



User's Guide

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1 Welcome

The Mobility Lab System is designed for the fast and easy capture of human motion within a clinical setting.

This guide will provide assistance on how to:

- Set up your hardware
- Use the Mobility Lab software to collect data
- Place the sensors on your subjects
- Upload data to the central data server
- Update your system
- Troubleshoot problems

2 System Overview

The Mobility Lab system allows the user to wirelessly record human movement from multiple, synchronized monitors.

The screenshot shows the Mobility Lab user interface. On the left, there is a sidebar with three main sections: 'Current Selection' (highlighted in blue), 'Hardware Configuration Status' (highlighted in red), and 'System Actions' (highlighted in green). The 'Current Selection' section displays details for the 'Mobility Lab Study', including 'Subject Public ID' (S01), 'Session Start Date' (Sun Jan 16 23:01:26 PST 2011), 'Test Type' (TUG), and 'Test Condition' (Default). The 'Hardware Configuration Status' section shows 'System Status' as 'Unconfigured'. The 'System Actions' section includes buttons for 'Configure' and 'Upload Data'. The main area features a tabbed interface with 'Setup', 'Studies', 'Subjects', 'Sessions', and 'Trials'. The 'Subjects' tab is active, displaying a table titled 'Subjects for study: Mobility Lab Study' with columns for 'Public ID', 'Control', and 'Year of Birth'. The table contains four rows of data. Below the table are buttons for 'Add Subject', 'Delete Subject', and 'Edit Subject'. A green box highlights the table and these buttons, labeled 'Data Entry and Navigation'.

Public ID	Control	Year of Birth
S01	true	1956
S02	false	1963
S03	false	1954
S04	false	1972

The Mobility Lab user interface

2.1 Mobility Lab Software

The Mobility Lab Software is used to configure your hardware and record your movement data. It also provides a simple interface for entering and editing meta-data, viewing your recordings, generating reports, and more.

- The Current Selection component of the interface provides information about the study, subject, session, and test that is currently selected.
- The Hardware Configuration Status indicates whether the hardware has been successfully configured for recording.
- The System Actions component of the interface provides easy access to system-wide actions such as configuration and data upload.
- The Data Entry and Navigation component uses a tab based table to navigate, edit, and collect data.

2.2 Movement Monitors



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

2.3 Docking Station



The docking station is used to charge and configure the movement monitors. Depending on your configuration, you may have up to 6 docking stations chained together into a single unit.

2.4 Access Point



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

3 Installing Mobility Lab

Mobility Lab is supported on the following platforms:

- Windows 32-bit (XP, Vista, Windows 7)
- Windows 64-bit (Vista, Windows 7, Windows 8)
- Mac OSX 64-bit

Locate the thumb drive or CD-ROM that was shipped with your system. This drive contains the Mobility Lab software in addition to 3rd party software that is required for automated analysis and reporting. The contents of the drive are shown below. Open the folder the corresponds to your operating system.

- MobilityLab_UserGuide.pdf (this document)
- Win32
 - MobilityLab_Setup_Win32.exe
 - vcredist_x86.exe*
 - MCRInstaller_Win32.exe*
 - basic-miktex-2.9.3927.exe*
- Win64
 - MobilityLab_Setup_Win64.exe
 - vcredist_x64.exe*
 - MCRInstaller_Win64.exe*
 - basic-miktex-2.9.3927.exe*
- MacOSX
 - MobilityLab_Mac64.dmg
 - MCRInstaller.dmg*

(* needed for analysis and report generation)

Note: You can download the Mobility Lab installer from <http://share.apdm.com/mlab>. The latest release of Mobility Lab for the different supported platforms can be found in the **release** folder. You will need to contact a support engineer for the login/password at support@apdm.com. The 3rd party software can be downloaded from <http://share.apdm.com/3rdParty>. No password is required.

3.1 Installing on Windows (32 and 64-bit)

Double click on the Mobility Lab setup file. This will guide you through *most* of the installation process.

Note: In Windows 8, when you launch the installer you will see a dialog indicating “Windows protected your PC” along with a “More info” link and an “OK” button at the below. This behavior is expected. Click on the “More info” link and select “Run anyway”.

Note: If you see a Windows User Account Control dialog asking “Do you want to allow the following program from an unknown publisher to make changes to this computer”, select “Yes”.

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

3.1.1 Windows XP USB Peripheral Behavior

Windows XP will prompt you with the “Found New Hardware” wizard every time you plug an access point or docking station into a USB port for the first time. This happens even if you have already installed it on a different port, and may even happen if you have already installed it on the same port. This is a “feature” of Windows XP and not an issue in Vista or Windows 7/8. If you have a chain of multiple docking stations, you will be prompted for each one.

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

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

The above steps are sufficient for data collection. In order to locally perform analysis and reporting, however, certain 3rd party software applications need to be installed.

3.1.2 Installing 3rd Party Windows Software

- Run the vcredist installer. This installs certain Microsoft tools required by the Matlab runtime.
- Run the MCRInstaller. This installs the Matlab runtime on your computer, which is needed for local analysis and report generation. **Note:** If you receive an error at the end of the installation indicating “Error 1904. Module ...\\mwcommgr.dll failed to register”, you may have to reboot your computer and start the MCRInstaller again.
- Run the MikTex installer. When prompted:
 - Specify that it be a shared installation (all users)
 - Use the default installation directory

- Choose “Letter” as the preferred paper size
- Select “Yes” for “Install missing packages on-the-fly”

We are actively working to remove Mobility Lab’s dependence on this 3rd party application so that this step will not be necessary in the future.

3.2 Installing on Mac OSX

- Double click on the MobilityLab_Mac64.dmg archive
- Drag the Mobility Lab application icon into the Applications shortcut displayed within the same Finder window. You can alternately drag it into your Applications folder in the Finder sidebar panel.

This is sufficient for data collection. In order to locally perform analysis and reporting, however, certain 3rd party software applications need to be installed.

3.2.1 Installing 3rd Party Mac OSX Software

- Run the MCRInstaller. This installs the Matlab runtime on your computer.
- Download and install the MacTeX package at <http://mirror.ctan.org/systems/mac/mactex/MacTeX.pkg>. This package is 2.1G in size, so make sure you have a good internet connection. We are actively working to remove Mobility Lab’s dependence on this 3rd party application so that this step will not be necessary in the future.

4 Setup

4.1 Hardware Setup

1. Plug in the Mobility Lab computer and turn it on. Wait for it to fully start up.
2. Grab a USB cable with a type-B (large, boxy) connector and plug it into the access point.
3. Plug the access point into an your computer (the computer in your kit may be a different model than the one pictured in the figure). You should see the light on the access point turn solid green.



4. If multiple docking stations are chained together, you must plug the external power adapter into the docking station. You should see the the lights on each docking station turn yellow when power is applied.
5. Grab a USB cable with a micro (small, flat) connector and plug it into your docking station. If you are using a USB hub, make sure that it is a USB 2.0 High Speed or USB 3.0 hub and that it has external power. The LEDs on the docking station(s) should turn to solid green when they are recognized by the computer.



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



4.2 Starting Mobility Lab

1. To start Mobility Lab, double-click on the “Mobility Lab” shortcut on the computer’s desktop, task bar, or start menu.



4.3 System Configuration

Click on the “Setup” tab to view your configuration options

1. Basic configuration
 - a) **Body Site:** Check the boxes next to the body sites you wish to record from.
 - b) **Monitor IDs:** For each body site you are recording from, you must specify the ID of the monitor you will place on that location. The monitor ID is a unique number found on the back of each monitor. For body sites with left/right options (e.g., Legs), you must specify a monitor for both the left and right.
 - c) **Measures:** Recording from different body sites enables the calculation of different movement measures. This column displays the measures that correspond to each body site and the test type(s) that provide these measures.
2. Advanced configuration

Movement Monitor Setup

Body Site	Monitor IDs		Measures (Instrumented Tests)
	Left	Right	
<input type="checkbox"/> Head			Turning (ITUG, ISAW, IWalk), Sit-to-Stand (ITUG), Turn-to-sit (ITUG)
<input type="checkbox"/> Trunk			
<input type="checkbox"/> Upper Arms			Arm (ITUG, ISAW, IWalk)
<input checked="" type="checkbox"/> Wrists	123	124	
<input checked="" type="checkbox"/> Lumbar		125	Turning (ITUG, ISAW, IWalk), Sway (ISway, ISAW)
<input type="checkbox"/> Thighs			
<input checked="" type="checkbox"/> Shins	126	127	Gait (ITUG, ISAW, IWalk)
<input type="checkbox"/> Feet			

Advanced

Custom Monitor Setup	Recording Options	
<input checked="" type="checkbox"/> Custom #1 ID 128 Label Marker	Record Mode	Wireless Streaming
<input type="checkbox"/> Custom #2 ID Label	Wireless Channel	90
<input type="checkbox"/> Custom #3 ID Label	Button Mode	Mark Data
<input type="checkbox"/> Custom #4 ID Label	Enable Remote	<input checked="" type="checkbox"/>

Re-apply Last Configuration Apply New Configuration

The Setup Tab

- Record Mode:** For most applications, Mobility Lab will be run in wireless streaming mode, enabling the real-time capture of data in a laboratory or clinical environment. In some environments, however, it may be desirable to record data in the synchronized logging mode. See Section ?? for details about using Mobility Lab in the synchronized logging mode.
- Custom Monitor Assignments:** Use these options if your study requires collecting synchronized data from another movement monitor. This may be a different body site or even a location off of the body (e.g., a cane). When collecting data in the synchronized logging mode, an additional monitor can be configured as a data marker, enabling you to insert synchronized markers into your data to specify crop points, medication intake, or any other event.
- Wireless Channel:** Monitors transmit data in the 2.4 ghz wireless spectrum range. Channel zero corresponds to roughly 2.40 ghz, and channel 90 corresponds to roughly 2.49 ghz. Many other consumer electronic devices make use of radio frequencies in the 2.4 ghz spectrum, such as WiFi routers, cordless phones, and blue-tooth devices. Because of this, it's important to choose a channel that is not heavily in use by another device or you may experience wireless issues. The default channel for Mobility Lab is 90, because it is typically out of the range of most WiFi routers. If you experience wireless issues, the most common source of interference is from WiFi routers. You can determine the channel that your WiFi router is running on and determine its corresponding

frequency from the following URL: http://en.wikipedia.org/wiki/IEEE_802.11.

- d) **Enable Remote:** Mobility Lab supports an external remote for navigating a recording session. See Section 8 for details.
3. Once you are done choosing your configuration options, click the “New Configuration” button in the Configuration panel on the left side of the screen. This will create a new configuration and save it for future use. The status panel on the left of the screen should indicate “Ready”.
4. If you get an error indicating that the wrong monitors are docked, make sure the monitor IDs that are entered in the left column match those that are etched onto the back of the monitor cases.
5. After successful configuration, undock the monitors. In a few moments (~10 seconds), they should start blinking green in unison, indicating that they are synchronized. The access point should also start blinking green at this time, indicating a good wireless signal has been established.

4.4 Charging

The monitor’s batteries will charge whenever they are docked and the power supply is attached to the docking station. It is not necessary to have the computer on or the USB cable attached to charge the monitors. If they configuration status of the system is “Ready”, and the monitors have not been powered off (see the next item), the monitors will turn on and will be ready for more recording when they are undocked.

4.5 Powering Off

If the monitors are fully charged or you want to store them overnight or for a longer duration, you can power them off. To do so, dock the monitors you want to power off and click on the “Power Off” button. They will remain charging as long as they are docked, but will power off the next time they are undocked.

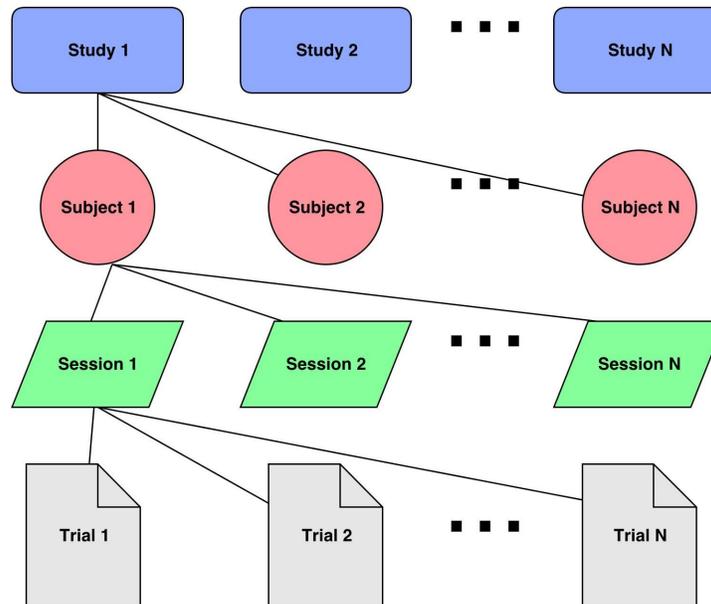
4.6 Re-applying your saved configuration

If you power off your monitors, reboot or put your PC to sleep, or unplug the access point, you will have to re-apply your saved configuration before recording. If your monitors are already powered on, it is not necessary to have them docked when re-applying the configuration. This is useful, for example, if you already have a subject instrumented with a number of monitors and you close Mobility Lab, your PC reboots unexpectedly, or the access point is accidentally unplugged.

5 Managing Meta-data

Mobility Lab provides a simple interface for associating clinical and demographic meta-data with your recordings. The user interface is intended for multi-subject studies, and has a minimal design that is optimized for ease of use in order to minimize training time.

Meta-data captured by Mobility Lab is organized hierarchically using the following structure:



This structure is mirrored in the tab bar, which can be used to navigate and edit this meta-data hierarchy.



Mobility Lab does not have any fields that are considered protected health information (PHI), simplifying the security safeguards that need to be implemented.

Entry of data is kept at a minimum, while providing enough meta-data for your recordings to facilitate downstream analysis.

and notes can be edited in the same way.

- You can generate session level reports of the session's trials by selecting (single-clicking) a session from the table, and clicking on the "PDF" button. This button will be disabled if there are no recorded trials for the session.
- The current status of the session (Not Started, Incomplete, Complete, Valid, or Invalid) is indicated in the last column of the table. It is considered complete when all of the session's trials have been completed.
- To view the trials associated with a specific session (drill-down), you can either:
 - Select (single-click) the session in the table, then click on the "Trials" tab
 - Double-click on the session in the table.

5.4 Trials

Trials for session started on Fri Apr 19 11:11:10 PDT 2013

Trial	Condition	Notes	Status	Date	Include in Analysis
ITUG trial 1	default		Valid	Fri Apr 19 11:11:10 PDT 2013	Yes
ISway trial 1	default		Not Started		

Trial Actions

Start Add Import Edit Delete Plot PDF Validate Export

- Trials represent a recording of a specific test. For example, a single session may include 2 ITUG trials, 1 ISway trial, and 3 IWalk trials.
- You can add additional trials to the current session by clicking on the “Add” button.
- To start a trial, click on the “Start” button. See Section 7 for more information.
- The trial notes can be edited by selecting the desired trial in the “Trials” table and clicking on the “Edit” button on the bottom of the screen.
- You can generate a raw data view by selecting (single-clicking) a trial from the table, and clicking on the “Plot” button. This button will be disabled if the trial has not yet been recorded.
- You can generate trial level reports by selecting (single-clicking) a trial from the table, and clicking on the “PDF” button. This button will be disabled if the trial has not yet been recorded.
- The current status of the trial (Not Started or Recorded) is indicated in the last column of the table.

