shimmer
DISCOVERY IN MOTION

Shimmer MATLAB™ Instrument Driver User Manual

Revision 2.9a

Legal Notices and Disclaimer

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1. Introduction

The *Shimmer* MATLAB™ *Instrument Driver* allows for realtime streaming of data from a Shimmer device into MATLAB™. It is designed to work with MATLAB™ 2008a (version 7.6) or later on a Windows OS (the driver has been tested on Windows 7 and Windows 10).

2. Pre-Requisites

In order to use the *Shimmer* MATLAB™ *Instrument Driver* you will need the following:

1. The most recent version of the *Shimmer User Manual*, which holds information on programming firmware onto Shimmer and information on how to pair a Shimmer. The *Shimmer User Manual* is available for download from the documentation section of the Shimmer website.[1]

2. MATLAB™,[2] 2008a (version 7.6) or later installed on your PC.

3. A *Shimmer2/2r* with the latest *BtStream firmware* or a *Shimmer3* programmed with the latest version of *LogAndStream firmware*.

   NOTE: *BtStream firmware* for *Shimmer3* is no longer officially supported after it has been deprecated.

4. The Shimmer needs to be paired with the PC (over Bluetooth); please refer to the *Shimmer User Manual* for information on how to pair your Shimmer with your PC.

5. Ensure you are using the latest version of the Instrument Driver and accompanying User guide, by checking the downloads section of the Shimmer website for the most recent version[3].

[1] http://www.shimmersensing.com/support/wireless-sensor-networks-documentation/
[2] The MathWorks Inc., 3 Apple Hill Drive, Natick, MA 01760-2098, USA.
[3] http://www.shimmersensing.com/support/wireless-sensor-networks-download/.

3. Installation

3.1. Download

Download the folder *Shimmer* MATLAB™ *Instrument Driver* and copy it to a suitable location.

3.2. Install Realterm

Download and install an application called *Realterm Serial Terminal*, which acts as the communication link between the Shimmer device and MATLAB™. Realterm version 2.0.0.57 was used in the development of this driver and can be downloaded from http://sourceforge.net/projects/realterm/files/Realterm/2.0.0.57/.

Note: Make sure MATLAB is closed before installing Realterm. Alternatively, restart MATLAB after installing Realterm.

Important 1: When you are installing *Realterm* you need to ensure that the option to *register Realterm automation server* is ticked when presented with the window at the end of the installation process as highlighted in **Error! Unknown switch argument.** below.

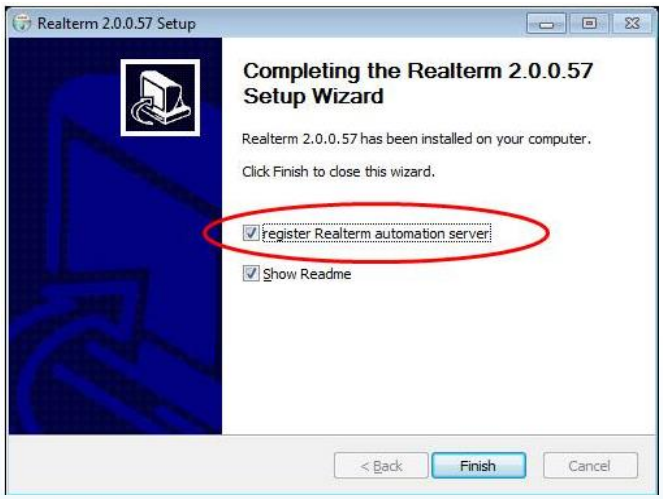

Figure 3-1 register Realterm automation server

3.3. Windows Users - Change User Account Control Settings

Users of Windows need to disable the *User Account Control Settings* to allow *Realterm* to run with administrator privileges always. For Windows 7, in order To locate the *User Account Control Settings* control panel you should search for it in the Start Menu. The control panel is illustrated in Figure 3-2. You need to set this control to *Never Notify*. You will need to restart your computer for the setting to take effect.

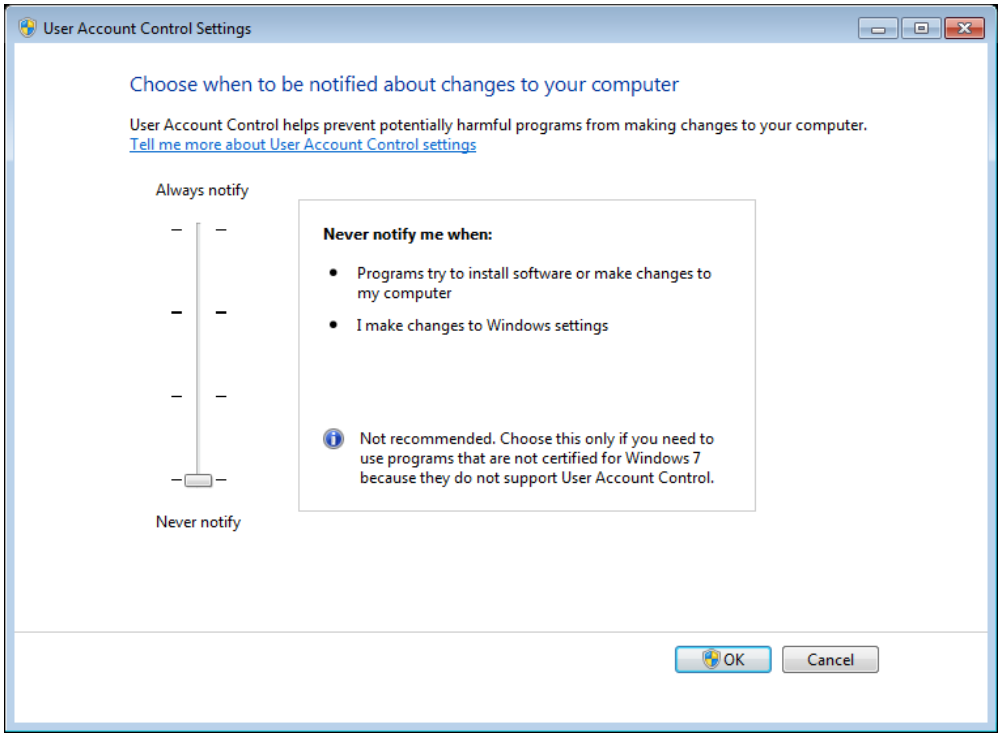

Figure 3-2 User Account Control Settings (Windows 7)

4. Getting Started

Start MATLAB™ and set the current working directory to the *Shimmer* MATLAB™ *Instrument Driver* folder you downloaded previously. Next to this User Manual the folder contains the following files:

- *Readme.txt*
- *ShimmerHandleClass.m*
- *plotandwriteexample.m*
- *orientation3Dexample.m*
- *twoshimmerexample.m*
- *plotandwriteemgexample.m*
- *plotandwriteecgexample.m*
- *plotandwriteexgtestsignalexample.m*
- *ppgtoheartrateexample.m*
- *ecgtoheartrateexample.m*
- *FilterClass.m*
- *ShimmerBiophysicalProcessingLibrary_Rev_X_Y.jar*
- *ReadmeShimmerBiophysicalProcessingLibrary.txt*
- *SetEnabledSensorsMacrosClass.m*
- *plotandwriteecgleadoffdetectionexample*
- *plotandwriteemgleadoffdetectionexample*

Next to the files listed above the folder contains a directory with supporting functions for quaternion algebra and a directory that holds the Sampling Rate Table.

4.1. ShimmerHandleClass

The file *ShimmerHandleClass.m* contains the code for the class, *ShimmerHandleClass*, which can be used to create Shimmer objects in MATLAB™. In the command window, type *doc ShimmerHandleClass* to get an explanation of the properties and methods of the class.

4.2. FilterClass

FilterClass.m contains an implementation of a configurable Chebyshev filter, which does not rely on the Matlab toolboxes. See for instance *plotandwriteemgexample.m*, *plotandwriteecgexample.m* or *ppgtoheartrateexample.m* for examples that make use of the filter class.

4.3. SetEnabledSensorsMacrosClass

To enable/disable sensors it was necessary to enter strings as arguments of *setenabledsensors* as shown in the example below:

```
shimmer.setenabledsensors('Accel',1,'Mag',1,'Gyro',1,'BattVolt',1);
```

The class *SetEnabledSensorsMacrosClass* - introduced in *Shimmer* MATLAB™ *Instrument Driver v2.3* - supports easier enabling sensors, without the need of entering strings, changing the example above into:

```
SensorMacros = SetEnabledSensorsMacrosClass;    % create an instance of the class

shimmer.setenabledsensors(SensorMacros.ACCEL,1,SensorMacros.MAG,1,...
    SensorMacros.GYRO,1,SensorMacros.BATT,1);
```

It is still possible to enable sensors by entering strings, but we think typing errors are easier made that way.

Also introduced in *Shimmer* MATLAB™ *Instrument Driver v2.3* is the function *disableallsensors* - for disabling all sensors.

4.4. ShimmerBiophysicalProcessingLibrary

A Java Archive (.jar file) is provided with the Instrument Driver to extract Heart Rate from either Electrocardiogram (ECG) or photoplethysmogram (PPG, measured with an optical pulse sensor) data.

(This library was called *ShimmerPPGtoHR_Rev_X_Y.jar* for *Shimmer* MATLAB™ *Instrument Driver v2.2* and contained only an algorithm for converting PPG to Heart Rate, which did not require calibrated timestamp as input, see note below.)

