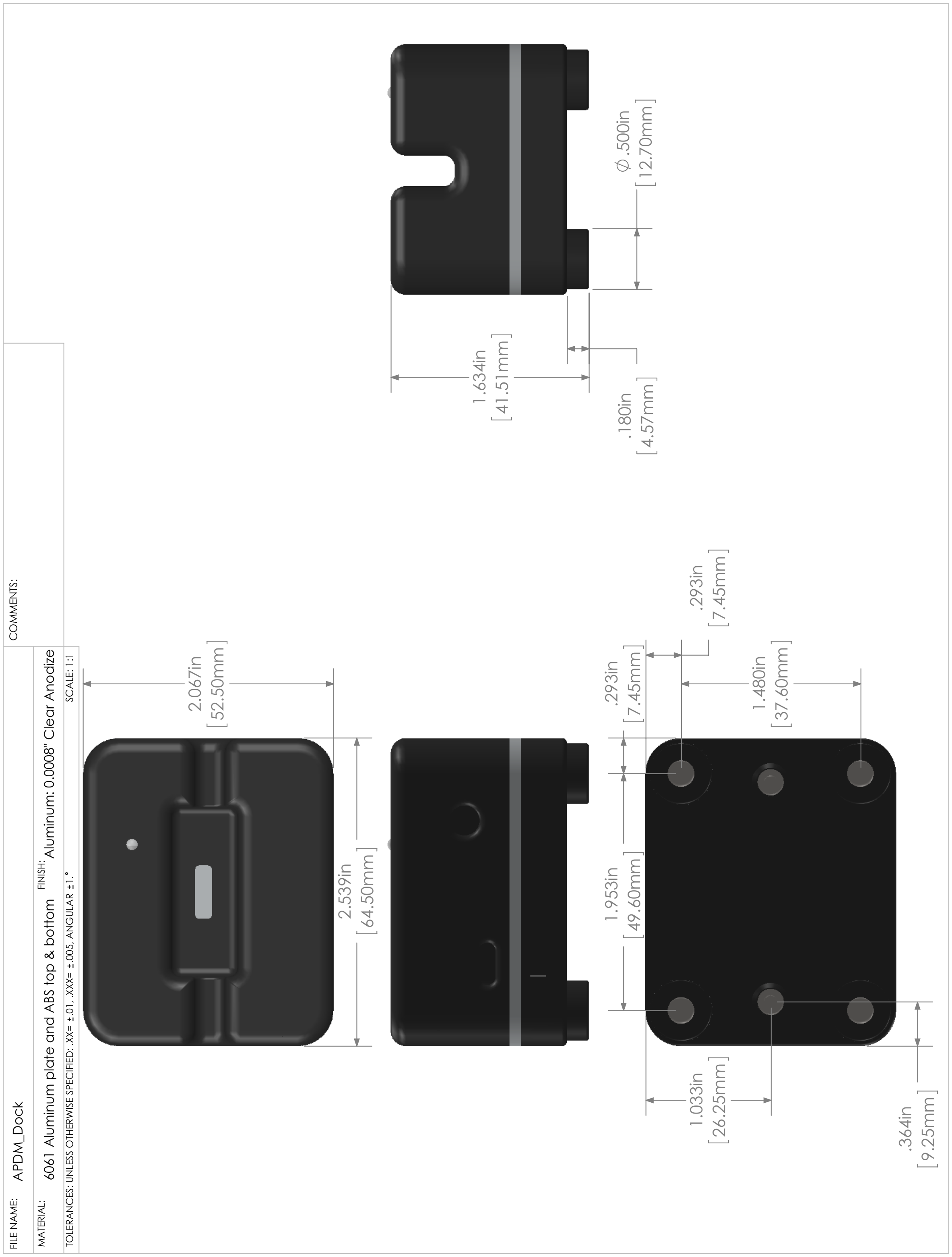
Electrical: 500mA at 5V over USB connection, or 500mA per dock when a chain is supplied by external power.

8.4 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 (●(red)), yellow (●(yellow)), green (●(green)), cyan (●(cyan)), blue (●(blue)), magenta (●(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 "●(yellow)_●(yellow)_" will blink yellow twice and then stay off until the pattern repeats.

State	LED Pattern
OK	●(green)
Powered off, USB suspended, or booloader pause	●(black)
OK, but USB not enumerated	●(yellow)
Power problem. Need to plug in external power or USB power.	●(yellow)_
Docking in progress	●(cyan)_
Docked, but SD unavailable to host	●(cyan)
SD Card mounting in progress	●(blue)_●(cyan)_
SD Card mounted and avaliable to host	●(blue)
SD card read-access in progress	●(blue)_
USB error	●(orange)
Error	●(red)_
Error: SD card mounting error	●(red)_●(red)_
Error: in-dock USB hub problem	●(red)_●(red)_●(red)_
Firmware error type 4, contact support	●(red)_●(red)_●(red)_●(red)_
Firmware error type 5, contact support	●(red)_●(red)_●(red)_●(red)_●(red)_
Firmware error type 6, contact support	●(red)_●(red)_●(red)_●(red)_●(red)_●(red)_
Bootloader mode	●(magenta)
Updating firmware	○
Hardware Error - DA	●(red)_○_●(red)_○_●(red)_○_
Hardware Error - GA	●(red)_●(blue)_●(red)_●(blue)_●(red)_●(blue)_
Hardware Error - PA	●(red)_●(yellow)_●(red)_●(yellow)_●(red)_●(yellow)_
Hardware Error - UA	●(red)_●(magenta)_●(red)_●(magenta)_●(red)_●(magenta)_

8.5 Technical Drawing



9 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. APDMequipment 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).

10 Troubleshooting

APDM is pleased to assist you with any issues you encounter using our products or questions you have about using our products.

Please contact us at:
web: support.apdm.com
email: support@apdm.com