6 Instrumenting the Subject

Testing requires 6 different sensors to be placed on the subject:

- Left and right wrists (monitors with velcro strap attachments)



- Left and right ankles (monitors with velcro strap attachments)



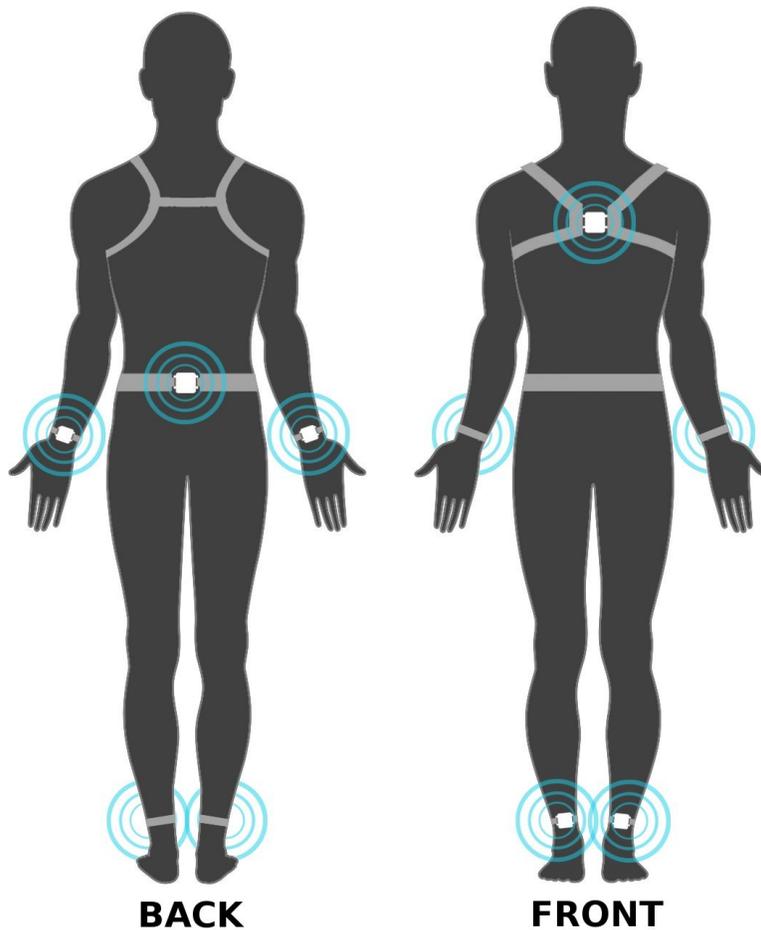
- Trunk (monitor with the chest holster)



- Lumbar (monitor with the elastic belt attachment)



Use the following visual guide and written tips for instrumenting the subject with the monitors:



- Before placing the monitors on the subject, check to make sure that:
 - The “System Status” indicator on the left panel in Mobility Lab says “Ready”
 - The LED on the access point is blinking green, indicating a good wireless signal.
 - The LEDs on the monitors are all blinking green in unison, indicating that they are synchronized.
- As a rule of thumb, the LED on each monitor should be oriented in the top left corner after it is placed on the subject. For the wrist monitors, this should hold true when the subjects arms are down at their side.



- The wrist monitors should be worn on the top of the wrist and underneath any clothing, as a wrist watch would be.
- The ankle monitors should be worn on the front of the ankles and underneath any clothing.
- The shoulder harness and belt can be worn over clothing.

7 Testing

Testing is the process of:

1. Selecting a trial to complete
2. Providing instruction to the subject, such that the test can be completed in specific way
3. Recording the trial

7.1 Current Selection

The current selection is always displayed in the upper left panel.

Current Selection

Study Name
Mobility Lab Study

Subject Public ID
S02

Session Creation Date
Mon Dec 10 23:25:01 PST 2012

Test Type
ISway

Test Condition
default

By default, the first incomplete trial from the first subject in the first study is selected. You can use the tabs at the top of the Mobility Lab interface to navigate the different levels of this selection.



7.2 Selecting a Trial

In order to change the current selection, start by pressing the study tab in the Mobility Lab workspace.



Double-click on the active study to drill-down to the list of subjects for the study. Repeat this process to select the desired session and trial. Use the “Add” button at any level to create a new subject, session, etc. See Section 5 for more information on managing study meta-data and adding new sessions or trials.

7.3 Starting the Trial

Once you have selected the trial you wish to record, either double-click on it, or press the “Start Trial” button to continue.

7.4 Subject Instructions Dialog

After starting the trial, the subject instructions dialog will first be presented. These are not typically the full set of instructions for the subject, but rather some key reminders that could be read aloud to the subject before each trial.

Subject Instructions for ISway test

Stand quietly with your arms folded across your chest. Look straight ahead at a fixed object and remain still without talking or moving. You should stand naturally, not rigidly. Remain in this stance until you hear the tone or are told the test is complete.

Options

 Enable Remote
 Enable External Sync

Annotations

#1 Freezing of gait

#2 Loss of balance



Exit



Subject Video



Record

The current test is ISway trial 1. The next test is ISway trial 2.

Along the bottom of the subject instructions dialog, there are three buttons: “Back”, “Subject Video”, and “Record”.

7.4.1 Back Button

The “Back” button will cancel the recording of the trial and will take you back to the “Trials” table in Mobility Lab.



7.4.2 Subject Video Button

The “Subject Video” button will play a short video for the subject to watch. This video should be viewed before the first trial is performed, and can be repeated for additional trials if it is believed the subject needs additional instruction.

Note: not all test types will have video instruction available. If a specific test does not have video available, then the “Subject Video” button will not become enabled.



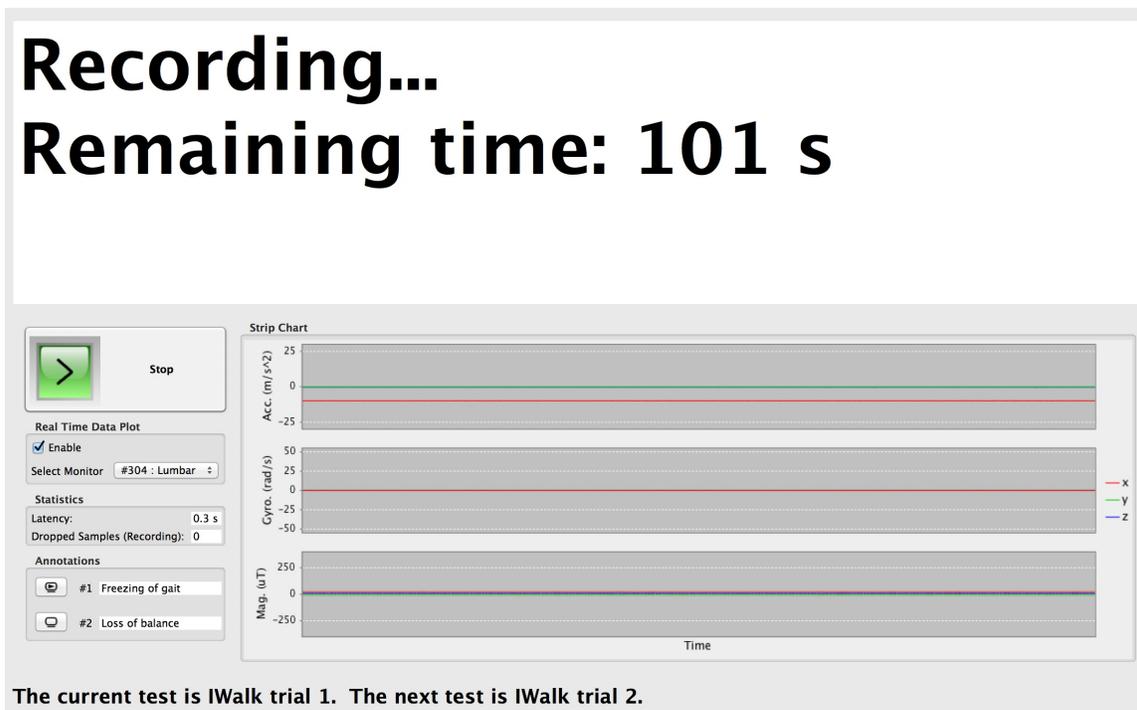
7.4.3 Record Button

When the subject instruction dialog is first opened, the system is working in the background to prepare for recording. Because of this, the “Record” button does not become enabled right away. After it has become enabled (this typically takes less than 10 seconds), clicking on the “Record” button will start the trial by opening the recording dialog and initiating the recording of data.



7.5 The Recording Dialog

While the recording dialog is open, data is being recorded wirelessly from the monitors being worn by the subject.



7.5.1 Quiescent Countdown

Some test types (e.g., TUG) require a brief countdown to collect baseline data, during which the subject is asked to stand or sit quiescently. Other test types (e.g., Sway) start immediately after pressing the record button in the subject instructions dialog. This type of countdown will be indicated by a red font type.

7.5.2 Stopping the Recording

Some test types (e.g., TUG) are indeterminate in length, and require that the test administrator click on the green “Stop” button to end the recording. Other test types (e.g., Sway) are fixed length, and will stop automatically once the recording duration has completed. Either type of test can be stopped prematurely by pressing the “Stop” button.



7.5.3 The Real-Time Data Plot

The real-time data plot provides a view of the raw data as it is being recorded. This can provide a visual indication that the data is being collected as expected. For tests that require multiple monitors, you can use the “Select Monitor” combo box to choose among the various monitors in your setup.

7.5.4 Latency

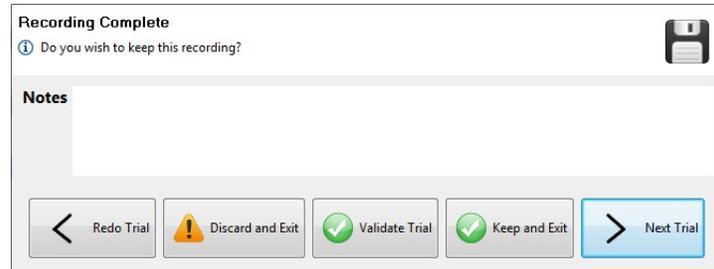
Typical latency for the wireless streaming of data is between 0.2-0.4 s. It is possible, however, that the latency may increase beyond this value. Some cases where this may occur are:

- Crowded wireless spectrum. The 2.4 GHz spectrum that the Mobility Lab system uses for wireless transmission is also used by numerous other consumer and industrial electronic devices such as cordless phones, computer WiFi networks, and Bluetooth devices.
- Poor wireless signal. It is recommended that there is clear line-of-sight between the access point and the instrumented subjects. The face of the access point should be pointing, as much as possible, towards the area the subject will occupy during testing.
- Obstruction. Sometimes, one or more monitors will become obstructed during the trial. For example, this may happen while the subject crosses their arms during a Sway test, or the back of a chair may block the signal from a monitor work on the lumbar region.

In most cases, some additional latency will not be a problem. The data is buffered to the monitors while recording, and will stream wirelessly once the obstruction has been removed. It is, however, important to have a clean signal at the time the system is preparing for recording. This happens when the subject instruction dialog is first opened and before the “Record” button is enabled. It is important during this time to have the access point directed at the subject, and to have all of the monitors unobstructed.

7.6 Saving Trial Data

After a trial has ended (either automatically for fixed duration recordings or by pushing the “Stop” button), you will be presented with the confirmation dialog.



In this dialog, you can:

- Add notes that may be relevant for future analysis of the raw data. These notes can also be added or edited from the “Trials” table in Mobility Lab.
- Redo the trial you just recorded.
- Discard the trial you just recorded and return to the “Trials” tab in Mobility Lab.
- Validate the trial you just recorded. For more information about validation, see Section 9.
- Keep the trial you just recorded and return to the “Trials” tab in Mobility Lab.
- Keep the trial that you just recorded and continue to the next trial. This option is not available for the last trial of the session.
- Validate the entire session and return to the “Trials” tab in Mobility Lab. This option is available for the last trial of the session.

8 Remote Control

Mobility Lab supports the use of a remote control to aid while collecting data. This functionality makes it possible for a single attendant to collect all of a session's data while following and possibly assisting the subject.

8.1 Supported Remotes

Mobility Lab has been designed to use a standard presentation remote intended for navigating a slide presentation. Our preferred remote is the Logitech R400, but other presentation remotes will most likely work out of the box because the buttons are typically standardized.

8.2 Enabling the Remote

Enabling and disabling the remote can be performed in both the configuration tab and in the Subject Instructions screen prior to recording a trial. When the remote is enabled, on-screen buttons that are mapped to remote functionality will have their standard icons either overlaid or replaced by special remote icons. These icons are modeled after those on the Logitech R400 remote to make the mapping clear.



Examples of Mobility Lab button icons that map to remote control buttons

8.3 Supported Actions

The remote functionality is available on the following screens:

- The Trials tab (can be used to start the selected trial)
- The Subject Instruction screen (can be used to show the instructional video, cancel recording the trial, or start the recording)
- The Trial Confirmation dialog (can be used to redo the trial, go to the next trial, or exit back to the Trials tab with or without keeping the trial just recorded)

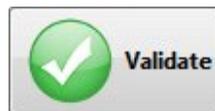
9 Validating Your Data

Mobility Lab's validation functionality enables you to determine which, if any, of your collected data is problematic for the analysis routines. This may be true if the data collected from a particular trial is aberrant and may be caused by:

- Placing the monitors incorrectly or on the wrong part of the body
- The subject did not follow instructions
- The subject had an event (e.g., a fall) during the trial
- The behavior of the subject during a trial was out of bounds (e.g., runs during the ITUG test instead of walks)
- A technical problem while recording

Other details about validation include:

- When you press the validate button, whatever is selected in the current tab is chosen for validation. Your data can be validated at any level: a single trial, a session, a subject, or an entire study.
- Trials will be labeled as either valid or invalid after the validation routine completes.
- A dialog will pop up if any trials fail validation. These files will be indicated.
- Validating the data provides an error message will provide information about the nature of invalid trials.



The Validate button

10 Reporting Your Data

Mobility Lab's report generation functionality enables you to generate reports in PDF format summarizing or detailing your data. When you press the report button, whatever is selected in the current tab is chosen for export. Your data can be exported at the trial, session, or subject level.

- There are several options when generating the report:
 - **Include gait variability section:** This section is available in the IWalk reports. It is recommended that you collect at least 2 minutes of walking to have accurate results.
 - **Include longitudinal plots:** Select this option if you want to show how measures vary for an individual subject over time.
 - **Include measure documentation:** Select this option if you want documentation about the measures to be embedded in the report. This helps make the reports self documenting.
 - **Include raw data plots:** Select this option if you want to have figures showing the raw inertial signals within the report. Detected events such as turns and gait cycles are indicated on these plots. This option can be useful for confirming results or troubleshooting analysis issues.
- You can click on the "Filters" button to reveal options for further refining the trials being reported.



The Report button

11 Importing and Exporting Your Data

11.1 Exporting Metadata, Analysis Results, and Raw Data



The Export button

Mobility Lab's export functionality enables you to export your study's metadata, analysis results, and even raw sensor data into a format appropriate for further analysis.

- When you press the export button, whatever is selected in the current tab is chosen for export. Your data can be exported at any level: a single trial, a session, a subject, or an entire study.
- In the export dialog, you can click on the “Filters” button to reveal options for further refining the trials being exported.
- Study metadata (e.g., subject information, trial notes, etc.) are exported in XML format. This is a plain text data format that can be opened in any text editor or web browser.
- Analysis results are exported using the comma separated value (CSV) format. This format can easily be read by 3rd party analysis software such as Excel and Matlab. There are 3 types of CSV files that are exported:
 - **Trials Export:** These files are identified by the word “trials” in the file name and have one row dedicated to each trial being exported. One such Trials file is created for each test type (e.g., IWalk) represented in the export.
 - **Sessions Export:** These files are identified by the word “sessions” in the file name. These are similar to the Trials export file, except some trials are merged together into a single row using the following rule: if there are multiple trials of the same condition within the same session (e.g., 3 “default” IWalk trials), the median value of these trials will be reported. This is important in some studies where multiple, repeated trials are desirable in order to make the results more robust to outliers. One such Sessions file is created for each test type represented in the export. If there are no repeated trials in any of your sessions, the Trials and Sessions exports will be the same.
 - **Trial Detail Export:** For some measure types, such as gait and turning, there may be repeated values within one trial. For example, most of the gait measures will have one value for each detected gait cycle. In the Trials and Sessions export types, the mean of these repeated values is reported. In the Trial Detail reports, however, values for each gait or turn cycle are reported, along with the time of the gait and turn events. This level of detail is may be necessary for some types of downstream analysis. One Trial Detail CSV file is generated for each trial with these repeated measures.