To use this library in conjunction with the MATLAB ID, save the ShimmerBiophysicalProcessingLibrary_Rev_X_Y.jar file to a local directory on your PC (e.g. C:\Users\username\Documents\MATLAB\Shimmer Matlab Instrument Driver vx.y) and add it to the Java dynamic class path in Matlab, using the following command:

```
javaaddpath('C:\Users\username\Documents\MATLAB\Shimmer Matlab Instrument Driver
vx.x\ ShimmerBiophysicalProcessingLibrary_Rev_X_Y.jar);
```

The examples *ppgtoheartrateexample.m* and ec*gtoheartrateexample.m* show how to use this functionality. A brief description of these examples can be found in section 4.5.

NOTE: The algorithms for estimating Heart Rate from ECG or PPG require the calibrated timestamp as input, which is demonstrated in the examples.

NOTE: The *ShimmerBiophysicalProcessingLibrary* update for *Shimmer* MATLAB™ *Instrument Driver v2.6* contains an improved ECGtoHR algorithm. For details refer to the ec*gtoheartrateexample.m* and the *ReadmeShimmerBiophysicalProcessingLibrary.txt*

For information on updating Java for MATLAB, see section 13.1.

4.5. Examples

The file, *plotandwriteexample.m*, contains a function which is used to demonstrate the use of the *ShimmerHandleClass*. Type *help plotandwriteexample* to get an explanation of the function.

The file, *orientation3Dexample.m*, contains a function which is used to demonstrate the ability of the *ShimmerHandleClass* to estimate the orientation of a Shimmer device in 3D and an example of how to visualise the orientation on screen. Type *help orientation3Dexample* to get an explanation of the function.

The file, *twoshimmerexample.m*, contains a function which is used to further demonstrate the use of the *ShimmerHandleClass*. Type *help twoshimmerexample* to get an explanation of the function.

The three ExG example files, *plotandwriteemgexample.m, plotandwriteecgexample.m* and *plotandwriteexgtestsignalexample.m*, demonstrate the ExG functionality for *Shimmer3* in combination with the *ExG Expansion Board*. For more information refer to Section 11 of this document.

In *ppgtoheartrateexample.m,* photoplethysmogram (PPG) data from an optical pulse sensor is converted to heart rate. The PPG data is pre-filtered with a second order Chebyshev low pass filter (LPF) with a corner frequency of 5Hz, by using *FilterClass.m*. This example makes use of the ShimmerBiophysicalProcessing Library.

In ec*gtoheartrateexample.m,* ECG data is converted to heart rate. The ECG data is pre-filtered with a second order Chebyshev low pass filter (LPF) with a corner frequency slightly smaller than the Nyquist frequency and a second order Chebyshev high pass filter (HPF) with a corner freq of 0.5Hz, by using *FilterClass.m*. This example makes use of the ShimmerBiophysicalProcessing Library.

Examples *plotandwriteecgleadoffdetectionexample.m*, *plotandwriteemgleadoffdetectionexample.m* show how to configure the lead-off detection for ECG and EMG data. When lead-off detection is enabled and an electrode does not make contact with the body or the electrode cable is unplugged, the corresponding lead-off signal changes accordingly. Lead-off detection is explained in more detail in section 11.

The example *plotandwritepressureandtemperatureexample.m* demonstrates how to plot and write pressure and temperature data from the BMP180/BMP280 sensor on a Shimmer3 unit.

5. Using the Instrument Driver

5.1. Plotandwriteexample

The best way to start using the instrument driver is to go through the *plotandwriteexample.m* mentioned in the previous section. In this section, some key functions within the example which users should take note of when using the instrument driver are presented.

- *shimmer = ShimmerHandleClass(comPort);*
    - creates a *ShimmerHandleClass* which takes in a string value of the Com Port given as the input argument *comPort*; each Shimmer device which has been paired to the PC will have a Com port associated with it.
- *shimmer.connect;*
    - connects the PC over Bluetooth to the Shimmer device whose Com port was specified in the *comPort* field for the *ShimmerHandleClass*.
- *shimmer.setsamplingrate(51.2);*
    - transmits a command to set the sampling rate of the Shimmer device. A list of supported sampling rates can be found in the Resources folder.
- *shimmer.setinternalboard('9DOF');*
    - specifies which daughter board is attached to the Shimmer device you have connected to; in the example, the *Shimmer IMU 9DoF daughterboard* is selected.
- shimmer.setenabledsensors(SensorMacros.ACCEL,1,SensorMacros.MAG,1,...
  SensorMacros.GYRO,1));
    - transmits a command to the Shimmer device, telling it which sensors it should enable; in the example, the gyroscope, magnetometer and accelerometer are enabled. (SensorMacros is an instance of the class SetEnabledSensorsMacrosClass, see section 4.3).
- *shimmer.start;*
    - transmits a start streaming command to the Shimmer device.
- *shimmer.stop;*
    - transmits a stop streaming command to the Shimmer device.
- shimmer.disconnect;
    - disconnects the Bluetooth connection between the PC and the Shimmer device.

Readers should note that *Timestamp* data can be returned in a raw (*RAW*) and in a calibrated (*CAL*) format. RAW timestamp data is generated from the crystal oscillator on the Shimmer which has a frequency of 32768 Hz. It is a 16-bit value and will loop around 0 when it exceeds 65536. CAL timestamp data is in units of milliseconds.

5.2. List of commands

Table 5-1 contains the list of commands available in the *ShimmerHandleClass*. The "Usage" column denotes the versions of Shimmer hardware with which each command is compatible: *Shimmer2* (2), *Shimmer2r* (2r) and/or *Shimmer3* (3).

Command	Description	Usage
setsamplingrate	Set the sampling rate of the Shimmer.	2/2r/3
setenabledsensors	Enables/disables the sensors on the Shimmer.	2/2r/3
setconfigbyte0	Set the config byte0 on the Shimmer.	2/2r
setfivevoltreg	Set the 5 volt regulator bit on the Shimmer.	2/2r
setpmux	Set the PMux bit on the Shimmer.	2/2r
setledblink	Set which LED is blinking on the Shimmer.	2/2r/3
setaccelrange	Set the accelerometer range of the Shimmer.	2/2r/3
setgsrrange	Set the Gsr Range on the Shimmer.	2/2r/3
setmagrange	Set the Mag Range on the Shimmer.	2/2r/3
setmagrate	Set the Mag Data Rate on the Shimmer.	2/2r/3
setinternalboard	Sets the internal daughter board on the Shimmer.	2/2r/3
setexternalboard	Sets the external daughter board on the Shimmer.	2/2r/3
setgyroinusecalibration	Enable/disable gyro in-use calibration.	2/2r/3
setbuffersize	Set the number of samples sent in each data packet.	2/2r/3
setemgcalibrationparameters	Store the EMG calibration parameters on the Shimmer.	2/2r/3
setecgcalibrationparameters	Store the ECG calibration parameters on the Shimmer.	2/2r/3
getcomport	Get the Com Port of the Shimmer.	2/2r/3
getstate	Get the state of the Shimmer.	2/2r/3
getshimmerversion	Get the version number of the Shimmer.	2/2r/3
getsamplingrate	Get the sampling rate of the Shimmer.	2/2r/3
getconfigbyte0	Get the config byte0 setting of the Shimmer.	2/2r
getfivevoltreg	Get the 5 volt Regulator setting of the Shimmer.	2/2r/3
getpmux	Get the PMux setting of the Shimmer.	2/2r
getaccelrange	Get the accelerometer range of the Shimmer.	2/2r/3
getgsrrange	Get the gsr range of the Shimmer.	2/2r/3
getmagrange	Get the mag range of the Shimmer.	2/2r/3
getconfigbytes	Get the config bytes setting (only config byte0 for Shimmer2 , Shimmer2r)	2/2r/3
getinternalboard	Get the internal board setting of the Shimmer.	2/2r/3
getexternalboard	Get the external board setting of the Shimmer.	2/2r/3
getcalibrationparameters	Get calibration parameters for Accel/Mag/Gyro.	2/2r/3
getenabledsignalnames	Get the names of the enabled sensor signals.	2/2r/3
getsignalname	Get the name of a sensor signal.	2/2r/3

getsignalindex	Get the index of a sensor signal.	2/2r/3
getdata	Get all available sensor data.	2/2r/3
getpercentageofpacketsreceived	calculate percentage of packets received.	2/2r/3
connect	Connect to the Shimmer over Bluetooth.	2/2r/3
start	Send start streaming command to the Shimmer.	2/2r/3
stop	Send stop streaming command to the Shimmer.	2/2r/3
toggleLED	Send command to the Shimmer to toggle the red LED.	2/2r/3
disconnect	Close serial connection with the Shimmer.	2/2r/3
setinternalexppower	Enable to power the external sensor when using the Shimmer GSR+ Expansion Board or Resistance input of Bridge Amplifier+ Expansion Board	3
getuncalibrateddata	Get uncalibrated data from the data buffer. Note: Deprecated function, use getdata instead.	2/2r/3
getexggain	Get the exg gain.	3
getexgrate	Get the exg rate.	3
getinternalexppower	Get the internal expansion power setting.	3
getpressureresolution	Get the pressure resolution.	3
getaccellpmode	Get acceleration low power mode setting	3
getaccelhrmode	Get acceleration high resolution mode setting	3
setaccelhrmode	Set acceleration high resolution mode	3
setaccellpmode	Set acceleration low power mode	3
setgyrorate	Set the data rate of the gyroscope.	3
setaccelrate	Set the data rate of the digital accelerometer.	3
setgyrorange	Set the range of the gyroscope.	3
setpressureresolution	Set the pressure resolution.	3
setconfigbytes	Set the config bytes.	3
setdefaultecgparameters	Set default ecg parameters.	3
setdefaultemgparameters	Set default emg parameters.	3
setexgconfiguration	Set the exg configuration.	3
setexggain	Set the exg gain.	3
setexgrate	Set the exg rate.	3
setexgtestsignalparameters	Set default exg testsignal parameters.	3
deprecatedgetdata	Get any type of available sensor data	2/2r/3
disableallsensors	Disable all sensors	2/2r/3
getbaudrate	Get baudrate setting	3
getexgleadoffcomparatorthreshold	Get lead-off comparator threshold setting	3
getexgleadoffdetectioncurrent	Get lead-off detection current setting	3
getexgleadoffdetectionmode	Get lead-off detection mode setting	3
getexgreferenceelectrodeconfiguration	Get ExG reference electrode configuration	3
getorientation3D	Get 3D orientation setting	3
setorientation3D	Set 3D orientation	3
getexpboardid	Get Expansion Board ID	3
getsdcarddirectoryname	Get SD card directoryname	3
getstatus	Get status	3