- If desired, all of the raw data can be exported as well (see Section 22 for details on how to work with the raw sensor data). If raw data is exported in conjunction with the associated metadata, the exported data can be re-imported into another Mobility Lab workspace.
- If you choose to compress the export, your export will be archived in the zip format.

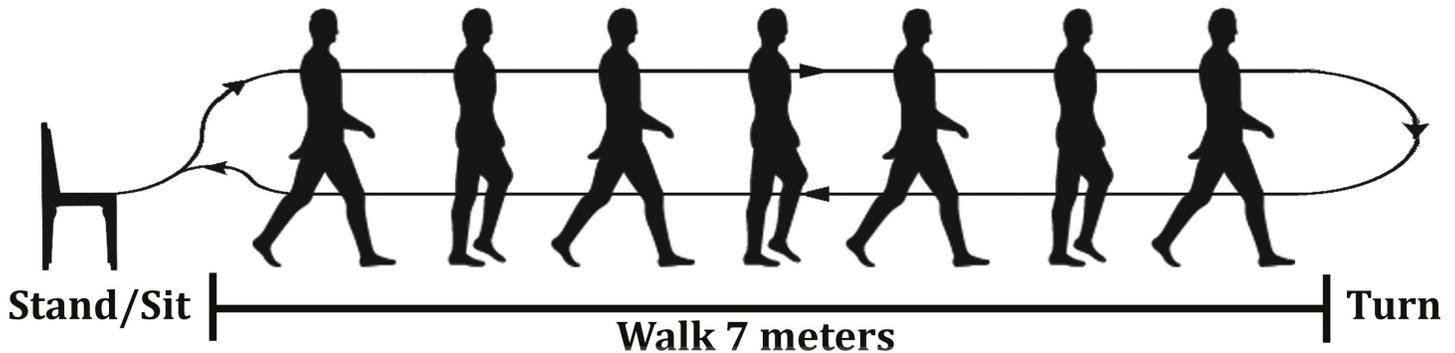
11.2 Importing Metadata and Raw Data

If you choose to export both the metadata and raw data from your study, subject, session, or trial, you can import these data into another Mobility Lab installation at a later date. This can be used for recovery purposes or for sharing data with other Mobility Lab users or technical support. To import data that has been previously exported, click on the **Tools**→**“Import Mobility Lab Data”** option in the menu bar. When prompted to select an XML metadata file, navigate to your export directory and choose the XML file that was exported. If there is associated raw data, make sure that the “rawData” folder that is generated during export is within the same folder as the XML metadata file (as it is when exported). If you opted to compress your export, you must first uncompress it before you can import the data.

11.3 Backing Up and Restoring Your Workspace

If you wish to back up your entire Mobility Lab Workspace (i.e., all of your Studies, Subjects, etc.), click on the **Tools**→**“Backup Mobility Lab Workspace”** option in the menu bar. This will create a complete backup of your workspace’s metadata and raw data, such that it can be restored into another workspace or installation. This is a convenience method and equivalent to exporting each study individually (without the analysis results). To import data from a backup, click on the **Tools**→**“Import Mobility Lab Data”** option in the menu bar.

12 The Instrumented Timed Up and Go (ITUG) Test



12.1 Monitor Placements and Measures

- Trunk: Turning, sit-to-stand, turn-to-sit, trunk range of motion (RoM)
- Wrists: Arm RoM during gait
- Lumbar: Turning (if trunk monitor is not present)
- Shins: Lower body gait
- **Note:** You can include additional body sites in your configuration, they just won't be used in the ITUG analysis.

12.2 Test Environment Setup

- Measure a 7 meter walkway, with significant space on either side
- Mark the start and finish of the walkway with colored tape on the floor
- Place a chair without arms or swivel at the start of the walkway, just behind the marked tape.
- Ensure that the computer screen is out of the subject's line of sight during testing.

12.3 Subject Attire

- The subject should wear clothing that does not bind or impede their movement in any significant way.
- The subject should wear comfortable walking shoes (i.e., no high-heels or flip-flops). If the subject does not have appropriate shoes, please have them walk barefoot (no socks) and **MAKE A NOTE** in the comments section of either the session or each TUG trial.

Before clicking on the “Start Trial” button, make sure that:

- The LED on the access point is blinking **green**, indicating a good wireless signal.



GOOD FOOTWEAR



BAD FOOTWEAR



If the access point is blinking **red** or **green-red**, you may not have a good wireless signal or one of the monitors may be obstructed. For example, it is possible that the chair being used is blocking the wireless signal from the lumbar monitor. If this is true, get a different chair that has an open lower back area and/or reposition the access point to get a better signal.

12.4 Instructing the Subject

After clicking on the “Start Trial” button in Mobility Lab, you will be presented with the subject instruction dialog and the following written instructions:

- “When I say ‘Walk’, stand up from the chair, walk to the line, turn around, walk back, and sit down. After you sit back down, sit quietly until you hear the tone or are told the test is complete. Walk at a natural and comfortable pace, looking straight ahead. Try not to use your hands to assist yourself during standing or sitting.”

Note: If the subject is unable to go from sit-stand in a safe manner, they should use their hands, but a NOTE in the comments section should be made.

The first time the subject takes the test, they should view the video instructions by clicking on the “Subject Video” button.



12.5 Before Recording the Trial

Prior to recording the trial, verify that the subject:

- is relaxed
- has his/her back is against the chair
- has his/her feet are on the ground behind the start line.
- has his/her hands are in their lap

12.6 Recording the Trial

- To begin recording, press the “Record” button or press the enter key.



- The time counter will start counting downwards on the record dialog (3..2..1..) as the baseline data is collected. Please ensure that the patient is motionless during this time.
- When the countdown is complete, the test administrator should say “Walk”.
- During the test the examiner should be “Spotting” the patient as needed (for safety) by walking slightly to the side and behind the subject so as not to affect their pace.
- When the patient has returned and is sitting with his/her back against the chair, press the “Stop button.
- The system will continue collecting data for 3 seconds. Please ensure that the patient is motionless during this time.
- The computer will then confirm that the trial has ended by closing the testing window and displaying the confirmation dialog. Here, you can enter any notes about the recording, if necessary. Choose to either keep or discard the recording.
- If a subject error occurs during the trial, such as:
 - Incompletion of the course.
 - The subject uses his/her hands during sit-stand or stand-sitnot due to necessity.
 - The subject does not fully cross the line.
 - The subject makes an incorrect turn (goes around the line, instead of across).
- The examiner can press the “Stop button, stopping the trial in the middle of testing. The examiner should then inform the subject of the error and how to correct it. If it is believed that the subject can complete the trial successfully, then the trial should be re-done.
- The subject instructions visible in the dialog box should be read aloud to the subject on each subsequent TUG trial (within reason) to ensure that the proper behavior is enforced for each trial.

12.7 ITUG Measure Definitions

The ITUG analysis algorithms automatically processes recorded movement data and provide objective measures related to four major components of the tests: turning, gait, sit-to-stand and turn-to-sit.

The primary outcomes in each table are highlighted by bold text. These measures might be of primary interest for clinical applications. Researchers might be interested in both primary and secondary outcomes.

12.7.1 Timed Up And Go

The total time of the timed up and go test is calculated in one of two ways:

1. If the trunk sensor is present and the sit-to-stand and turn-to-sit events are both detected, the total test time is defined as the period between the initiation of sitting up to the termination of sitting back down.
2. If the sit-to-stand and turn-to-sit events are not detected, the total test time is defined as the period between the pressing of the record button and the stop button. The 3-second rest period at the beginning and end of the test are subtracted from this total.

Measure	Unit	Description
Total Time	Time (seconds)	The total time of the timed up and go test.

12.7.2 Sit To Stand

Sit-to-Stand transition is detected and assessed using the signals from the trunk sensor [5].

Measures	Unit	Sensors	Description
SiSt Duration	Time (seconds)	Trunk	Duration of sit-to-stand. Measured according to the mathematical model of sit-to-stand transition.
Peak SiSt Velocity	Degrees / second	Trunk	Peak (95%) angular velocity of trunk in the sagittal plane during sit-to-stand transition.
RoM Trunk	Degrees	Trunk	RoM of trunk in the sagittal plane during sit-to-stand transition.

12.7.3 Gait

Gyroscopes attached on the shanks are used to detect the basic gait events, i.e. time feet hit the ground and leave the ground (initial and terminal contacts). Temporal gait measures are then calculated based on the time of gait events. In the next step, ranges of motions (RoM) of the shank segments are estimated by integrating the gyroscopes signals. Finally, spatial gait measures are estimated using a biomechanical model [6]. Gait measures are reported for individual gait cycles in the CSV export. A gait cycle is defined as

the period between two consecutive initial contacts (heel-strike) of the right foot.

Spatial gait measures

Measures	Unit	Sensors	Description
Stride Length	% of Subjects body height*	Shanks	Distance between two consecutive foot falls at the moments of initial contacts. Averaged for left and right side. The value is normalized for height.
Stride Length R	% of Subjects height*	Shanks	Distance between two consecutive right foot falls at the moments of initial contacts
Stride Length L	% of Subjects height*	Shanks	Distance between two consecutive left foot falls at the moments of initial contacts
Stride Velocity	% of Subjects height / second*	Shanks	Walking speed. Average of the right and left sides.
Stride Velocity R	% of Subjects height / second*	Shanks	Walking speed of right leg
Stride Velocity L	% of Subjects height / second*	Shanks	Walking speed of left leg

*Values are given relative to the subject's body height to enable comparison to normative data. If the subject's height is entered through Mobility Lab, then values will additionally be provided in units of meters.

Temporal gait measures

Measures	Unit	Sensors	Description
Cadence	Steps / minute	Shanks	Stepping rate
Gait Cycle Time	Time (seconds)	Shanks	Duration of a complete gait cycle
Double Support	% of GCT	Shanks	Percentage of a gait cycle that both feet are on the ground
Swing	% of GCT	Shanks	Average percentage of a gait cycle that either foot is off the ground
Swing R	% of GCT	Shanks	Percentage of a gait cycle that right foot is off the ground
Swing L	% of GCT	Shanks	Percentage of a gait cycle that left foot is off the ground
Stance	% of GCT	Shanks	Average percentage of a gait cycle that either foot is on the ground
Stance R	% of GCT	Shanks	Percentage of a gait cycle that right foot is on the ground
Stance L	% of GCT	Shanks	Percentage of a gait cycle that left foot is on the ground
Initial Contact R	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that right foot hits the ground. Sometimes referred to as heel-strike.
Terminal Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that right foot leaves the ground. Sometimes referred to as toe-off.
Initial Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that left foot hits the ground.
Terminal Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that left foot leaves the ground.

Ranges of motions (RoM) and angular velocities

Measures	Unit	Sensors	Description
Shank RoM	Degrees	Shanks	RoM of shanks; averaged of the left and right sides.
RoM Shank R	Degrees	Shanks	RoM of right shank.
RoM Shank L	Degrees	Shanks	RoM of left shank.
Peak Shank Velocity	Degrees / seconds	Shanks	Peak (95%) angular velocity of shanks. Average of the left and right sides.
Peak Shank Velocity R	Degrees / seconds	Shanks	Peak (95%) angular velocity of right shank.
Peak Shank Velocity L	Degrees / seconds	Shanks	Peak (95%) angular velocity of left shank.
Peak Arm Velocity	Degrees / second	Shanks + Arms	Peak (95%) angular velocity of arms. Average of the left and right sides.
Peak Arm Velocity R	Degrees/ second	Shanks + Arms	Peak (95%) angular velocity of right arm. Measured as the norm of 3D angular velocity vector.
Peak Arm Velocity L	Degrees/ second	Shanks + Arms	Peak (95%) angular velocity of left arm. Measured as the norm of 3D angular velocity vector.
Arm-Swing Velocity Asymmetry	%	Shanks + Arms	Asymmetry of left/right arm-swing angular velocity. Defined as the difference between the two sides as percentage of the fastest side.
Arm RoM	Degrees	Shanks + Arms	RoM of arms during arm-swing. Average of the left and right sides.
RoM Arm R	Degrees	Shanks + Arms	RoM of right Arm. Measures as the norm of 3D arm rotation vector.
RoM Arm L	Degrees	Shanks + Arms	RoM of right Arm. Measures as the norm of 3D arm rotation vector.
Trunk Sagittal RoM	Degrees	Shanks + Trunk	RoM of trunk in sagittal plane.
Trunk Horizontal RoM	Degrees	Shanks + Trunk	RoM of trunk in horizontal plane.
Trunk Sagittal Peak Velocity	Degrees /second	Shanks + Trunk	Peak angular velocity of trunk in sagittal plane.
Trunk Horizontal Peak Velocity	Degrees / second	Shanks + Trunk	Peak angular velocity of trunk in horizontal plane.

12.7.4 Turn

Turning is detected and assessed based using gyroscopes within the trunk or lumbar sensor. A mathematical model is used to detect the exact moment of beginning and end of turning [4].

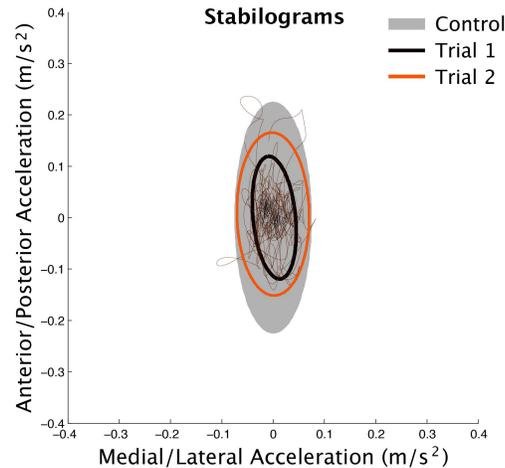
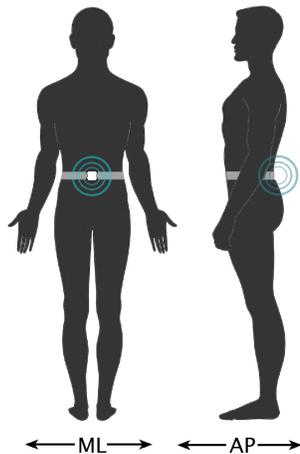
Measures	Unit	Sensors	Description
Turning Duration	Time (seconds)	Trunk	Duration of 180 turn. Measured according to the mathematical model of turning.
Number of Steps	Number	Shanks + Trunk	Number of steps during 180 turn. Steps which are at least 50% within turning period are counted.
Peak Turning Velocity	Degrees / second	Trunk	Peak (95%) angular velocity of trunk during turning.
Step time	Time (seconds)	Shanks + Trunk	Average step duration during turning.
Step time before turn	Time (seconds)	Shanks + Trunk	The last step duration right before the turn.

12.7.5 Turn To Sit

Turn-to-Sit movement is a combination of turning and stand-to-sit transition. Related measures are extracted by combining models of the two previous activities.

Measures	Unit	Sensors	Description
TurSit Duration	Time (seconds)	Trunk	Duration of turn-to-sit transition. Measured according to the mathematical model of turn-to-sit transition.
Peak TurSit Velocity	Degrees / second	Trunk	Peak (95%) angular velocity of trunk during turn-to-sit transition.
TurSit RoM	Degrees	Trunk	RoM trunk in the sagittal plane during turn-to-sit transition.

13 The Instrumented Sway (ISway) Test



13.1 Monitor Placements and Measures

- Lumbar: Sway
- **Note:** You can include additional body sites in your configuration, they just won't be used in ISway analysis.

13.2 Test Environment Setup

- Locate a clear area that is 1-4 meters from a wall.
- Place a picture at head height on the wall. The subject will be instructed to look at this picture in order to maintain their balance and focus.
- Place the foot block (included with the Mobility Lab kit) on the floor where the subject will stand.
- Ensure that the computer screen is out of the subject's line of sight during testing.

Before clicking on the "Start Trial" button, make sure that:

- The LED on the access point is blinking **green**, indicating a good wireless signal.

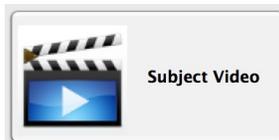
If the access point is blinking **red** or **green-red**, you may not have a good wireless signal or one of the monitors may be obstructed. For example, it is possible that the subject's crossed arms are covering a wrist or trunk monitor. If this is true, reposition the arms and/or access point to get a better signal.