setbaudrate	Set baudrate	3
setexgleadoffcomparatorthreshold	Set ExG lead-off comparator threshold	3
setexgleadoffdetectioncurrent	Set ExG lead-off detection current	3
setexgleadoffdetectionmode	Set ExG lead-off detection mode	3
setexgreferenceelectrodeconfiguration	Set ExG reference electrode configuration	3
startdatalogandstream	Send start logging+streaming command to the Shimmer	3
resettodefaultconfiguration	Reset Shimmer configuration to default.	3
getrealtimeclock	Get Real Time Clock value set on the Shimmer	3
setrealtimeclock	Set Real Time Clock on Shimmer with PC System time	3
getbatteryvoltage	Get Shimmer Battery Voltage in Connected state	3
stopdatalogandstream	Send stop logging+streaming command to the Shimmer	3
startloggingonly	Send start logging only command to the Shimmer	3
stoploggingonly	Send stop logging only command to the Shimmer	3
disablevbattfreq	Disable sending battery voltage while streaming	3
enabletimestampunix	Enable PC system timestamps	3

Table 5-1 ShimmerHandleClass Commands

For further information on each command, either use the MATLAB™ help function or directly refer to the *ShimmerHandleClass.m* file. To use MATLAB™ help, select (highlight) the command and press F1 as shown in the example in Figure 5-1.

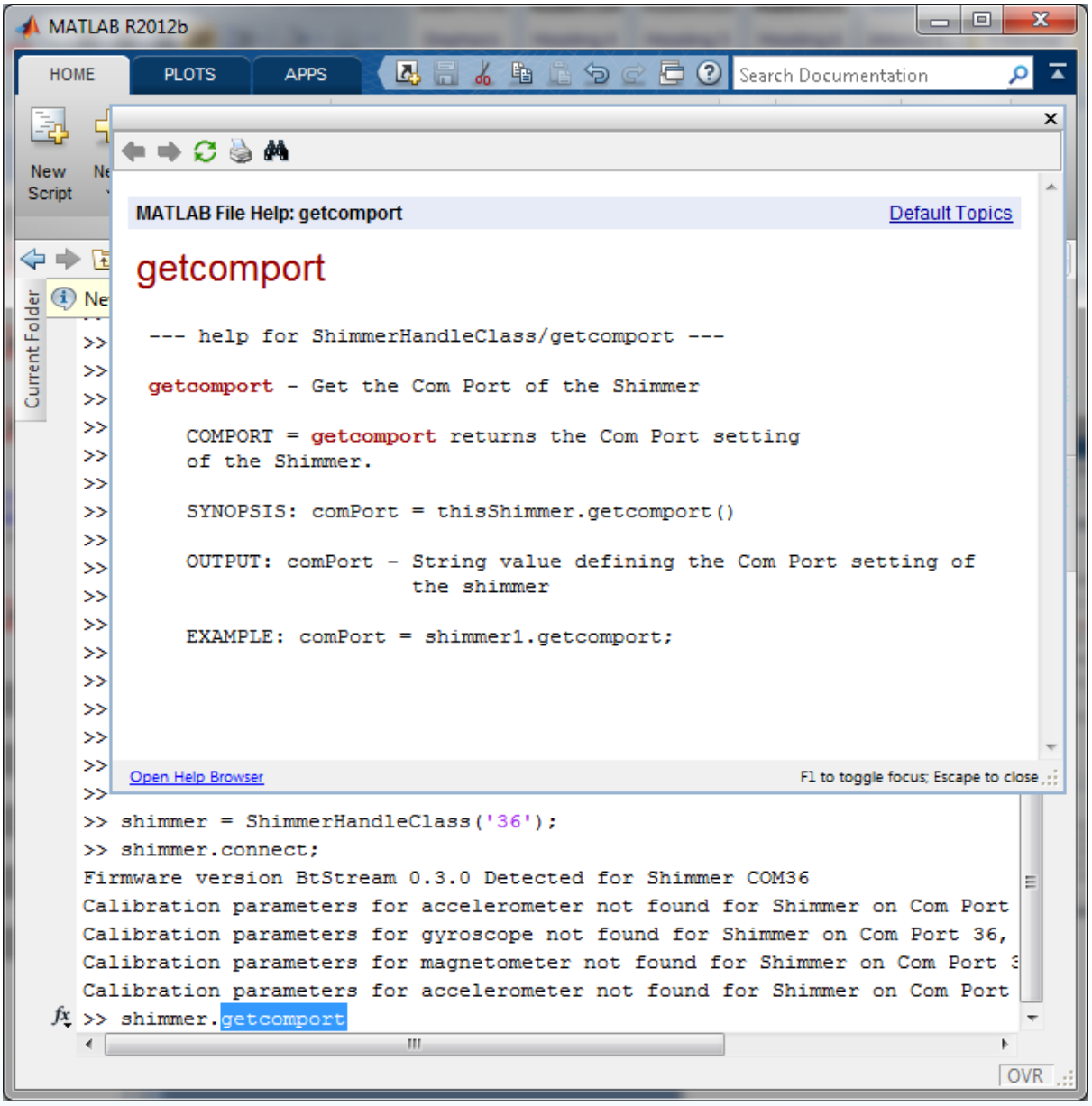

Figure 5-1: Using Help

5.3. Shimmer State Machine

The Shimmer essentially behaves as a state machine. Figure 5-2 illustrates the behaviour of the state machine.

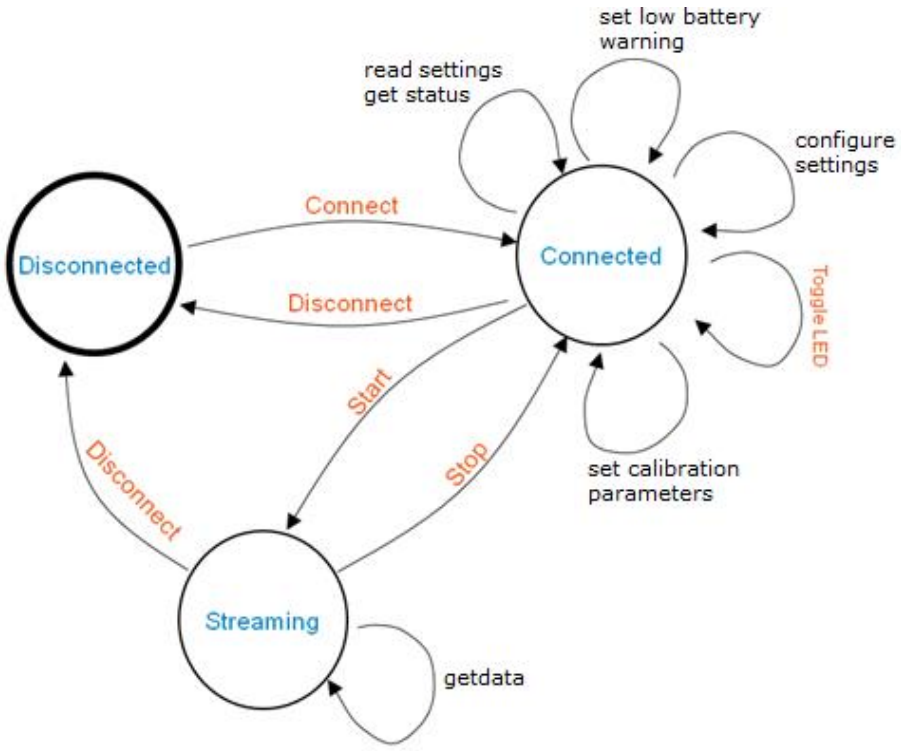

Figure 5-2: Shimmer State Machine

The Shimmer state machine has 3 possible states, *Disconnected*, *Connected* and *Streaming*. The default state is *Disconnected*. Action Methods are used to transition from one state to another (apart from *ToggleLed*) as illustrated by the orange text in Figure 5-2. These Action Methods are explained in more detail in Table 5-2.

For setting calibration parameters, read or configure settings, get status updates or set the low battery warning the Shimmer needs to be in the *Connected* state.

To capture data with the *getdata* method the Shimmer needs to be in *Streaming* state.

A priori State	**Action Command**	**A posteriori State**	Description
Disconnected	Connect	Connected	Establishes a connection with the COM Port/Shimmer defined at the input **COM Port**
Connected	Disconnect	Disconnected	Closes the connection with the COM Port/Shimmer defined at the input **COM Port**
Connected	Start / Startdatalogandstream	Streaming	Starts data streaming from the Shimmer device
Connected	Toggle LED	Connected	Toggles the red LED on the Shimmer
Streaming	Stop	Connected	Stops data streaming from the Shimmer device
Streaming	Disconnect	Disconnected	Stops data streaming and closes the connection with the COM Port/Shimmer defined at the input **COM Port**

Table 5-2: Action methods

5.4. Data format

When the Action Method *Connect* is called to change the Shimmer state to *Connected*, see Table 5-2 for details, the function *inquiry* is called that sends an *Inquiry Command* to the Shimmer. The Shimmer responds with an *Inquiry Response* in the form of a serial string array. This string array is parsed by means of the function *parseinquiryresponse*, which in turn calls the function *interpretdatapacketformat* to interpret the data packet format output of *parseinquiryresponse*. The data packet format is an array of bytes which identifies the sensor signals located in each channel in the data packet based on sensors currently enabled on the Shimmer. The different values associated with each signal are outlined in Table 5-3 and Table 5-4 for *Shimmer2/2r* and *Shimmer3*, respectively.

Signal Name	Byte Value	Signal Datatype
Accelerometer X*	0	u12
Accelerometer Y*	1	u12
Accelerometer Z*	2	u12
Gyroscope X*	3	u12
Gyroscope Y*	4	u12
Gyroscope Z*	5	u12
Magnetometer X*	6	i16
Magnetometer Y*	7	i16
Magnetometer Z*	8	i16
ECG_RA_LL	9	u12
ECG_LA_LL	0A	u12
GSR Raw	0B	u16
GSR Res	0C	u16
EMG	0D	u12
AnEx A0	0E	u12
AnEx A7	0F	u12
Strain Gauge High	10	u12
Strain Gauge Low	11	u12
Heart Rate	12	u16 (u8 in legacy FW versions)

Table 5-3: Signal names, byte values and data types for possible sensor signals in the Data Packet Format array for Shimmer2/2r

Signal Name	Byte Value	Signal Datatype
Low Noise Accelerometer X*	0	u12
Low Noise Accelerometer Y*	1	u12
Low Noise Accelerometer Z*	2	u12
Battery	3	u12
Wide Noise Accelerometer X*	4	i16
Wide Noise Accelerometer Y*	5	i16
Wide Noise Accelerometer Z*	6	i16
Magnetometer X*	7	i16†
Magnetometer Y*	8	i16†
Magnetometer Z*	9	i16†
Gyroscope X*	A	i16†
Gyroscope Y*	B	i16†
Gyroscope Z*	C	i16†
External ADC 7	D	u12
External ADC 6	E	u12
External ADC 15	F	u12
Internal ADC 1	10	u12
Internal ADC 12	11	u12
Internal ADC 13	12	u12
Internal ADC 14	13	u12
BMP180 Temperature*	1A	u16†
BMP180 Pressure*	1B	u24†
GSR Raw	1C	u16
ExG Chip1 Status*	1D	u8
ExG1 Ch1*	1E	i24†
ExG1 Ch2*	1F	i24†
ExG Chip2 Status*	20	u8
ExG2 Ch1*	21	i24†
ExG2 Ch2*	22	i24†
ExG1 Ch1 16bit*	23	i16†
ExG1 Ch2 16bit*	24	i16†
ExG2 Ch1 16bit*	25	i16†
ExG2 Ch2 16bit*	26	i16†
Bridge Amplifier High*	27	u12
Bridge Amplifier Low*	28	u12

Table 5-4: Signal names, byte values and data types for possible sensor signals in the Data Packet Format array for Shimmer3 († denotes MSB first; otherwise LSB first)

6. Usage Considerations

6.1. General

In *Shimmer* MATLAB™ *Instrument Driver v2.3* the function *getdata* was subject to a major overhaul and is now used to retrieve all available data from all the enabled sensors. The function returns either uncalibrated data, calibrated data or both uncalibrated and calibrated data for all enabled sensors and is called as like this for the object *shimmer* of *ShimmerHandleClass*:

```
shimmer.getdata('u');        % for uncalibrated data
shimmer.getdata('c');        % for calibrated data
shimmer.getdata('a');        % for all data, i.e. uncalibrated and calibrated data
```

6.2. Deprecatedgetdata

The *getdata* function from *Shimmer* MATLAB™ *Instrument Driver v2.2* and older is deprecated and is called *deprecatedgetdata*. The function relies on the *capturedata* function which reads data from the buffer. The user should note that once the *capturedata* function is completed, the buffer is cleared. Thus, to retrieve data from multiple sensors or in multiple formats, data retrieval functions should NEVER be used consecutively; instead, multiple arguments should be used in a single call to the data retrieval function. The figure below shows the wrong way (left) and the correct way (right) to retrieve calibrated gyroscope and accelerometer data.

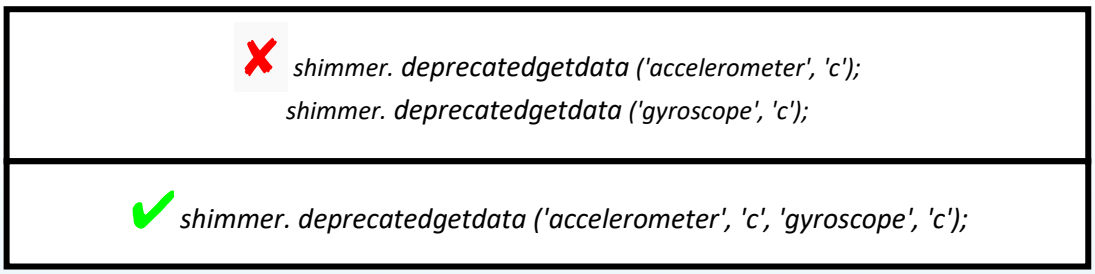

Figure 6-1: Retrieving Data

The *deprecatedgetdata* function returns four different arrays, e.g.:

```
[sensorData,signalName,signalFormat,signalUnit] =
        Shimmer1.deprecatedgetdata('accelerometer','c');.
```

The first array, *sensorData*, holds the sensor data, whilst the other three arrays describe the content of the data. The second array identifies the Property/Signal Name; this is the name of the signal (e.g. Timestamp, Accelerometer X, EMG, etc). The third array identifies the format of the data, (e.g. CAL or RAW). The fourth array identifies the units of the signal (e.g. *degrees/s*, *millivolts*, etc.).

Note: An asterisk after the *Units* indicates that default offset and sensitivity values from the sensor datasheet have been used to calibrate the sensor data (e.g. *millivolts**).

6.3. Differences between *Shimmer2r* and *Shimmer3*

When using the *Shimmer MATLAB™ Instrument Driver*, readers should take note of some fundamental differences between *Shimmer2r* and *Shimmer3*. The first is that the following two commands for *Shimmer2r* hardware are not available for *Shimmer3*:

SET_5V_REGULATOR_COMMAND (when using the *External Expansion Board* with *Shimmer2r*)

SET_PMUX_COMMAND (when monitoring battery voltage on *Shimmer2r*)

Inertial Sensors

In terms of accelerometers, the *Shimmer3* has more than a single Accelerometer. Currently the *Shimmer* MATLAB™ *Instrument Driver* supports the Low Noise analog accelerometer (KXRB5-2042) and the Wide Range Accelerometer (LSM303DLHC). Since *Shimmer* MATLAB™ *Instrument Driver v2.2* using the *getdata* method to retrieve accelerometer data, only inserts the Low Noise and Wide Range Accelerometer for *Shimmer3* as shown in Figure 6-2.

A	B	C	D	E	F	G	H	I	J	K	L
TimeStamp	LowNoiseAccelerometerX	LowNoiseAccelerometerY	LowNoiseAccelerometerZ	GyroscopeX	GyroscopeY	GyroscopeZ	MagnetometerX	MagnetometerY	MagnetometerZ	VSenseBatt	VSenseBatt1
NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER	NUMBER
Time Stamp	Low Noise Accelerometer X	Low Noise Accelerometer Y	Low Noise Accelerometer Z	Gyroscope X	Gyroscope Y	Gyroscope Z	Magnetometer X	Magnetometer Y	Magnetometer Z	VSenseBatt	VSenseBatt
19.531	-0.40964	0.26506	9.7229	0	0	0	-162	471	579	2873	4209.5
39.063	-0.42169	0.24096	9.7108	43.298	-2.5038	23.985	-159	479	591	2865	4197.8
58.594	-0.44578	0.24096	9.6988	0.36641	1.7863	2.4427	-160	491	580	2850	4175.8
78.125	-0.43373	0.25301	9.6627	0.24427	1.7252	2.3511	-162	504	575	2865	4197.8
97.656	-0.39759	0.21687	9.6627	0.10687	1.6489	2.3053	-169	496	587	2865	4197.8
117.19	-0.40964	0.21687	9.7108	0.35115	1.7099	2.3969	-161	475	578	2873	4209.5
136.72	-0.43373	0.22892	9.7229	0.30534	1.8473	2.3206	-171	483	584	2864	4196.3
156.25	-0.42169	0.24096	9.6506	0.50382	1.7557	2.2443	-162	493	580	2850	4175.8
175.78	-0.42169	0.25301	9.6506	0.36641	1.8931	2.2748	-159	478	588	2868	4202.2
195.31	-0.44578	0.22892	9.7349	0.42748	1.6794	2.2595	-165	495	588	2862	4193.4
214.84	-0.44578	0.22892	9.6988	0.30534	1.7405	2.4122	-159	476	586	2852	4178.8
234.38	-0.43373	0.25301	9.6386	0.42748	1.8321	2.2901	-173	495	589	2867	4200.7

Figure 6-2: Extra Fields for Accelerometer

In earlier versions of the instrument driver three extra fields: 'Accelerometer X', 'Accelerometer Y', 'Accelerometer Z') were inserted with duplicated values of either the Low Noise or Wide Range Accelerometer. These extra fields were included to maintain backwards compatibility in case 'Accelerometer X', 'Accelerometer Y', 'Accelerometer Z' were used by developers using the instrument driver.