13.3 Instructing the subject

After clicking on the “Start Trial” button in Mobility Lab, you will be presented with the subject instruction dialog and the following written instructions:

- “Stand quietly looking at the picture in front of you. Each trial will take 30 seconds and you will have your arms comfortably over your chest. You should stand naturally, not rigidly, but do not talk or move your arms.”

The first time the subject takes the test, they should view the video instructions by clicking on the “Subject Video” button.



13.4 Before recording the trial

Prior to recording the trial, verify that the subject:

- has his or her arms crossed across their chest in a comfortable manner
- is looking at the picture on the wall

13.5 Recording the trial

- To begin recording, press the “Record” button or press the enter key.



- Recording will begin immediately, and a 30 second countdown will begin.
- After the 30 second trial has completed, it will stop automatically.
- The computer will then confirm that the trial has ended by closing the testing window and displaying the confirmation dialog. Here, you can enter any notes about the recording, if necessary. Choose to either keep or discard the recording.
- If a subject error occurs during the trial, such as:
 - Begins to talk
 - Stumbles accidentally

- The examiner can press the “Stop button, stopping the trial in the middle of testing. The examiner should then inform the subject of the error and how to correct it. If it is believed that the subject can complete the trial successfully, then the trial should be re-done.
- The subject instructions visible in the dialog box should be read aloud to the subject on each subsequent TUG trial (within reason) to ensure that the proper behavior is enforced for each trial.

13.6 ISway Measure Definitions

The ISway analysis algorithm automatically processes your ISway recordings and generates a number of measures related to sway in both the time and the frequency domains.

The primary outcomes are highlighted by bold text. These measures might be of primary interest for clinical applications. Researchers might be instructed in both primary and secondary outcomes (and note that there are planar, 2D measures as well as only medio-lateral or antero-posterior measures).

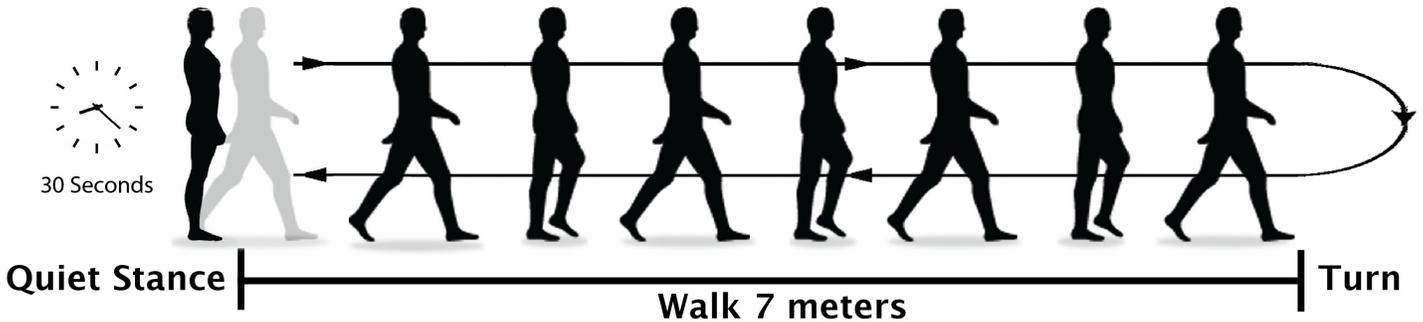
13.6.1 Sway

All sway measures are assessed using the 3-axial accelerometer from the lumbar sensor. In the following table, the sway trajectory refers to the path of the acceleration signal in the transverse plane (top view looking down) recorded from the lumbar monitor. All details are in Mancini M. et. al. [2].

Measures	Unit	Description
Jerk*	m^2/s^5	Smoothness of sway from the time derivative of the lumbar's acceleration
NJerk*	-	Normalized Jerk (normalized to the range of the sway trajectory's excursion and duration)
Time-Domain Measures		
Sway Area	m^2/s^5	Sway area, computed as the area included in the sway trajectory per unit of time
Area CC	m^2/s^4	Area of the 95% confidence circle encompassing the sway trajectory in the transverse plane
Area CE	m^2/s^4	Area of the 95% confidence ellipse encompassing the sway trajectory in the transverse plane
RMS*	m/s^2	RMS of the sway trajectory
MV*	m/s	Mean velocity of the lumbar's trajectory
Dist*	m^2/s^2	Mean distance of the lumbar's acceleration trajectory from the center of this trajectory
Path*	m^2/s^2	Total length of the lumbar's acceleration trajectory
Range*	m^2/s^2	Total range of the lumbar's acceleration trajectory
Frequency-Domain Measures		
Mean Frequency*	Hz	Mean sway frequency, calculated from the lumbar's acceleration trajectory length and duration (MF = PATH/(2 * π * DIST * trial duration))
Centroidal Frequency*	Hz	Frequency of sway from the centroid of the sway power spectrum
Frequency Dispersion*	-	Frequency dispersion
Total Power*	m^2/s^4	Total power
95% Frequency*	Hz	95% power frequency (frequency below which the 95 th percentile of total power (PWR) is present)
Median Frequency*	Hz	Median frequency (frequency below which the 50 th percentile of total power (PWR) is present)
High Frequency Power	Hz	Median frequency (frequency below which the 50 th percentile of total power (PWR) is present)
Median Frequency*	Hz	Median frequency (frequency below which the 50 th percentile of total power (PWR) is present)

**These measures are calculated for Anterior/Posterior (forward-backward) and Medial/Lateral (side-to-side) projections, in addition to the 2D transverse plane (top view looking down).

14 The Instrumented Stand and Walk (ISAW) Test



14.1 Monitor Placements and Measures

- Trunk: Turning, trunk range of motion (RoM)
- Wrists: Arm RoM during gait
- Lumbar: Sway, turning (if trunk monitor is not present)
- Shins: Lower body gait
- **Note:** You can include additional body sites in your configuration, they just won't be used in the ISAW analysis.

14.2 Test Environment Setup

- Measure a 7 meter walkway, with significant space on either side
- Mark the start and finish of the walkway with colored tape on the floor
- Ensure that the computer screen is out of the subject's line of sight during testing.

14.3 Subject Attire

- The subject should wear clothing that does not bind or impede their movement in any significant way.
- The subject should wear comfortable walking shoes (i.e., no high-heels or flip-flops). If the subject does not have appropriate shoes, please have them walk barefoot (no socks) and **MAKE A NOTE** in the comments section of either the session or each TUG trial.

Before clicking on the "Start Trial" button, make sure that:

- The LED on the access point is blinking **green**, indicating a good wireless signal.

If the access point is blinking **red** or **green-red**, you may not have a good wireless signal or one of the monitors may be obstructed. For example, it is possible that the subject's crossed arms are covering a wrist or trunk



GOOD FOOTWEAR



BAD FOOTWEAR



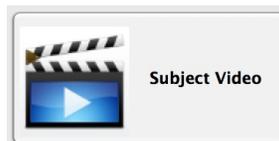
monitor. If this is true, reposition the arms and/or access point to get a better signal.

14.4 Instructing the Subject

After clicking on the “Start Trial” button in Mobility Lab, you will be presented with the subject instruction dialog and the following written instructions:

- “Start by standing with your arms at your side. Look straight ahead at a fixed object and remain still without talking or moving. You should stand naturally, not rigidly. When I say “Walk”, start walking forward at a natural and comfortable pace. When you cross the line at the end of the walkway, turn around, and start walking back. After you cross the line at the beginning of the walkway, stand with your arms by your side and look straight ahead until you hear the tone or are told the test is complete.”

The first time the subject takes the test, they should view the video instructions by clicking on the “Subject Video” button.



14.5 Before Recording the Trial

Prior to recording the trial, verify that the subject:

- has his or her arms comfortably by their side
- is standing behind the piece of tape at the start of the walkway

- is looking ahead at a fixed object or picture

14.6 Recording the Trial

- To begin recording, press the “Record” button or press the enter key.



- The time counter will start counting upwards. When it reaches 30s, the test administrator should say “Walk”.
- During the test the examiner should be “Spotting” the patient as needed (for safety) by walking slightly to the side and behind the subject so as not to affect their pace.
- When the patient has completed the turn, returned to the start tape strip, and is standing still, press the “Stop button.
- The system will continue collecting data for 3 seconds. Please ensure that the patient is motionless during this time.
- The computer will then confirm that the trial has ended by closing the testing window and displaying the confirmation dialog. Here, you can enter any notes about the recording, if necessary. Choose to either keep or discard the recording.
- If a subject error occurs during the trial, such as:
 - Incompletion of the course.
 - The subject uses his/her hands during sit-stand or stand-sit not due to necessity.
 - The subject does not fully cross the line.
 - The subject makes an incorrect turn (goes around the line, instead of across).
- The examiner can press the “Stop button, stopping the trial in the middle of testing. The examiner should then inform the subject of the error and how to correct it. If it is believed that the subject can complete the trial successfully, then the trial should be re-done.
- The subject instructions visible in the dialog box should be read aloud to the subject on each subsequent ISAW trial (within reason) to ensure that the proper behavior is enforced for each trial.

14.7 ISAW Measure Definitions

The Instrumented Stand and Walk (ISAW) analysis algorithms automatically processes recorded movement data and provide objective measures related to four major components of the test: sway, gait, anticipatory postural adjustments (APA), and turning.

The primary outcomes in each table are highlighted by bold text. These measures might be of primary interest for clinical applications. Researchers might be interested in both primary and secondary outcomes.

14.7.1 Step Initiation (APA)

All details are in Mancini M. et. al. [1].

Measures	Unit	Description
APA ML amplitude	m/ s ²	Peak acceleration toward the stance foot of the lateral trunk acceleration
APA AP amplitude	m ² / s ²	Peak trunk acceleration forward from baseline
APA Duration	Time (s)	Time from APA onset to end
First Step Latency	Time (s)	Time-to-peak angular velocity of the stepping leg from the APA onset
First Step Length	Degrees	Range of motion of the shank (calculated from the integrated sagittal angular velocity)

14.7.2 Turn

Turning is detected and assessed based using gyroscopes within the trunk or lumbar sensor. A mathematical model is used to detect the exact moment of beginning and end of turning [4].

Measures	Unit	Sensors	Description
Turning Duration	Time (seconds)	Trunk	Duration of 180 turn. Measured according to the mathematical model of turning.
Number of Steps	Number	Shanks + Trunk	Number of steps during 180 turn. Steps which are at least 50% within turning period are counted.
Peak Turning Velocity	Degrees / second	Trunk	Peak (95%) angular velocity of turnk during turning.
Step time	Time (seconds)	Shanks + Trunk	Average step duration during turning.
Step time before turn	Time (seconds)	Shanks + Trunk	The last step duration right before the turn.

14.7.3 Sway

All sway measures are assessed using the 3-axial accelerometer from the lumbar sensor. In the following table, the sway trajectory refers to the path of the acceleration signal in the transverse plane (top view looking down) recorded from the lumbar monitor. All details are in Mancini M. et. al. [2].

Measures	Unit	Description
Jerk*	m^2/s^5	Smoothness of sway from the time derivative of the lumbar's acceleration
NJerk*	-	Normalized Jerk (normalized to the range of the sway trajectory's excursion and duration)
Time-Domain Measures		
Sway Area	m^2/s^5	Sway area, computed as the area included in the sway trajectory per unit of time
Area CC	m^2/s^4	Area of the 95% confidence circle encompassing the sway trajectory in the transverse plane
Area CE	m^2/s^4	Area of the 95% confidence ellipse encompassing the sway trajectory in the transverse plane
RMS*	m/s^2	RMS of the sway trajectory
MV*	m/s	Mean velocity of the lumbar's trajectory
Dist*	m^2/s^2	Mean distance of the lumbar's acceleration trajectory from the center of this trajectory
Path*	m^2/s^2	Total length of the lumbar's acceleration trajectory
Range*	m^2/s^2	Total range of the lumbar's acceleration trajectory
Frequency-Domain Measures		
Mean Frequency*	Hz	Mean sway frequency, calculated from the lumbar's acceleration trajectory length and duration (MF = PATH/(2 * π * DIST * trial duration))
Centroidal Frequency*	Hz	Frequency of sway from the centroid of the sway power spectrum
Frequency Dispersion*	-	Frequency dispersion
Total Power*	m^2/s^4	Total power
95% Frequency*	Hz	95% power frequency (frequency below which the 95 th percentile of total power (PWR) is present)
Median Frequency*	Hz	Median frequency (frequency below which the 50 th percentile of total power (PWR) is present)
High Frequency Power	Hz	Median frequency (frequency below which the 50 th percentile of total power (PWR) is present)
Median Frequency*	Hz	Median frequency (frequency below which the 50 th percentile of total power (PWR) is present)

**These measures are calculated for Anterior/Posterior (forward-backward) and Medial/Lateral (side-to-side) projections, in addition

to the 2D transverse plane (top view looking down).

14.7.4 Gait

Gyroscopes attached on the shanks are used to detect the basic gait events, i.e. time feet hit the ground and leave the ground (initial and terminal contacts). Temporal gait measures are then calculated based on the time of gait events. In the next step, ranges of motions (RoM) of the shank segments are estimated by integrating the gyroscopes signals. Finally, spatial gait measures are estimated using a biomechanical model [6]. Gait measures are reported for individual gait cycles in the CSV export. A gait cycle is defined as the period between two consecutive initial contacts (heel-strike) of the right foot.

Spatial gait measures

Measures	Unit	Sensors	Description
Stride Length	% of Subjects body height*	Shanks	Distance between two consecutive foot falls at the moments of initial contacts. Averaged for left and right side. The value is normalized for height.
Stride Length R	% of Subjects height*	Shanks	Distance between two consecutive right foot falls at the moments of initial contacts
Stride Length L	% of Subjects height*	Shanks	Distance between two consecutive left foot falls at the moments of initial contacts
Stride Velocity	% of Subjects height / second*	Shanks	Walking speed. Average of the right and left sides.
Stride Velocity R	% of Subjects height / second*	Shanks	Walking speed of right leg
Stride Velocity L	% of Subjects height / second*	Shanks	Walking speed of left leg

*Values are given relative to the subject's body height to enable comparison to normative data. If the subject's height is entered through Mobility Lab, then values will additionally be provided in units of meters.

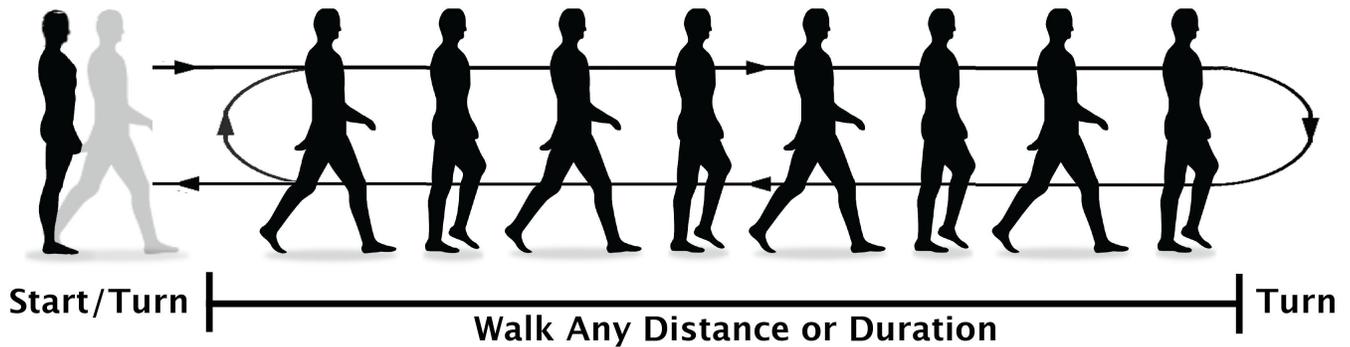
Temporal gait measures

Measures	Unit	Sensors	Description
Cadence	Steps / minute	Shanks	Stepping rate
Gait Cycle Time	Time (seconds)	Shanks	Duration of a complete gait cycle
Double Support	% of GCT	Shanks	Percentage of a gait cycle that both feet are on the ground
Swing	% of GCT	Shanks	Average percentage of a gait cycle that either foot is off the ground
Swing R	% of GCT	Shanks	Percentage of a gait cycle that right foot is off the ground
Swing L	% of GCT	Shanks	Percentage of a gait cycle that left foot is off the ground
Stance	% of GCT	Shanks	Average percentage of a gait cycle that either foot is on the ground
Stance R	% of GCT	Shanks	Percentage of a gait cycle that right foot is on the ground
Stance L	% of GCT	Shanks	Percentage of a gait cycle that left foot is on the ground
Initial Contact R	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that right foot hits the ground. Sometimes referred to as heel-strike.
Terminal Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that right foot leaves the ground. Sometimes referred to as toe-off.
Initial Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that left foot hits the ground.
Terminal Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that left foot leaves the ground.