Also, readers should note that the data rate of the gyroscope (MPU9150), accelerometer (LSM303DLHC) and magnetometer (LSM303DLHC) are configurable for the *Shimmer3*.

Pressure Sensor

The *Shimmer3* also includes a Pressure sensor (BMP180). The pressure sensor's resolution is configurable (ultra low power, standard, high resolution and ultra high resolution). Users should take note of the Max Conversion time when selecting the sampling rate and the resolution mode; further details can be found in the BMP180 data sheet.

Optical Pulse

There is an external sensor option when using the Shimmer *GSR+ Expansion Board* for Shimmer3, which is not available for *Shimmer2r*. Among other things, this can be used to measure photoplethysmogram (PPG) data, using the *Shimmer Optical Pulse Sensor Probe*. To measure PPG with a *GSR+ Expansion Board*, the following must be enabled:

- Int ADC A13/PPG - The output of the sensor connected to the *GSR+ Expansion Board* is measured by the internal ADC A13
- Internal Exp Power - To power the external sensor, e.g. PPG.

For example, when using the *GSR+ Expansion Board,* executing the following commands will enable the internal expansion power and the Internal ADC A13 channel:

SensorMacros = SetEnabledSensorsMacrosClass;

shimmer.setinternalboard('GSR');

shimmer.setenabledsensors(SensorMacros.INTA13,1);

shimmer.setinternalexppower(1);

PPG data output will be under the signal name *Internal ADC A13*. For further information on the *GSR+ Expansion Board*, users are encouraged to read the *GSR+ Expansion Board User Guide*.

PPG data can also be measured on *Shimmer3* via the *PROTO3 Deluxe Expansion Board*. For details on which channels should be enabled, please refer to the *Optical Pulse Sensing Probe User Guide* .

ECG and EMG

Support for using the *ExG Expansion Board* for *Shimmer3* is incorporated in the instrument driver from *v2.1* and later, allowing ECG or EMG data to be measured. In order to use the *ExG Expansion Board* with *Shimmer3,* the *internalboard* setting must be set to *'EXG'*, *'ECG'* or *'EMG'* and the relevant sensors need to be enabled. For *Shimmer3*, the ExG data resolution is either 16-bit or 24-bit. For *Shimmer2/2r*, the ECG/EMG data resolution is always 12-bit.

For example, executing the following commands:

SensorMacros = SetEnabledSensorsMacrosClass;

shimmer.setinternalboard('EMG');

shimmer.setenabledsensors(SensorMacros.EMG,1);

sets the internalboard to 'EMG' and enables the sensor 'EMG'.

In Section 11 of this document, the ExG functionality in the *Shimmer* MATLAB™ *Instrument Driver v2.1* is further explained. For further information on using the *ExG Expansion Board* in combination with *Shimmer3*, users are also encouraged to read the *ExG User Guide for EMG* and/or the *ExG User Guide for ECG*.

Bridge Amplifier+

The *Bridge Amplifier+ Expansion Board* for *Shimmer3* has an extra input that can be used to measure resistance-based metrics, such as temperature. To use this input, the following must be enabled:

- Int ADC A1 - The output of the sensor connected to the *Bridge Amplifier+ Expansion Board* is measured on the *Internal ADC A1* Channel.
- Internal Exp Power - To power the external sensor.

Users should refer to the *Shimmer3 Bridge Amplifier+ User Guide* for more details.

Get Expansion Board ID

New for *Shimmer3* in *Shimmer* MATLAB™ *Instrument Driver v2.3* is the function *getexpboardid* that returns an array containing the Expansion Board ID bytes of the Expansion Board that is connect to the Shimmer:

ID Byte 0 - Board ID

ID Byte 1 - Board Rev

ID Byte 2 - Special revision

Configurable Baud Rate

Also included in *Shimmer* MATLAB™ *Instrument Driver v2.3* and later is the option to configure the baud rate between the processor and the Bluetooth module of the Shimmer. The default baud rate is 115200 kB/s. Alternative baud rates can be set using *setbaudrate*. Refer to the help of this function for a list of valid baud rates. The function *getbaudrate* can be used to check what the currently set baud rate is.

LogAndStream FW

The *LogAndStream* firmware for *Shimmer3* is supported in *Shimmer* MATLAB™ *Instrument Driver v2.3* and later. This firmware support makes it possible to stream data over Bluetooth while logging the same data on the SD card. Please refer to the corresponding firmware user manual on our website for more information[4].

Key functions enabling *LogAndStream* support are:

getsdcarddirectoryname - returns the currently active SD card directory on the SD card of the Shimmer.

getstatus - returns the status of the *Shimmer3* that is connected: the status tell whether the Shimmer is docked/not docked, and actively sensing/not actively sensing. The ShimmerClass properties *Docked* and *Sensing* are updated accordingly.

startdatalogandstream - sends the command to the connected Shimmer to start logging and streaming at the same time.

stopdatalogandstream - sends the command to the connected Shimmer to stop logging and streaming at the same time. Since *Shimmer* MATLAB™ *Instrument Driver v2.6* the function *stop()* only stops streaming.

startloggingonly - sends the command to the connected Shimmer to start logging.

stoploggingonly - sends the command to the connected Shimmer to stop logging.

By means of the *getstatus()* function, *Shimmer* MATLAB™ *Instrument Driver v2.6* (and higher) detects whether a Shimmer is already logging data to its internal SD card when establishing a Bluetooth connection to this Shimmer.

NOTE: For *LogAndStream v0.6.0* and logging by pressing the User Button can only be started when the Shimmer is not in the *Disconnected* state.

NOTE: For older versions of the *Shimmer* MATLAB™ *Instrument Driver*, in combination with *LogAndStream v0.5.0* or older, pressing the User Button on the Shimmer was not supported and the Shimmer would go back to its Connected state.

NOTE: The ExG sensors and *Shimmer Dock* share the same port, therefore no ExG signals can be acquired when the Shimmer is docked.

[4] http://www.shimmersensing.com/support/wireless-sensor-networks-documentation/category/11

Reset the Shimmer configuration to default

For *Shimmer3* the function *resettodefaultconfiguration* is added since *Shimmer* MATLAB™ *Instrument Driver v2.4* to reset the configuration of the Shimmer to its default values:

Sensors - (Only) WR Accel, Gyro, Mag, Battery Voltage are enabled.

Ranges - AccelRange = 0; GyroRange=1; MagRange=1; GsrRange=4; PressureResolution=0.

Rates - SamplingRate=51.2Hz; AccelWideRangeDataRate=5; GyroRate=155; MagRate=6.

ExG - Use *setdefaultemgparameters/setdefaultecgparameters* to set default parameters for EMG/ECG after *resettodefaultconfiguration* has been called, or use *setexgconfiguration* for setting custom ExG settings.

7. Synchronisation

In *Shimmer* MATLAB™ *Instrument Driver v2.6* synchronisation to the System Time of the PC has been introduced. With the function *enabletimestampunix* this functionality can be enabled. When enabled, the last sample in each serial buffer gets a system timestamp in Unix format. The function *getdata* will return an extra signal *Time Stamp Unix* containing the system timestamp in Unix format.

The most recent system timestamp is stored in the class property *LastSampleSystemTimeStamp*.

> **NOTE**: Apart from added a timestamp to a common clock (System Time of the PC) the *Shimmer* MATLAB™ *Instrument Driver v2.6* does not facilitate in further synchronisation among multiple Shimmers.

8. Battery Monitoring and Low Battery Warnings

In the *Shimmer* MATLAB™ *Instrument Driver v1.4* and later, battery monitoring can be done by using the *setenabledsensors* function.

For *Shimmer2/2r*, battery monitoring is done via the same ADC channels that are used by ExpBoard A0 and ExpBoard A7; thus, while monitoring the battery you will be unable to use those ports. For *Shimmer3*, there is a dedicated battery monitoring channel.

There is also a low battery warning functionality built in, which will cause the green LED of the Shimmer device to turn yellow when the voltage has dropped below a specified value. By default, the value of the limit is set to 3.4 volt. This value can be specified via the function *setbattlimitwarning.* In order to use both battery monitoring and low battery notification on the Shimmer device, the battery voltage sensor has to be enabled prior to streaming. In the case of low battery, the warning is sent to the Shimmer device after the *getdata* is executed. When *getdata* is executed, the driver checks the battery data, and sends a command to change the LED on the Shimmer device if the battery value is below the limit. Users should note that after the warning is transmitted the ACK from the Shimmer device is only retrieved when *getdata* is executed again.

Note: Low battery notification is not supported on *Shimmer3* devices since deprecation of *BtStream* firmware. Low battery and empty battery indications are now automatically handled in *LogAndStream* firmware.

9. 3D orientation estimation

In the *Shimmer* MATLAB™ *Instrument Driver v1.5* and later, the 3D orientation of the Shimmer device can be estimated; for *Shimmer2/2r* this requires that a *Shimmer IMU 9DoF* daughterboard be attached to the mainboard, that the internal board be set to *9DOF* and that the accelerometer, gyroscope and magnetometer are all enabled.

The orientation estimates for each sample are calculated and output in quaternion format if the option, *'quaternion'*, is passed to the *getdata()* function. For an example of how this method is used, refer to the *orientation3Dexample.m* sample code, which allows the user to acquire data from the Shimmer, visualise the 3D orientation of the Shimmer and write the data to a file. The accelerometer, gyroscope and magnetometer should be calibrated prior to using the *Shimmer orientation3Dexample.m*; the *Shimmer 9DoF Calibration Application* is available on our website. for *Shimmer*, by default the low noise accelerometer is used for estimating the orientation. If this accelerometer is disabled, but the wide range accelerometer is enabled, the latter is used instead.