Ranges of motions (RoM) and angular velocities

Measures	Unit	Sensors	Description
Shank RoM	Degrees	Shanks	RoM of shanks; averaged of the left and right sides.
RoM Shank R	Degrees	Shanks	RoM of right shank.
RoM Shank L	Degrees	Shanks	RoM of left shank.
Peak Shank Velocity	Degrees / seconds	Shanks	Peak (95%) angular velocity of shanks. Average of the left and right sides.
Peak Shank Velocity R	Degrees / seconds	Shanks	Peak (95%) angular velocity of right shank.
Peak Shank Velocity L	Degrees / seconds	Shanks	Peak (95%) angular velocity of left shank.
Peak Arm Velocity	Degrees / second	Shanks + Arms	Peak (95%) angular velocity of arms. Average of the left and right sides.
Peak Arm Velocity R	Degrees/ second	Shanks + Arms	Peak (95%) angular velocity of right arm. Measured as the norm of 3D angular velocity vector.
Peak Arm Velocity L	Degrees/ second	Shanks + Arms	Peak (95%) angular velocity of left arm. Measured as the norm of 3D angular velocity vector.
Arm-Swing Velocity Asymmetry	%	Shanks + Arms	Asymmetry of left/right arm-swing angular velocity. Defined as the difference between the two sides as percentage of the fastest side.
Arm RoM	Degrees	Shanks + Arms	RoM of arms during arm-swing. Average of the left and right sides.
RoM Arm R	Degrees	Shanks + Arms	RoM of right Arm. Measures as the norm of 3D arm rotation vector.
RoM Arm L	Degrees	Shanks + Arms	RoM of right Arm. Measures as the norm of 3D arm rotation vector.
Trunk Sagittal RoM	Degrees	Shanks + Trunk	RoM of trunk in sagittal plane.
Trunk Horizontal RoM	Degrees	Shanks + Trunk	RoM of trunk in horizontal plane.
Trunk Sagittal Peak Velocity	Degrees /second	Shanks + Trunk	Peak angular velocity of trunk in sagittal plane.
Trunk Horizontal Peak Velocity	Degrees / second	Shanks + Trunk	Peak angular velocity of trunk in horizontal plane.

15 The Instrumented Long Walk (IWalk) Test



15.1 Monitor Placements and Measures

- Trunk: Turning, trunk range of motion (RoM)
- Wrists: Arm RoM during gait
- Lumbar: Turning (if trunk monitor is not present)
- Shins: Lower body gait
- **Note:** You can include additional body sites in your configuration, they just won't be used in the IWalk analysis.

15.2 Test Environment Setup

- The IWalk is an open ended test, requiring only that the subject walk at least 5 full gait cycles.
- The walkway should be straight.
- It is not required that a turn be present in the walkway, but it needs to be a 180 degree turn to ensure proper detection and to be comparable with the normative turn measure data.
- Each trial can include any number of turns (i.e., the subject can walk back and forth any number of times).

15.3 Subject Attire

- The subject should wear clothing that does not bind or impede their movement in any significant way.
- The subject should wear comfortable walking shoes (i.e., no high-heels or flip-flops). If the subject does not have appropriate shoes, please have them walk barefoot (no socks) and **MAKE A NOTE** in the comments section of either the session or each TUG trial.

Before clicking on the “Start Trial” button, make sure that:



GOOD FOOTWEAR



BAD FOOTWEAR



- The LED on the access point is blinking **green**, indicating a good wireless signal.

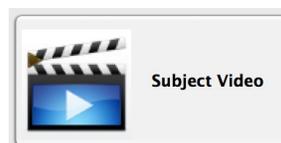
If the access point is blinking **red** or **green-red**, you may not have a good wireless signal or one of the monitors may be obstructed. For example, it is possible that the subject is covering one of the monitors with a limb. If this is true, reposition the subject and/or reposition the access point to get a better signal. If the walkway is longer than the range of the monitors (30m with good line of site), the data will be buffered on the monitors themselves, and will stream to the computer when back within range. If there is a lot of catch up to do when the trial is finished, there will be a progress indicator to show how much of the buffered data still needs to be sent before saving the trial.

15.4 Instructing the Subject

After clicking on the “Start Trial” button in Mobility Lab, you will be presented with the subject instruction dialog and the following written instructions:

- “When I say “Walk”, start walking at a natural and comfortable pace. When I say “Stop”, stop where you are and wait for the beep or are told the test is complete.”

The first time the subject takes the test, they should view the video instructions by clicking on the “Subject Video” button.



15.5 Before Starting the Trial

Prior to recording the trial, verify that the subject:

- is relaxed
- is standing and prepared to start walking

15.6 Recording the Trial

- To begin recording, press the “Record” button or press the enter key.



- After clicking on the “Record” button, the test administrator should say “Walk”.
- During the test the examiner should be “Spotting” the patient as needed (for safety) by walking slightly to the side and behind the subject so as not to affect their pace.
- When the trial is complete, press the Stop button and tell the subject they can stop walking.
- The computer will then confirm that the trial has ended by closing the testing window and displaying the confirmation dialog. Here, you can enter any notes about the recording, if necessary. Choose to either keep or discard the recording.
- If a subject error occurs during the trial, such as:
 - Incompletion of the course
 - Falling
- The examiner can press the Stop button, stopping the trial in the middle of testing. The examiner should then inform the subject of the error or problem and how to correct it. If it is believed that the subject can complete the trial successfully and safely, then the trial should be re-done.
- The subject instructions visible in the dialog box should be read aloud to the subject on each subsequent TUG trial (within reason) to ensure that the proper behavior is enforced for each trial.

15.7 IWalk Measure Definitions

The Instrumented Walk (IWalk) analysis algorithms automatically processes recorded movement data and provide objective measures related to gait and turning.

The primary outcomes in each table are highlighted by bold text. These measures might be of primary interest for clinical applications. Researchers might be interested in both primary and secondary outcomes.

15.7.1 Turn

Turning is detected and assessed based using gyroscopes within the trunk or lumbar sensor. A mathematical model is used to detect the exact moment of beginning and end of turning [4].

Measures	Unit	Sensors	Description
Turning Duration	Time (seconds)	Trunk	Duration of 180 turn. Measured according to the mathematical model of turning.
Number of Steps	Number	Shanks + Trunk	Number of steps during 180 turn. Steps which are at least 50% within turning period are counted.
Peak Turning Velocity	Degrees / second	Trunk	Peak (95%) angular velocity of turnk during turning.
Step time	Time (seconds)	Shanks + Trunk	Average step duration during turning.
Step time before turn	Time (seconds)	Shanks + Trunk	The last step duration right before the turn.

15.7.2 Gait

Gyroscopes attached on the shanks are used to detect the basic gait events, i.e. time feet hit the ground and leave the ground (initial and terminal contacts). Temporal gait measures are then calculated based on the time of gait events. In the next step, ranges of motions (RoM) of the shank segments are estimated by integrating the gyroscopes signals. Finally, spatial gait measures are estimated using a biomechanical model [6]. Gait measures are reported for individual gait cycles in the CSV export. A gait cycle is defined as the period between two consecutive initial contacts (heel-strike) of the right foot.

Spatial gait measures

Measures	Unit	Sensors	Description
Stride Length	% of Subjects body height*	Shanks	Distance between two consecutive foot falls at the moments of initial contacts. Averaged for left and right side. The value is normalized for height.
Stride Length R	% of Subjects height*	Shanks	Distance between two consecutive right foot falls at the moments of initial contacts
Stride Length L	% of Subjects height*	Shanks	Distance between two consecutive left foot falls at the moments of initial contacts
Stride Velocity	% of Subjects height / second*	Shanks	Walking speed. Average of the right and left sides.
Stride Velocity R	% of Subjects height / second*	Shanks	Walking speed of right leg
Stride Velocity L	% of Subjects height / second*	Shanks	Walking speed of left leg

*Values are given relative to the subject's body height to enable comparison to normative data. If the subject's height is entered through Mobility Lab, then values will additionally be provided in units of meters.

Temporal gait measures

Measures	Unit	Sensors	Description
Cadence	Steps / minute	Shanks	Stepping rate
Gait Cycle Time	Time (seconds)	Shanks	Duration of a complete gait cycle
Double Support	% of GCT	Shanks	Percentage of a gait cycle that both feet are on the ground
Swing	% of GCT	Shanks	Average percentage of a gait cycle that either foot is off the ground
Swing R	% of GCT	Shanks	Percentage of a gait cycle that right foot is off the ground
Swing L	% of GCT	Shanks	Percentage of a gait cycle that left foot is off the ground
Stance	% of GCT	Shanks	Average percentage of a gait cycle that either foot is on the ground
Stance R	% of GCT	Shanks	Percentage of a gait cycle that right foot is on the ground
Stance L	% of GCT	Shanks	Percentage of a gait cycle that left foot is on the ground
Initial Contact R	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that right foot hits the ground. Sometimes referred to as heel-strike.
Terminal Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that right foot leaves the ground. Sometimes referred to as toe-off.
Initial Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that left foot hits the ground.
Terminal Contact L	Time (seconds)	Shanks	The time (relative to the beginning of the trial) that left foot leaves the ground.

Ranges of motions (RoM) and angular velocities

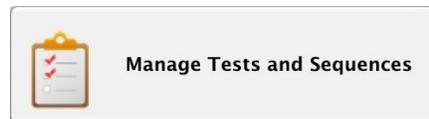
Measures	Unit	Sensors	Description
Shank RoM	Degrees	Shanks	RoM of shanks; averaged of the left and right sides.
RoM Shank R	Degrees	Shanks	RoM of right shank.
RoM Shank L	Degrees	Shanks	RoM of left shank.
Peak Shank Velocity	Degrees / seconds	Shanks	Peak (95%) angular velocity of shanks. Average of the left and right sides.
Peak Shank Velocity R	Degrees / seconds	Shanks	Peak (95%) angular velocity of right shank.
Peak Shank Velocity L	Degrees / seconds	Shanks	Peak (95%) angular velocity of left shank.
Peak Arm Velocity	Degrees / second	Shanks + Arms	Peak (95%) angular velocity of arms. Average of the left and right sides.
Peak Arm Velocity R	Degrees/ second	Shanks + Arms	Peak (95%) angular velocity of right arm. Measured as the norm of 3D angular velocity vector.
Peak Arm Velocity L	Degrees/ second	Shanks + Arms	Peak (95%) angular velocity of left arm. Measured as the norm of 3D angular velocity vector.
Arm-Swing Velocity Asymmetry	%	Shanks + Arms	Asymmetry of left/right arm-swing angular velocity. Defined as the difference between the two sides as percentage of the fastest side.
Arm RoM	Degrees	Shanks + Arms	RoM of arms during arm-swing. Average of the left and right sides.
RoM Arm R	Degrees	Shanks + Arms	RoM of right Arm. Measures as the norm of 3D arm rotation vector.
RoM Arm L	Degrees	Shanks + Arms	RoM of right Arm. Measures as the norm of 3D arm rotation vector.
Trunk Sagittal RoM	Degrees	Shanks + Trunk	RoM of trunk in sagittal plane.
Trunk Horizontal RoM	Degrees	Shanks + Trunk	RoM of trunk in horizontal plane.
Trunk Sagittal Peak Velocity	Degrees /second	Shanks + Trunk	Peak angular velocity of trunk in sagittal plane.
Trunk Horizontal Peak Velocity	Degrees / second	Shanks + Trunk	Peak angular velocity of trunk in horizontal plane.

Symmetry Measures

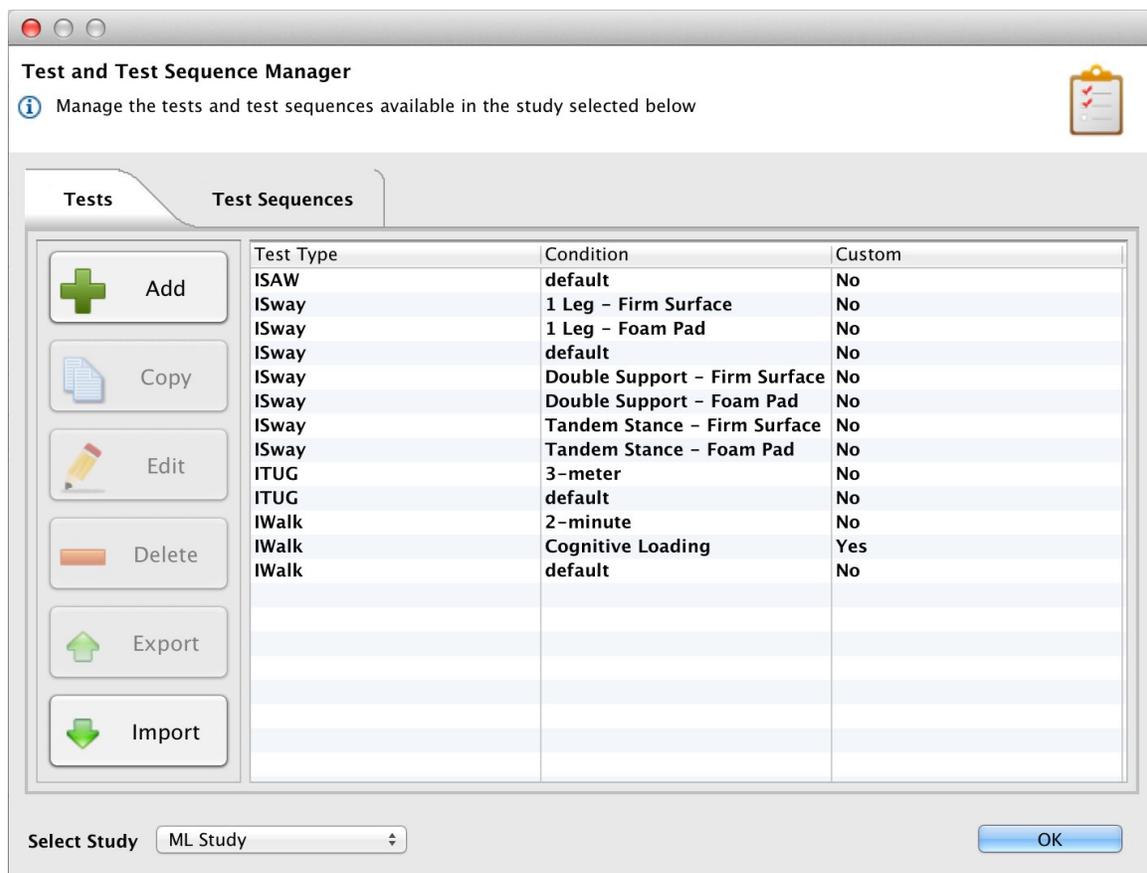
Measures	Unit	Sensors	Description
Stride Velocity Asymmetry	%	Shanks	Mean asymmetry of the left and right stride velocities
Stride Length Asymmetry	%	Shanks	Mean asymmetry of the left and right stride lengths
Swing Asymmetry	%	Shanks	Mean asymmetry of the left and right swing (percentage of a gait cycle that either foot is off the ground)
Stance Asymmetry	%	Shanks	Mean asymmetry of the left and right stance (percentage of a gait cycle that either foot is on the ground)
Shank Asymmetry	%	Shanks	Mean asymmetry of the left and right shank rotations
Peak Shank Velocity Asymmetry	%	Shanks	Mean asymmetry of the left and right shank velocities
Peak Arm Velocity Asymmetry	%	Arms	Mean asymmetry of the left and right arm swing velocities
Arm SSI	%	Arms	Arm Symbolic Symmetry Index [7]
Shank SSI	%	Shanks	Shank Symbolic Symmetry Index [7]
Phase Difference	%	Shanks	The phase relationship between the left and right legs [3]
Phase Coordination Index	%	Shanks	A measure of the consistency and accuracy in the generation of anti-phased left/right leg movements [3]

16 Creating Custom Test Types and Sequences

When creating or editing sessions, you can specify which tests (e.g., ISway) and/or test sequences (e.g., ICTSIB) will be included. The Test and Test Sequence Manager enables you to view, add, and edit tests and test sequences that are available in your study. To get started, click on the “Manage Tests and Sequences” button in the left panel (pictured below).



16.1 The Test Editor



When selecting the “Tests” tab, you will see a table of all the tests currently available in the study selected in the bottom left corner. The buttons on the left provide options available for any selected test:

- **Add:** This enables you to create a new test or test condition. A dialog will be displayed enabling you to specify the details of the test.
 - **Test Type:** This determines which analysis algorithm is applied to the recorded data. You can create your own, custom test type by selecting “Custom...” from the dropdown list and specifying

Create a New Test Type

Use the fields below to define a new test type to use in your study

Test Type: IWalk Custom Test Type:

Condition Name: Cognitive Loading

Record Type: Indeterminate Record Duration (s):

Start Delay (s): 3 End Delay (s): 3

Instruction Text

When I say "Walk", start walking at a natural and comfortable pace. Count backwards from 100 by 7's. When I say "Stop", stop where you are and wait for the beep or are told the test is complete.

Video File:

Audio Cues

Start Time | File

Start Time	File

Buttons: Cancel, Add

your own test name in the “Custom Test Type” field. Note that custom test types will not generate any metrics when reported on or exported, although their metadata will still be represented.

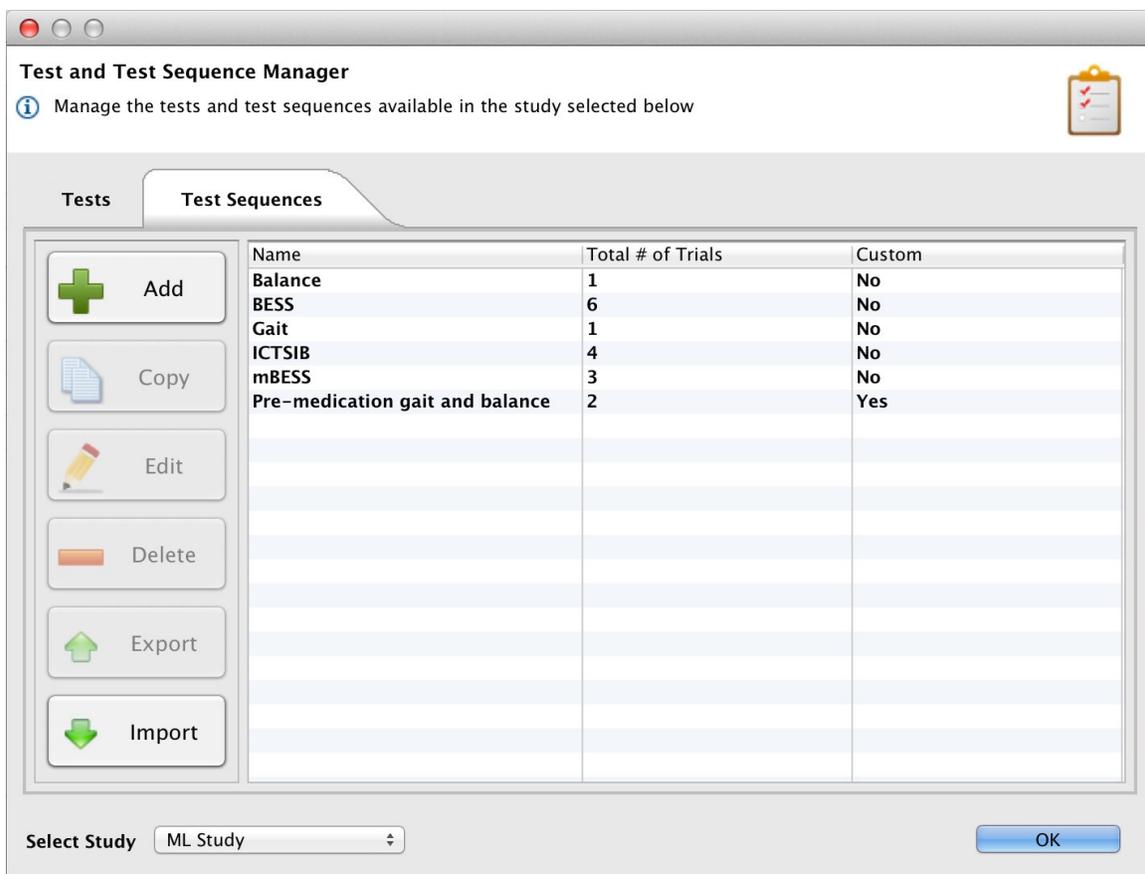
- **Condition Name:** This specifies the name of the condition. This is a field when exporting data to CSV. In PDF reports, values for distinct conditions are reported independently, enabling you to compare results.
- **Record Type:** This specified whether it is an indeterminate or determinate length test. If it is determinate, you must also specify the duration in seconds in the “Record Duration (s)” field.
- **Start Delay:** Specifying this to be non-zero will result in a countdown when starting the test. This delay period is not included in the computed duration of the test. It is recommended to have at least a 3s silent period at the beginning of IWalk, ISAW, and ITUG trials, as it helps the analysis routine auto-calibrate the sensor data.
- **End Delay:** Specifying this to be non-zero will result in a countdown when ending the test. This delay period is not included in the computed duration of the test. It is recommended to have at least a 3s silent period at the end of IWalk, ISAW, and ITUG trials, as it helps the analysis routine auto-calibrate the sensor data.
- **Instruction Text:** This will be displayed in the “Subject Instructions” display when recording the

trial.

- **Audio Cues:** You can specify custom audio cues to be played during the trial at specific times. You can specify the string “beep” to get that standard beep or specify your own audio file. Custom audio files must be in 16-bit WAV format.

- **Copy:** This enables you to make a copy of the selected test. You can copy it into the same study or into another study you have created. If you copy it into the same study, the name of the condition will include “(copy)” at the end.
- **Edit:** This enables you to edit the selected test.
- **Delete:** This deletes selected tests. You cannot delete any of the default tests (these are indicated by a “No” in the “Custom” column).
- **Export:** This exports selected tests in a format that can be imported into another Mobility Lab system.
- **Import:** This imports test definitions that were exported from Mobility Lab.

16.2 The Test Sequence Editor



When selecting the “Tests Sequences” tab, you will see a table of all the sequences currently available in the study selected in the bottom left corner. The buttons on the left provide options available for any selected test:

- **Add:** This enables you to create a new test sequence. A dialog will be displayed enabling you to specify how many of each desired test will appear in the sequence and in what order. You need to specify a sequence name and at least one test to belong in the sequence.

Create a New Test Sequence
Use the fields below to define a new test sequence to use in your study

Test Sequence Name
Pre-medication gait and balance

Test Type iWalk (Cognitive Loading) **Iterations** 1

Insert Above Selection Add to End of Sequence

Type	Condition	#
iWalk	Cognitive Loading	1
iSway	default	1

Delete Cancel Add

- **Copy:** This enables you to make a copy of the selected test sequence. You can copy it into the same study or into another study you have created. If you copy it into the same study, the name of the sequence will include “(copy)” at the end.
- **Edit:** This enables you to edit the selected test sequence.
- **Delete:** This deletes selected test sequences. You cannot delete any of the default sequences (these are indicated by a “No” in the “Custom” column).
- **Export:** This exports selected test sequences in a format that can be imported into another Mobility Lab system.
- **Import:** This imports test sequence definitions that were exported from Mobility Lab.

17 When You Are Done

17.1 Docking Monitors

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

17.2 Power Off

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

18 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/stop 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.

18.1 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.

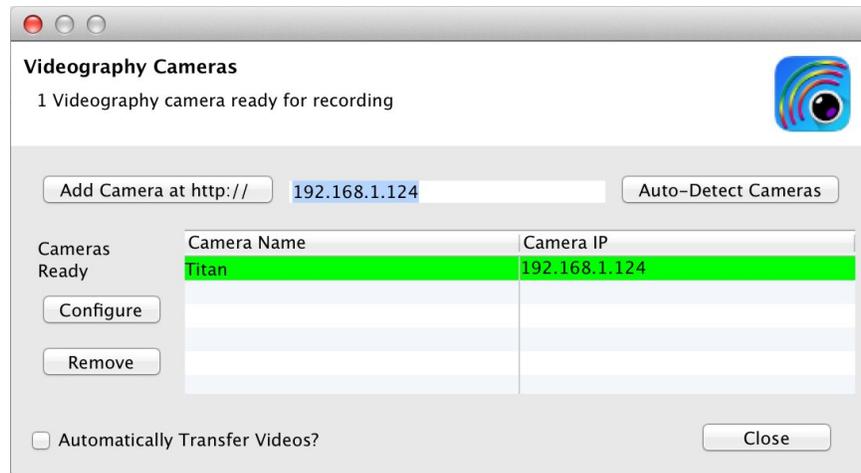
18.1.1 Network Setup

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.

18.1.2 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



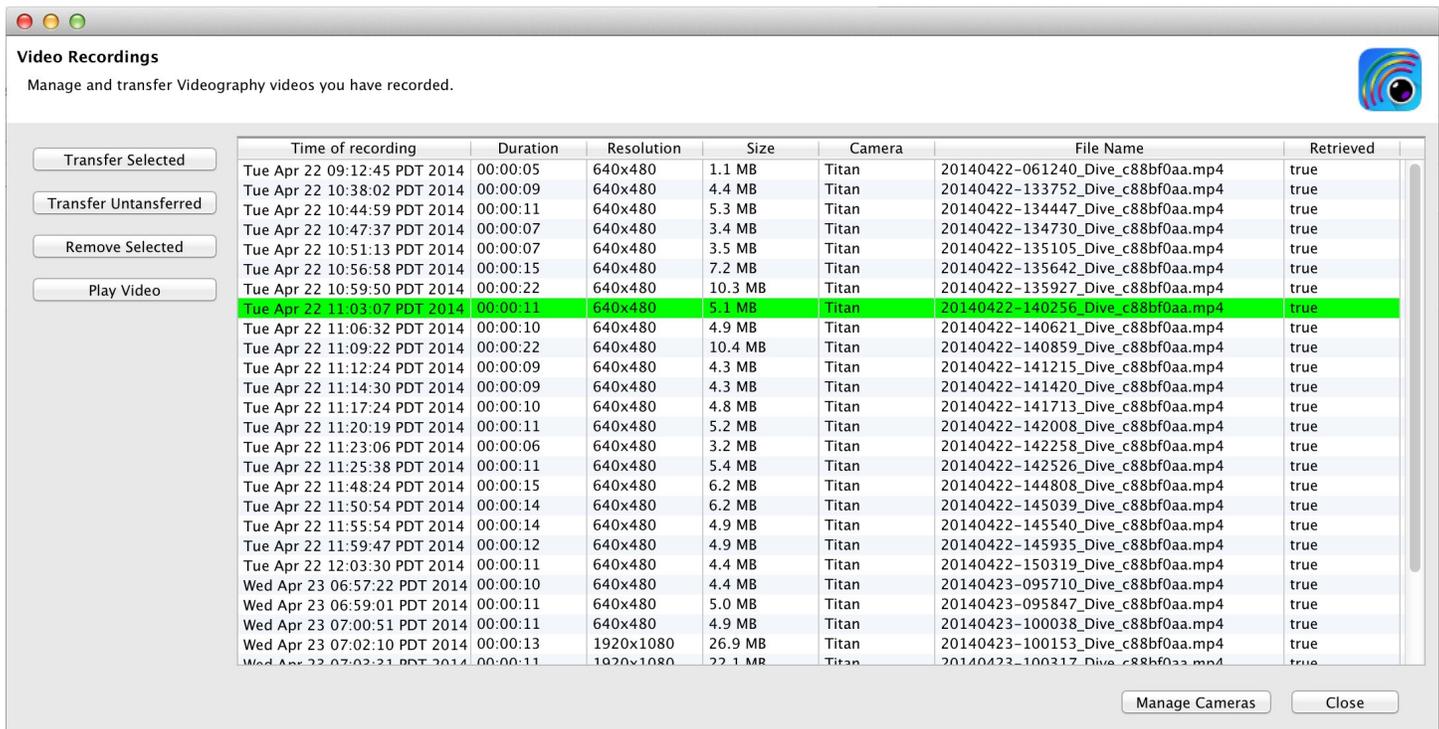
The Videography Camera Configuration Dialog

- 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.

18.1.3 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.

18.1.4 Managing Videography Videos



Video Recordings
Manage and transfer Videography videos you have recorded.

Time of recording	Duration	Resolution	Size	Camera	File Name	Retrieved
Tue Apr 22 09:12:45 PDT 2014	00:00:05	640x480	1.1 MB	Titan	20140422-061240_Dive_c88bf0aa.mp4	true
Tue Apr 22 10:38:02 PDT 2014	00:00:09	640x480	4.4 MB	Titan	20140422-133752_Dive_c88bf0aa.mp4	true
Tue Apr 22 10:44:59 PDT 2014	00:00:11	640x480	5.3 MB	Titan	20140422-134447_Dive_c88bf0aa.mp4	true
Tue Apr 22 10:47:37 PDT 2014	00:00:07	640x480	3.4 MB	Titan	20140422-134730_Dive_c88bf0aa.mp4	true
Tue Apr 22 10:51:13 PDT 2014	00:00:07	640x480	3.5 MB	Titan	20140422-135105_Dive_c88bf0aa.mp4	true
Tue Apr 22 10:56:58 PDT 2014	00:00:15	640x480	7.2 MB	Titan	20140422-135642_Dive_c88bf0aa.mp4	true
Tue Apr 22 10:59:50 PDT 2014	00:00:22	640x480	10.3 MB	Titan	20140422-135927_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:03:07 PDT 2014	00:00:11	640x480	5.1 MB	Titan	20140422-140256_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:06:32 PDT 2014	00:00:10	640x480	4.9 MB	Titan	20140422-140621_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:09:22 PDT 2014	00:00:22	640x480	10.4 MB	Titan	20140422-140859_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:12:24 PDT 2014	00:00:09	640x480	4.3 MB	Titan	20140422-141215_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:14:30 PDT 2014	00:00:09	640x480	4.3 MB	Titan	20140422-141420_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:17:24 PDT 2014	00:00:10	640x480	4.8 MB	Titan	20140422-141713_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:20:19 PDT 2014	00:00:11	640x480	5.2 MB	Titan	20140422-142008_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:23:06 PDT 2014	00:00:06	640x480	3.2 MB	Titan	20140422-142258_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:25:38 PDT 2014	00:00:11	640x480	5.4 MB	Titan	20140422-142526_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:48:24 PDT 2014	00:00:15	640x480	6.2 MB	Titan	20140422-144808_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:50:54 PDT 2014	00:00:14	640x480	6.2 MB	Titan	20140422-145039_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:55:54 PDT 2014	00:00:14	640x480	4.9 MB	Titan	20140422-145540_Dive_c88bf0aa.mp4	true
Tue Apr 22 11:59:47 PDT 2014	00:00:12	640x480	4.9 MB	Titan	20140422-145935_Dive_c88bf0aa.mp4	true
Tue Apr 22 12:03:30 PDT 2014	00:00:11	640x480	4.4 MB	Titan	20140422-150319_Dive_c88bf0aa.mp4	true
Wed Apr 23 06:57:22 PDT 2014	00:00:10	640x480	4.4 MB	Titan	20140423-095710_Dive_c88bf0aa.mp4	true
Wed Apr 23 06:59:01 PDT 2014	00:00:11	640x480	5.0 MB	Titan	20140423-095847_Dive_c88bf0aa.mp4	true
Wed Apr 23 07:00:51 PDT 2014	00:00:11	640x480	4.9 MB	Titan	20140423-100038_Dive_c88bf0aa.mp4	true
Wed Apr 23 07:02:10 PDT 2014	00:00:13	1920x1080	26.9 MB	Titan	20140423-100153_Dive_c88bf0aa.mp4	true
Wed Apr 23 07:02:21 PDT 2014	00:00:11	1920x1080	22.1 MB	Titan	20140423-100217_Dive_c88bf0aa.mp4	true

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>)

18.1.5 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.