The *orientation3Dexample* displays a graphic representation of the 3D Orientation of the Shimmer, as shown in Figure 9-1. The graphic consists of an object with the outlines of a Shimmer and its dock connector.

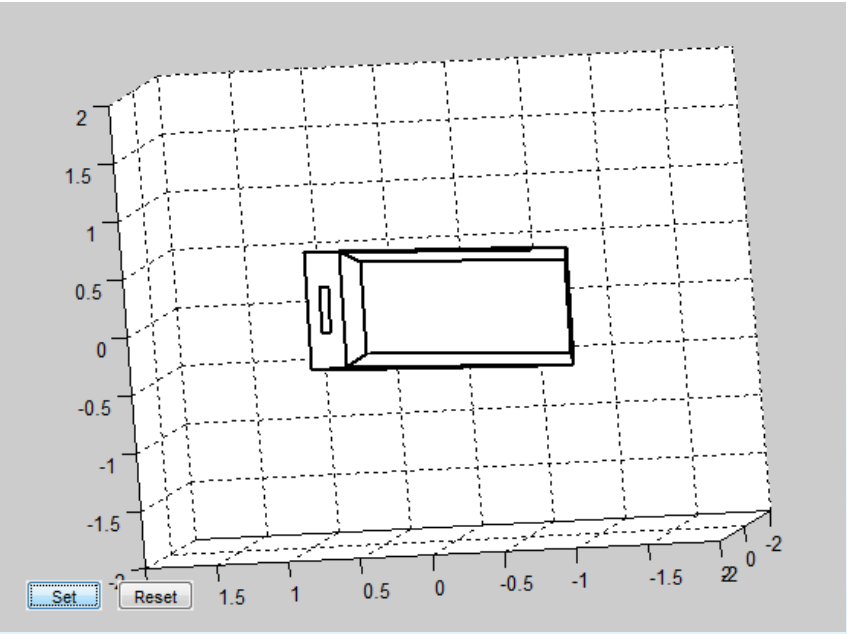

Figure 9-1: Shimmer outline and dock connector

Because the screen on which the graphic is being displayed has an unknown orientation, the visualised device may not initially appear to be aligned with the physical Shimmer unit. In order to align the graphic with the physical device, the user should place the Shimmer on a flat surface facing away from the screen as shown in Figure 9-2 and Figure 9-3 for *Shimmer3* and *Shimmer2r*, respectively. Then, the user should press the *Set* button.

Figure 9-2:Orientation for aligning Shimmer3

Figure 9-3:Orientation for aligning Shimmer2r + 9DoF daughterboard

After pressing the *Set* button, the orientation of the graphic will change to look like that in Figure 9-4 with the dock connector on the left side for *Shimmer3* and on the right side for the combination of *Shimmer2r* plus *Shimmer IMU 9DoF* daughterboard. This orientation should match that of the physical device and all further rotations of the device will be visualised relative to this orientation. To return to the initial orientation, simply press the *Reset* button.

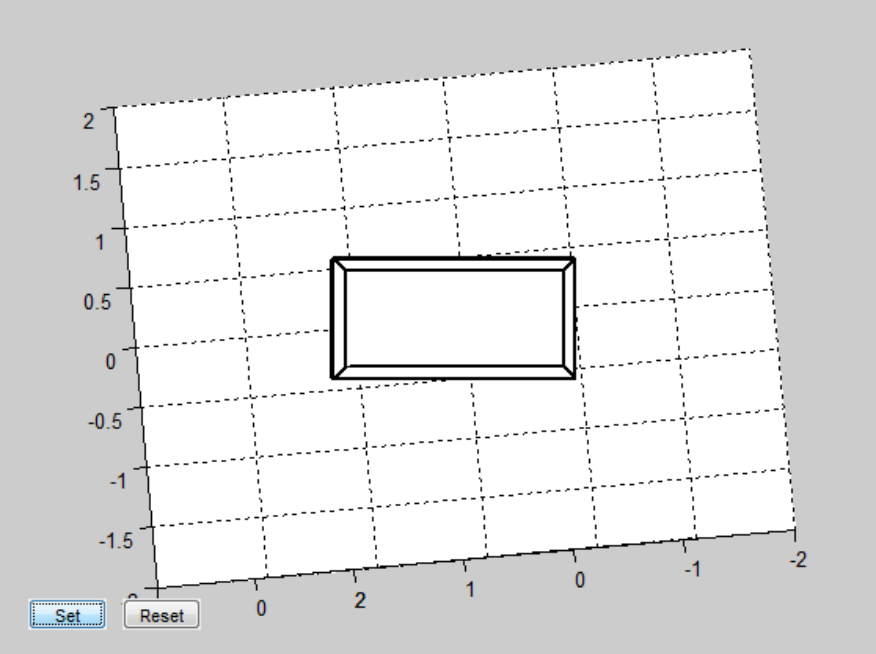

Figure 9-4: Orientation of Shimmer outline after pressing set

Note: It may take the graphic up to 10 seconds to converge to its initial orientation estimate when streaming starts; it is advisable to leave the device motionless during this settling time. When the graphic object stops visibly rotating, the initial orientation estimate can be assumed to have converged.

In the *Shimmer* MATLAB™ *Instrument Driver v2.3* the function *setorientation3D* is introduced to enable 3D orientation and to allow *getdata* to output data in quaternion format. The function *getorientation3D* can be used to check if 3D orientation is enabled.

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10. Gyroscope in-use calibration

In the *Shimmer* MATLAB™ *Instrument Driver v1.5* and later, the offset bias for the gyroscope on the Shimmer device can be estimated during use to improve calibration stability over time.

For *Shimmer2r*, this requires that a *Shimmer IMU 9DoF* or *Shimmer IMU Gyro* daughterboard be attached to the mainboard. The internal board needs to be set to *9DOF* or *Gyro* and the gyroscope must be enabled. For *Shimmer3*, the 9DoF sensors are all contained on the mainboard.

The method is enabled by calling the function, *setgyroinusecalibration*, with an argument of 1. If this method is enabled, the uncalibrated gyroscope data is continuously buffered in a buffer of length 2 seconds, and the function, *nomotiondetect*, is called from the *getdata* function to determine if the device is moving or motionless. If the device remains motionless for 2 seconds, the gyroscope offset bias vector is updated. For an example of how this method is enabled, refer to the *orientation3Dexample.m* sample code.

> **Note:** The updated value of the offset bias vector is used locally in the instrument driver only and is not sent to the Shimmer device.

11. ExG functionality for *Shimmer3*

Support for using *Shimmer3* with the *ExG Expansion Board* is incorporated in the *ShimmerHandleClass*.m of *Shimmer* MATLAB™ *Instrument Driver v2.1* and later.

The following examples are provided to demonstrate this functionality:

- *plotandwriteemgexample.m.*
- *plotandwriteecgexample.m.*
- *plotandwriteexgtestsignalexample.m*.

The first two examples explain how to plot and write EMG and ECG data, respectively. The third example shows how to use the ExG testsignal that is generated by the chips on the *ExG Expansion Board*; this is a square wave with a frequency of 1Hz and an amplitude of ±1mV.

11.1. Key Functions

Some key functions regarding ExG are highlighted below:

- *setinternalboard*
    - The internalboard can be set to 'EXG', 'ECG' or 'EMG'.
- *setenabledsensors*
    - The following ExG sensors can be set: EMG, ECG, EXG1, EXG2, EMG 16BIT, ECG 16BIT, EXG1 16BIT, EXG2 16BIT. If EMG, ECG, EMG 16BIT or ECG 16BIT is set, the default configuration parameters for ECG or EMG are automatically loaded, as appropriate; see setdefaultemgparameters, setdefaultecgparameters.
    - The ExG data output format can be either 16-bit or 24-bit. For 16-bit format '16BIT' needs to be appended to the name of the sensor, as shown above.
- *setexgtestsignalparameters(chipIdentifier)*
    - Sets the ExG configuration for the testsignal for SENSOR_EXG1 or SENSOR_EXG2 depending on the value of the chipIdentifier,which can have a value of either 1 or 2. If the testsignal for a sensor is enabled, the testsignal is fed to both channels of that sensor.
- *setdefaultemgparameters*
    - When sensor 'EMG' or 'EMG 16BIT' is set (shimmer.setenabledsensors('EMG',1) e.g.), the default configuration parameters for EMG are loaded automatically.
    - By default, the EMG data rate is set as close to the sampling rate of the Shimmer as possible and always higher than this sampling rate.
    - For details on the EMG parameters, refer to the *ExG User Guide for EMG.*

- *setdefaultecgparameters*
    - When sensor 'ECG' or 'ECG 16BIT' is set (shimmer.setenabledsensors('ECG',1) e.g.), the default configuration parameters for ECG are loaded automatically.
    - By default, the ECG data rate is set as close to the sampling rate of the Shimmer as possible and always higher than this sampling rate.
    - For details on the ECG parameters, refer to the *ExG User Guide for ECG.*
- *setexgconfiguration*
    - Sets the ExG configuration parameters. Refer to *ExG User Guide for ECG / ExG User Guide for EMG* for detailed information.
- *setexgreferenceelectrodeconfiguration*
    - Set the ExG reference electrode configuration. Valid values for this function are: **0..15**. The supported standard values are for ECG: **0** - *Fixed Potential* and **13** - *Inverse Wilson Central Terminal* (default), and for EMG: **0** - *Fixed Potential* (default) and **3** - *Inverse of Ch1*. Refer to the datasheet of the ADS1292R for details on non-standard values.
- *setexggain*
    - Sets the ExG gain. Use the MATLAB™ help function to check the valid gain settings.
- *setexgrate*
    - Sets the ExG rate. Use the MATLAB™ help function to check the valid rate settings.