19 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.

External Synchronization 

 Configure your system to start and/or stop recording from external events or to trigger external events when you start and/or stop recording.

Select Access Point To Configure #9149

Input Trigger

Shape Level Trigger



- The black line represents the input into the access point's synchronization port.
- The blue region represents when recording is triggered in Motion Studio.
- In this figure, the start and end of the recording is triggered externally, but it could be started or stopped manually as well.

Output Trigger

Shape Level Trigger



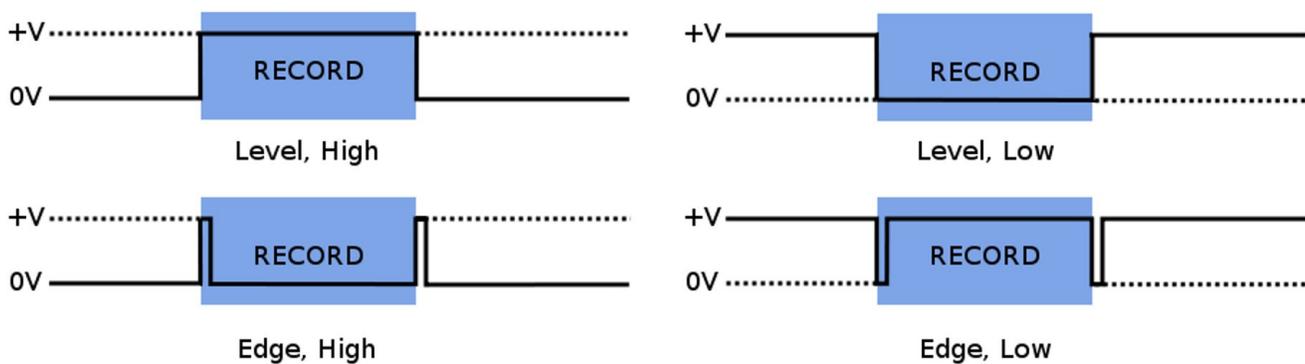
- The blue region represents a recording that you initiate in Motion Studio.
- The black line is the output from the access point's synchronization port, which can be used to trigger recording on an external system.
- In this figure, the output pulse is generated only at the beginning of the recording.

The External Synchronization Configuration Dialog

19.1 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.

19.2 Input Synchronization



Input synchronization trigger types

19.2.1 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.

19.2.2 Input Trigger Level

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

19.2.3 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.

19.2.4 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.

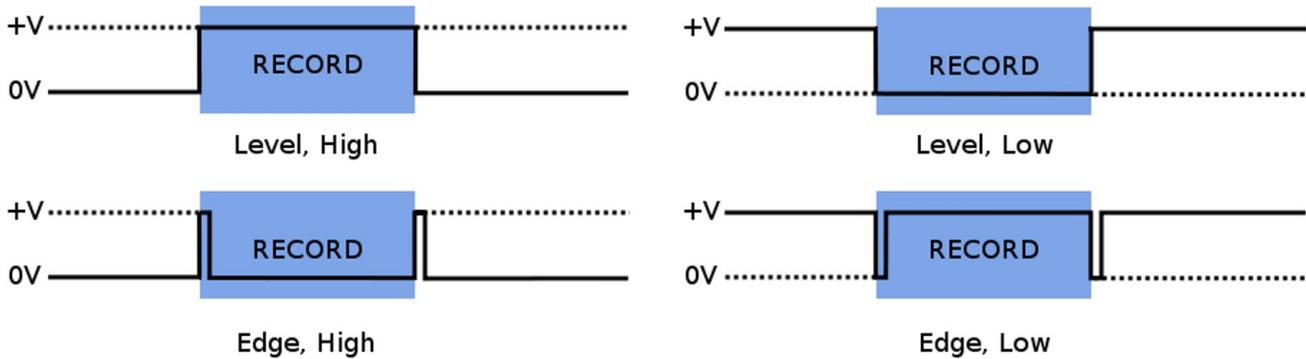
19.2.5 Annotation of Externally Triggered Recordings

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.

19.3 Output Synchronization

19.3.1 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.

19.3.2 Output Trigger Level

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

19.3.3 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.

19.4 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.

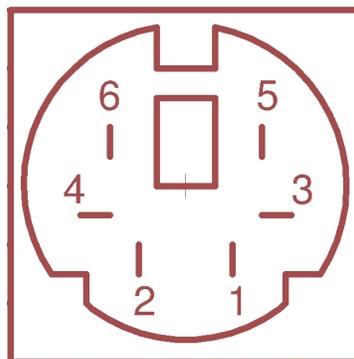
The 6 pin mini-din connector is similar to those used for older style PS/2 keyboards and mice. Choose a connector that is small enough to fit fully inside the recessed hollow in the AP body. Some PS/2 extension cables can be cut into excellent pigtails for this connector.

19.4.1 RCA Inter-AP Sync Connector

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

19.4.2 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 47.5k Ω resistors, and each have a series resistance of nearly 1.2k Ω 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.

19.4.3 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:

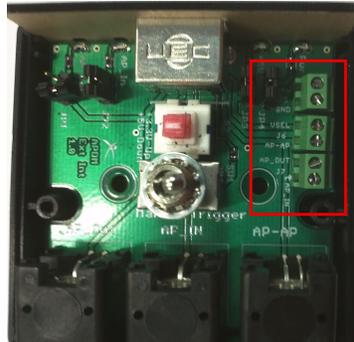
- PWR: Lights when power is applied to the external interface.
- +5V: Lights to indicate that the external interface is configured for 5V operation. Default is 3.3V (Light out)
- AP In: Lights to indicate that the APIn signal is High
- AP Out: Lights to indicate that the AP Out signal is High

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

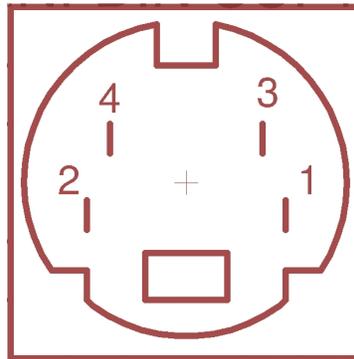
- +V: Positive voltage rail from the isolated supply located inside the AP.
- GND: Ground rail from the isolated supply located inside the AP.
- VSEL: Tie to Ground or leave floating to select output and +V operation at +3.3V, tie to +V to select +5V operation.
- AP-AP: Allows multiple AP configurations, 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.

19.4.4 4 Pin Analog Input/Output Connector

Note: This connector is currently reserved for future expansion.

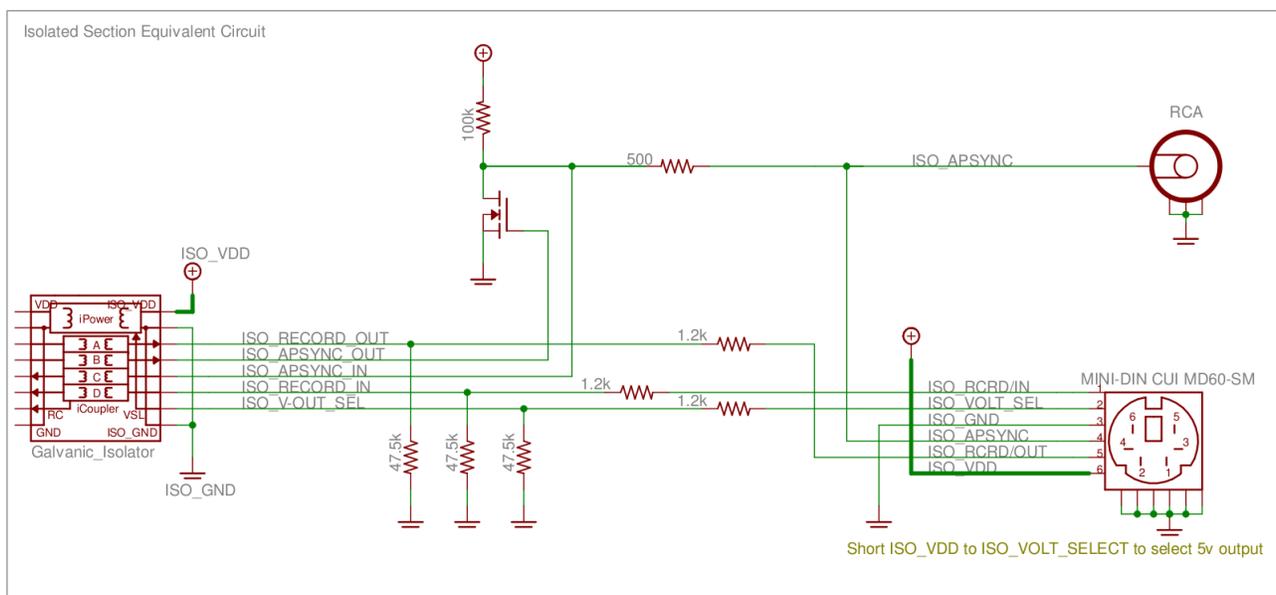
- 4 Pin Mating Connector: Digikey part number CP-2040-ND, CUI Inc part number MD-40
- 4 Pin Mating Pig Tail Cable: Digikey part number 839-1049-ND



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 controlled 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.

19.4.5 Schematic



20 Firmware Updates

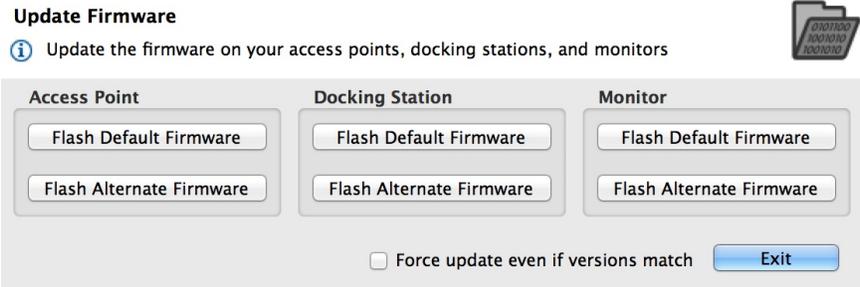
Firmware controls the various hardware components of your APDM product line (monitors, access points, and docking stations). It is important to keep the firmware up to date to ensure that your system gets the latest bug fixes and has access to the latest features. Firmware updates are bundled with updates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

20.1 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.

20.2 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

20.2.1 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.

20.2.2 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.

20.2.3 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.

21 Calibration

21.1 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.

21.1.1 Accelerometers

The calibrated accelerometer measurements are calculated as

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

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

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

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

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.

21.1.2 Gyroscopes

The calibrated gyroscope measurements are calculated as

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

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

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

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

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

where 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.

21.1.3 Magnetometers

The calibrated magnetometer measurements are calculated as

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

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

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

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

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

where 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.

21.1.4 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.

21.2 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.

21.2.1 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 [26](#).

21.3 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.

21.3.1 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).

21.3.2 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.

21.3.3 Accelerometer Recalibration

Coming soon!

21.4 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.

22 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.

22.1 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>.

22.2 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.

22.3 File Structure

22.3.1 Versions 3 and 4

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaselIDList
- **CaselIDList Attribute** containing an array of monitor case IDs in the same order as the MonitorLabelList
- **FileFormatVersion** Attribute containing the file format version (3)
- **Annotations** Table containing annotations
 - **Time** Annotation time in epoch microseconds
 - **Case ID** A movement monitor case ID associated with the annotation
 - **Annotation** The annotation string
- **AA-XXXXXX** A group is included in the file for each monitor in the CaselIDList, with the name equal to the case ID
 - **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 ($^{\circ}C$)
 - **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 ($^{\circ}C/s$)
 - * **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**
- **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

22.3.2 Version 3

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaselIdList
- **CaselIdList Attribute** containing an array of monitor case IDs in the same order as the MonitorLabelList
- **FileFormatVersion** Attribute containing the file format version (3)
- **Annotations** Table containing annotations
 - **Time** Annotation time in epoch microseconds
 - **Case ID** A movement monitor case ID associated with the annotation
 - **Annotation** The annotation string
- **AA-XXXXXX** A group is included in the file for each monitor in the CaselIdList, with the name equal to the case ID
 - **SampleRate** Attribute containing the output data rate for the monitor
 - **DecimationFactor** Decimation factor for the monitor's internal processing
 - **ModuleID** The module ID for the monitor
 - **TimeGood** Flag indicating whether the time has been set on the monitor since it powered on
 - **RecordingMode** One of: "Wireless streaming", "Synchronized logging", or "Unsynchronized logging"
 - **DataMode** Indicates whether the data was retrieved wirelessly or copied from the monitor's internal storage while docked. One of: "Streamed wirelessly" or "Logged to monitor"
 - **AccelerometersEnabled** 1 for enabled, 0 for disabled
 - **GyroscopesEnabled** 1 for enabled, 0 for disabled
 - **MagnetometersEnabled** 1 for enabled, 0 for disabled
 - **DecimationBypass** Internal use, deprecated
 - **CalibrationVersion** Version of the calibration data used to convert from raw samples to calibrated SI units
 - **VersionString1** Firmware version string 1
 - **VersionString2** Firmware version string 2
 - **VersionString3** Firmware version string 3
 - **CalibratedDataPopulated** 1 for populated, 0 for unpopulated
 - **LocalTimeOffset** Time in milliseconds to add to UTC to convert to local time
 - **SyncValue** Dataset containing the internal sync value for each sample
 - * **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
 - **Time** Dataset containing a timestamp for each sample
 - * **Units** Attribute string containing the units (microseconds since 0:00 Jan 1, 1970 UTC)
 - **ButtonStatus** Dataset containing the button status for each sample (1==pressed, 0==unpressed)
 - **Calibrated** Group containing calibrated data
 - * **Accelerometers** Dataset containing accelerometer data (Nx3)
 - **Units** Attribute string containing the accelerometer units (m/s²)
 - **Range** Attribute containing the range setting for the accelerometer (2g or 6g)
 - * **Gyroscopes** Dataset containing gyroscope data (Nx3)
 - **Units** Attribute string containing the gyroscope units (rad/s)
 - * **Magnetometers** Dataset containing magnetometer data (Nx3)
 - **Units** Attribute string containing the magnetometer units (μ T)
 - * **Temperature** Dataset containing the temperature (Nx1)

- **Units** Attribute string containing the temperature units (°C)
- * **TemperatureDerivative** Dataset containing the temperature derivative (Nx1)
 - **Units** Attribute string containing the temperature derivative units (°C/s)
- * **Orientation** Dataset containing the orientation quaternion (Nx4). The orientation is relative to a (magnetic) north, west, up reference frame. The scalar component of the quaternion is the first element.
- **Raw** Group containing raw data if selected during import
 - * **Accelerometers**
 - * **Gyroscopes**
 - * **Magnetometers**
 - * **DataFlags**
 - * **OptData**
 - * **Temperature**
 - * **TemperatureDerivative**