For more information on each command regarding the ExG functionality in the *Shimmer MATLAB™ Instrument Driver*, either use the MATLAB™ help function or directly refer to the *ShimmerHandleClass.m* file.

Users may also refer to the *ExG User Guide for EMG* and *ExG User Guide for ECG* for more information about the use of the *ExG Expansion Board* with *Shimmer3.*

11.2. Filtering

As described in the *ExG User Guide for ECG / ExG User Guide for EMG* filtering the ExG signals might be necessary in order to enhance the desired information by suppressing undesired frequency components.

In the *plotandwriteemgexample.m and plotandwriteecgexample.m* examples, filters are implemented. Please note that there are no functions for filtering in the *ShimmerHandleClass.* For filtering in the examples, functions of the class, *FilterClass.m*, are used.

In case of measuring EMG, we recommend the use of a high pass filter with a corner frequency of 5Hz. When measuring ECG in a diagnostic setting, we recommend setting the corner frequency of

the high pass filter to 0.05Hz. For ECG monitoring applications, we recommend setting this corner frequency to 0.5Hz.

The band stop filter is used to suppress mains interference. If the mains frequency (power line frequency) in your area is 50Hz, set the corner frequencies of the band stop filter to 49Hz and 51Hz. For a mains frequency of 60Hz, set the corner frequencies to 59Hz and 61Hz. For details on the filter settings refer to *FilterClass.m*.

11.3. ExG lead-off detection

In *Shimmer* MATLAB™ *Instrument Driver v2.3* ExG lead-off detection is introduced. The following functions have been introduced to enable this functionality.

setexgleadoffdetectionmode	- sets detection mode to *off* or to *DC Current*
setexgleadoffcomparatorthreshold	- sets comparator threshold
setexgleadoffdetectioncurrent	- sets detection current

The functions: *getexgleadoffdetectionmode, getexgleadoffcomparatorthreshold* and *getexgleadoffdetectioncurrent* return the active settings.

The lead-off detection information is incorporated in the ExG status bytes, which are included in the uncalibrated ExG data. When lead-off detection is enabled, by setting the lead-off detection mode to *DC Current,* the information inside the ExG status bytes is parsed out in lead-off detection bits, one for each electrode input. These lead-off detection bits are included in the calibrated data.

The comparator threshold and detection current that are set by default when the lead-off detection mode is set to *DC Current* are: lead-off detection current = 22nA, lead-off comparator threshold = Pos: 90% - Neg:10%. These values have been found to work well in testing, but can be changed by the user if desired.

In *plotandwriteecgleadoffdetectionexample* and p*lotandwriteemgleadoffdetectionexample*, uncalibrated as well as calibrated data are retrieved, i.e. *getdata('a')* is called, therefore the ExG status bytes and the lead-off detection bits are included in the data. (If only the calibrated data is acquired, i.e. *getdata('c')* is called, then the ExG status bytes are not included.)

NOTE: Refer to the help of the functions, the provided examples, and the datasheet of the ADS1292R for more detailed information on ExG lead-off detection.

ECG

Figure 11-1 - is created as a result of running *plotandwriteecgleadoffdetectionexample* and disconnecting the connectors one by one - shows where the lead-off detection bits of the first ExG status byte *EXG1 STA* are located and to which input they correspond. Figure 11-2 shows the same but then for the second ExG status byte *EXG2 STA*.

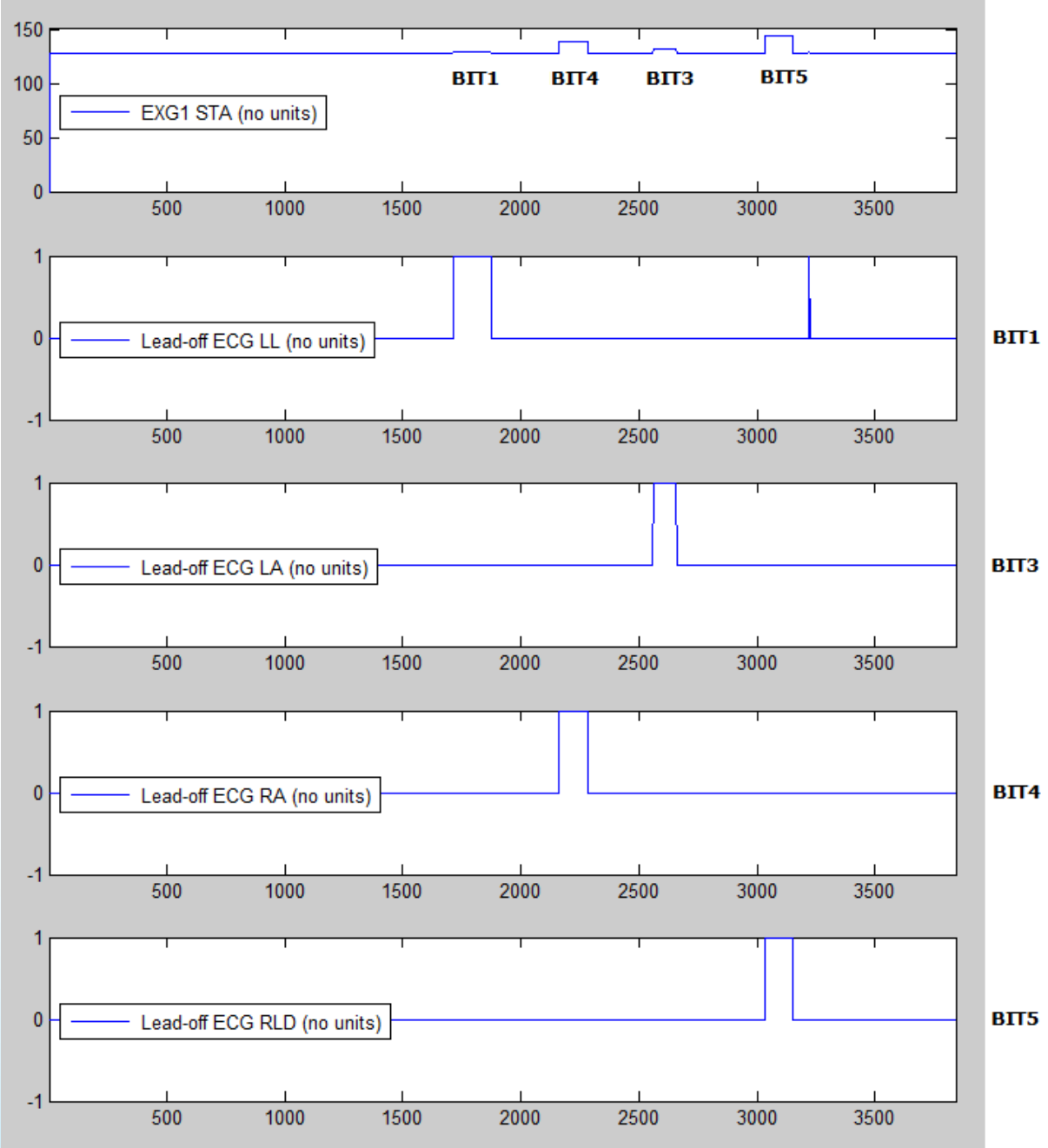


Figure 11-1: ExG1 Status byte with parsed out lead-off detection bits (ECG).

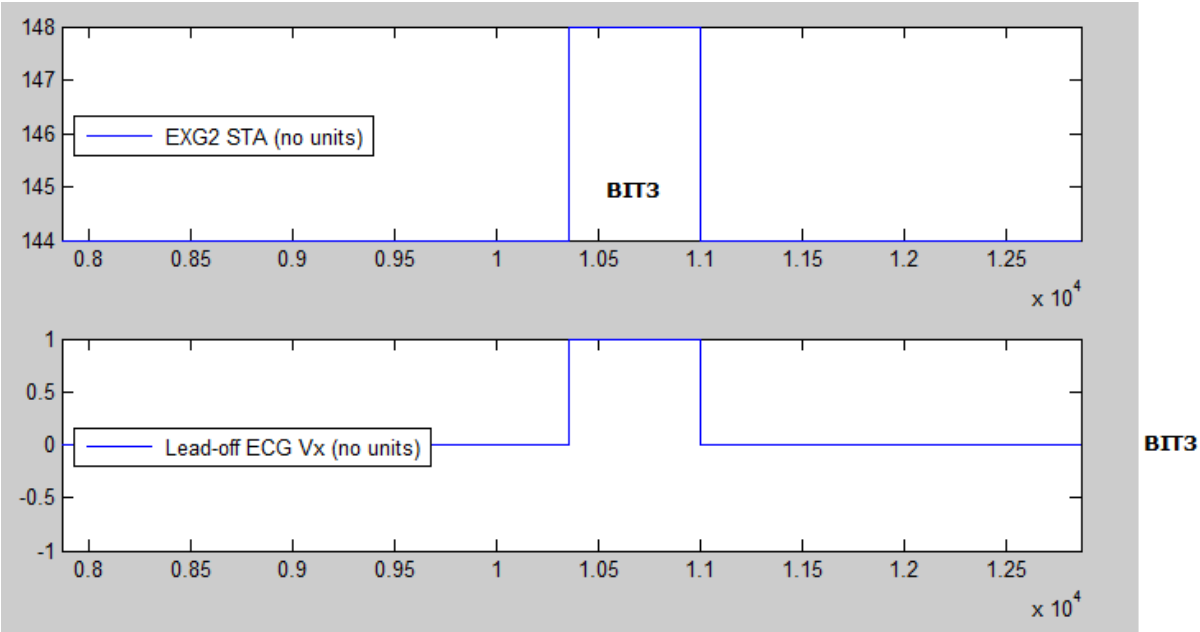


Figure 11-2: ExG2 Status byte with parsed out lead-off detection bit (ECG).