22.3.3 Version 2

- **MonitorLabelList** Attribute containing an array of monitor labels in the same order as the CaselIdList
- **CaselIdList** Attribute containing an array of monitor case IDs in the same order as the MonitorLabelList
- **FileFormatVersion** Attribute containing the file format version (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 CaselIdList, with the name equal to the case ID
 - **SampleRate** Attribute containing the output data rate for the monitor
 - **DecimationFactor** Decimation factor for the monitor's internal processing
 - **ModuleID** The module ID for the monitor
 - **TimeGood** Flag indicating whether the time has been set on the monitor since it powered on
 - **RecordingMode** One of: "Wireless streaming", "Synchronized logging", or "Unsynchronized logging"
 - **DataMode** Indicates whether the data was retrieved wirelessly or copied from the monitor's internal storage while docked. One of: "Streamed wirelessly" or "Logged to monitor"
 - **AccelerometersEnabled** 1 for enabled, 0 for disabled
 - **GyroscopesEnabled** 1 for enabled, 0 for disabled
 - **MagnetometersEnabled** 1 for enabled, 0 for disabled
 - **DecimationBypass** Internal use, deprecated
 - **CalibrationVersion** Version of the calibration data used to convert from raw samples to calibrated SI units
 - **VersionString1** Firmware version string 1
 - **VersionString2** Firmware version string 2
 - **VersionString3** Firmware version string 3
 - **CalibratedDataPopulated** 1 for populated, 0 for unpopulated
 - **LocalTimeOffset** Time in milliseconds to add to UTC to convert to local time
 - **SyncValue** Dataset containing the internal sync value for each sample
 - * **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)

- **Time** Dataset containing a timestamp for each sample
 - * **Units** Attribute string containing the units (microseconds since 0:00 Jan 1, 1970 UTC)
- **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**

22.3.4 Version 1

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

- **Device_List** Attribute containing a list of monitors present in the file
- **File_Format_Version** Attribute containing the file version
- **Annotations** Table containing annotations
 - **Time** Annotation time in epoch microseconds
 - **Device ID** A movement monitor ID associated with the annotation
 - **Annotation** The annotation string
- **Opal_xxx/** Group containing information about and data from monitor ID xxx
 - **Sample_Rate** Attribute containing the output data rate for the monitor
 - **Decimation_Factor** Decimation factor for the monitor's internal processing
 - **Time_Good** Flag indicating whether the monitor has had its time set since turning on
 - **Decimation_Bypass** Internal use, deprecated
 - **Calibration_Version** Version of the calibration data used to convert from raw samples to calibrated SI units
 - **Version_String1** Firmware version string 1
 - **Version_String2** Firmware version string 2
 - **Version_String3** Firmware version string 3

- **Acceleration** Dataset containing data from the accelerometers (Nx3)
 - * **Units** Attribute string containing the acceleration units (m/s²)
- **Angular_Velocity** Dataset containing data from the gyroscopes (Nx3)
 - * **Units** Attribute string containing the angular velocity units (rad/s)
- **Magnetic_Field** Dataset containing data from the magnetometers (Nx3)
 - * **Units** Attribute string containing the magnetic field units (a.u.)
- **Temperature** Dataset containing the temperature of the monitor (Nx1)
 - * **Units** Attribute string containing the temperature units (°C)
- **Temperature_Derivative** Dataset containing the rate of change of temperature
 - * **Units** Attribute string containing the temperature derivative units (°C/s)
- **Sync_Value** Dataset containing the internal timestamp of each sample
 - * **Units** Attribute string containing the timestamp units (1/2560th of a second since 0:00 Jan 1, 1970 UTC)
 - * **Time** Dataset containing the time for each sample in microseconds since 0:00 Jan 1, 1970 UTC

Additional fields present when raw data is also stored:

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

22.4 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.

`hdf5reads1ab` reads a portion of a dataset from the HDF5 file.

22.5 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
```

```

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);

```

22.6 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

23 Movement Monitor Reference

23.1 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).

23.2 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.

23.3 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 Lab is used to import the data. Alternately, there are functions in the SDK to do this conversion programmatically.

23.4 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.

23.5 Storage

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

23.6 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.

23.7 Firmware Updates

Updating the movement monitor firmware should be done using the Mobility Lab software. This process is detailed in Section 20 of this document.

23.8 Technical Specifications

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

23.9 LED Reference

23.9.1 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.

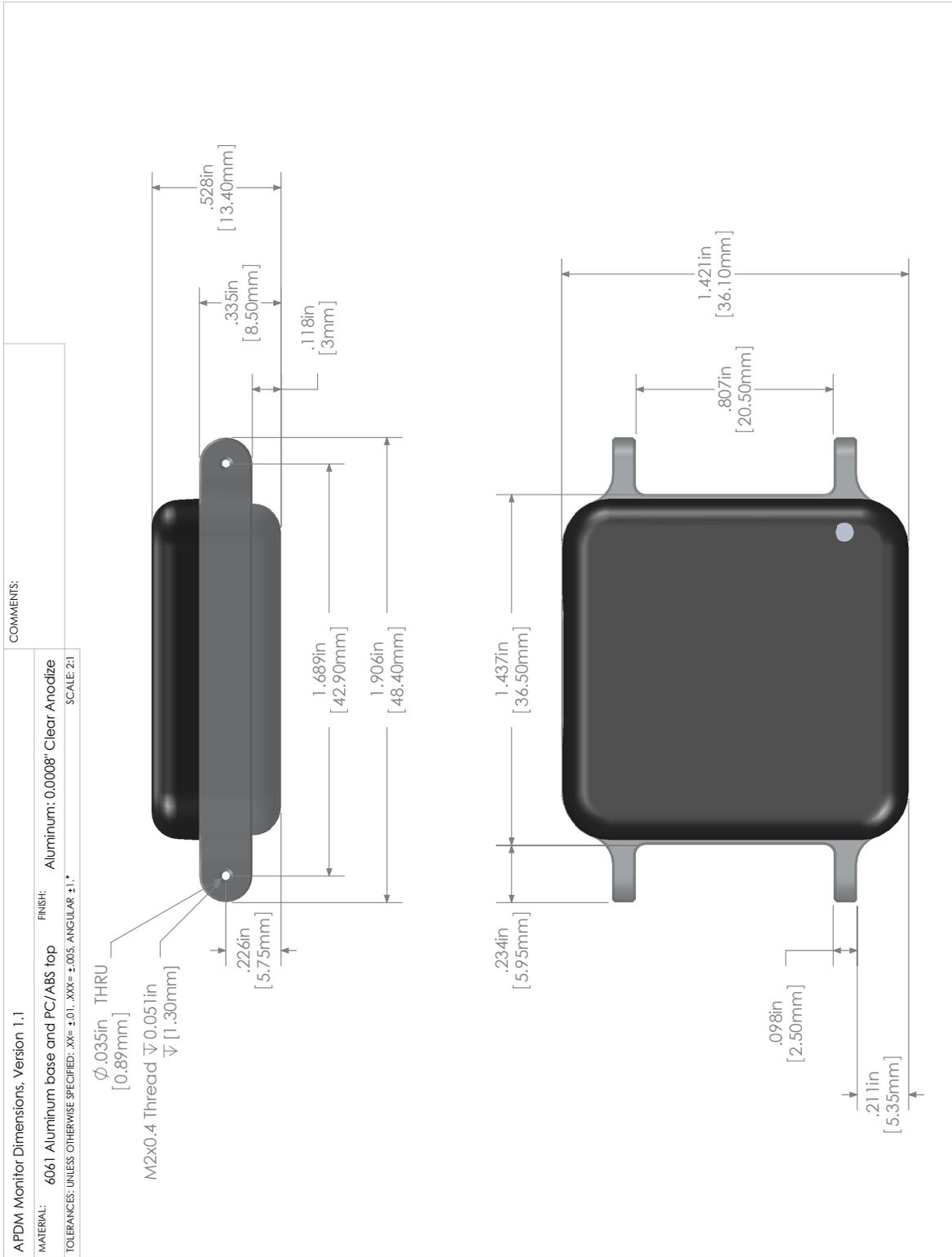
23.9.2 Movement Monitor LED Reference

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

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

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

23.10 Technical Drawing



24 Access Point Reference

24.1 Drivers

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

24.2 Firmware Updates

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

24.3 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.

24.4 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.

24.4.1 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.

24.4.2 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.

24.5 LED Reference

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

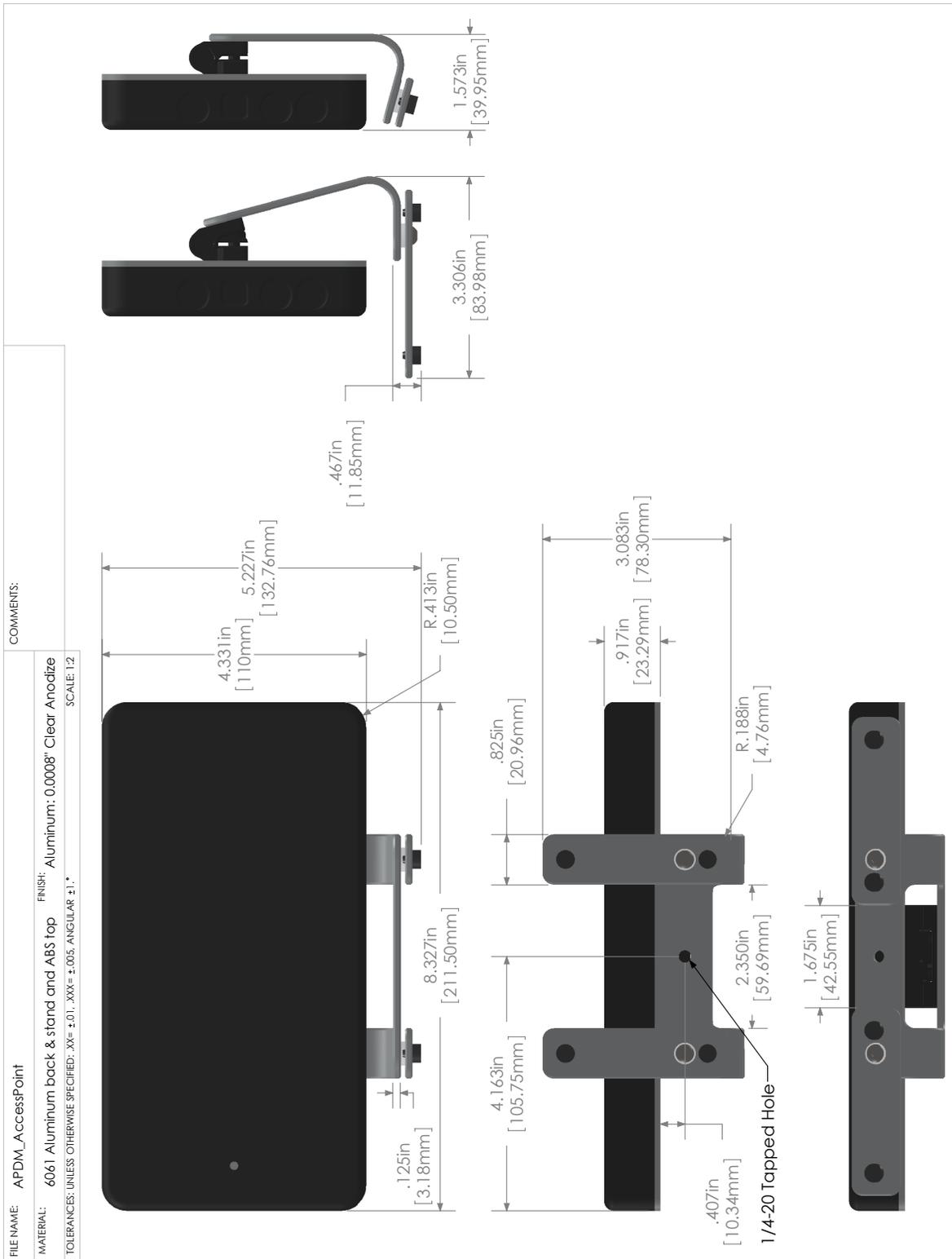
State	LED Pattern
Access point is powered on and is not receiving data from any monitors	●
Access point is receiving data from all monitors and there is no excessive latency for any of the monitors	●_
Access point is receiving data from all monitors but there is excessive latency (>3s) in one or more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

24.6 Mechanical and Electrical Specifications

Weight: 1.2lbs, (550 grams)

Electrical: 290mA at 5V over USB connection

24.7 Technical Drawing



25 Docking Station Reference

25.1 Drivers

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

25.2 Power

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

25.3 Mechanical and Electrical Specifications

Weight: 0.2 lbs, (90 grams)

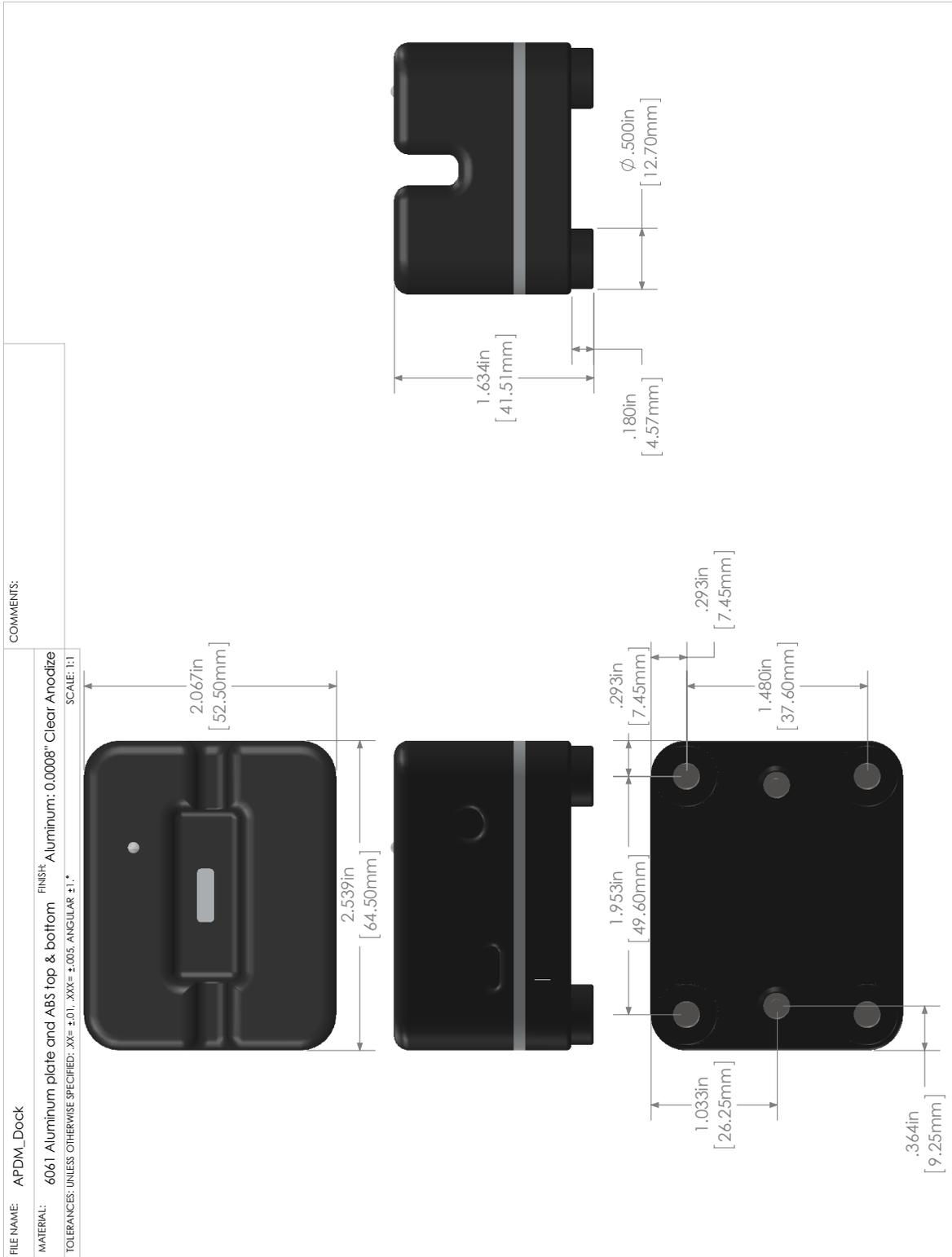
Electrical: 500mA at 5V over USB connection, or 500mA per dock when a chain is supplied by external power.

25.4 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 (●), yellow (●), green (●), cyan (●), blue (●), magenta (●), and led off (·). All LED patterns are output on a repeating cycle which may vary in period depending on the pattern. In all cases the last color listed will stay constant until the pattern repeats. For example “●●·” will blink yellow twice and then stay off until the pattern repeats.

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

25.5 Technical Drawing



26 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

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