EMG

Figure 11-3 - shows where the lead-off detection bits of the first ExG status byte *EXG1 STA* are located and to which input they correspond for EMG. The same is shown for the second ExG status byte *EXG2 STA* in Figure 11-4.

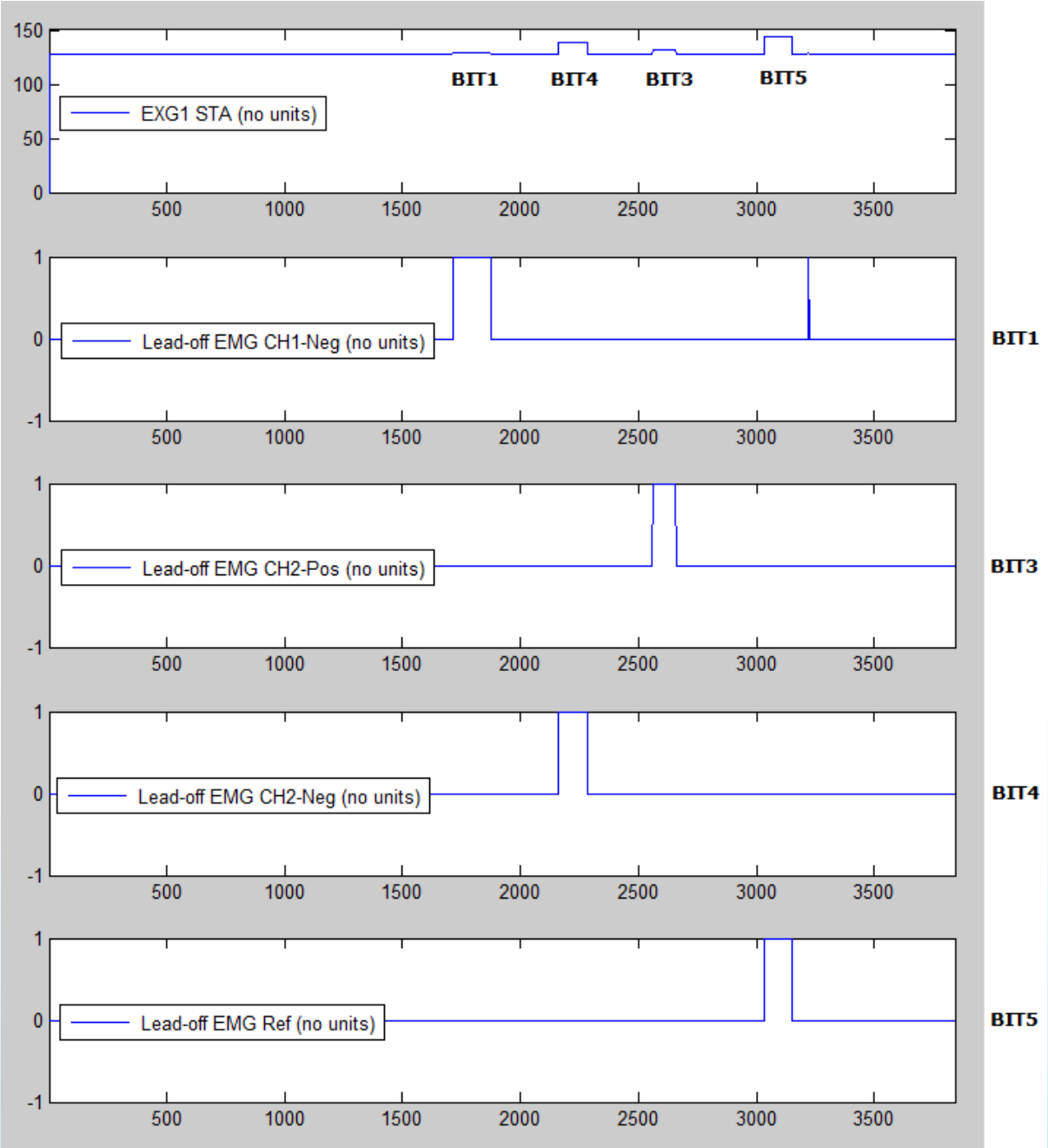


Figure 11-3: ExG1 Status byte with parsed out lead-off detection bits (EMG).

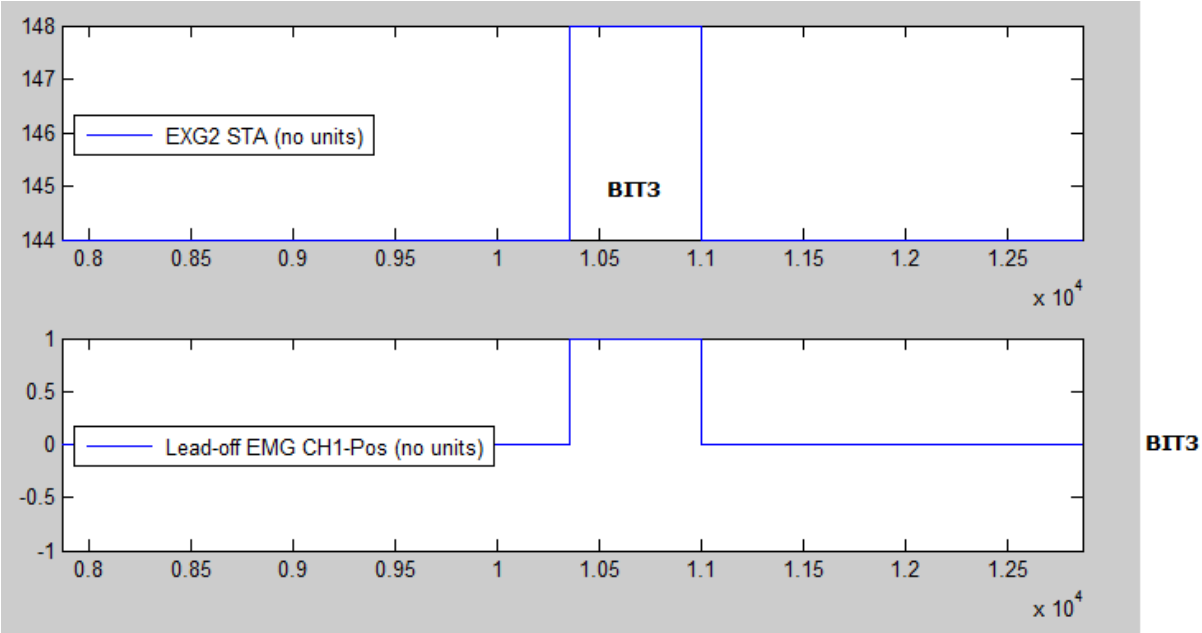


Figure 11-4: ExG2 Status byte with parsed out lead-off detection bits (EMG).

NOTE: The EMG Ref lead-off detection only functions if the ExG reference electrode configuration is set to *Inverse of* Ch1 (not default).

12. Verisense

For further information please visit out GitHub repository. Moving forward this will replace the user guide as the primary means of providing information on Shimmer's Matlab API.

13. Appendices

13.1. How to update Java for MATLAB

For updating the Java version for MATLAB, which might be necessary for using the ShimmerBiophysicalProcessingLibrary_Rev_X_Y.jar, refer to this link on the Mathworks website:

http://www.mathworks.com/matlabcentral/answers/130359-how-do-i-change-the-java-virtual-machine-jvm-that-matlab-is-using-on-windows

13.2. More than 7 Shimmers via Bluetooth on a Single Computer

If the user wishes to stream data from more than 7 Shimmers simultaneously on a single computer using Bluetooth a solution is proposed here. The solution requires the use of 2 or more Bluetooth dongles (a dongle is required for every 7 Shimmers) with each Bluetooth dongle having its own Bluetooth Driver. This method has been verified in-house using a Toshiba driver and a Microsoft driver.

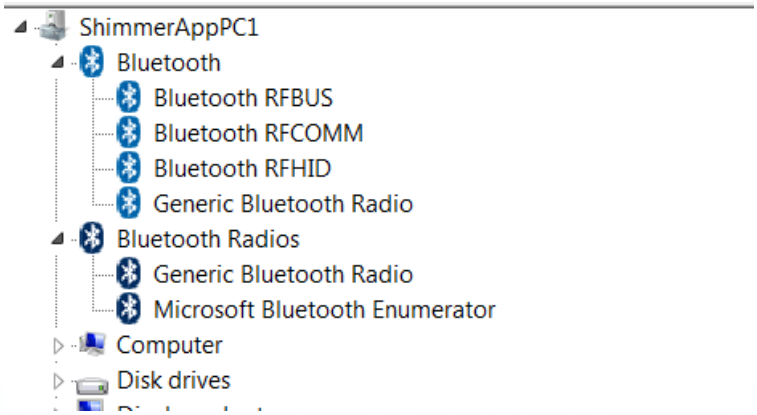


Figure 13-1: Multiple Bluetooth Driver

Figure 5 shows an example of what the device manager will show when two Bluetooth dongles with different stacks are used simultaneously. The top one uses a Bluetooth Toshiba driver while the bottom one uses a Microsoft driver.

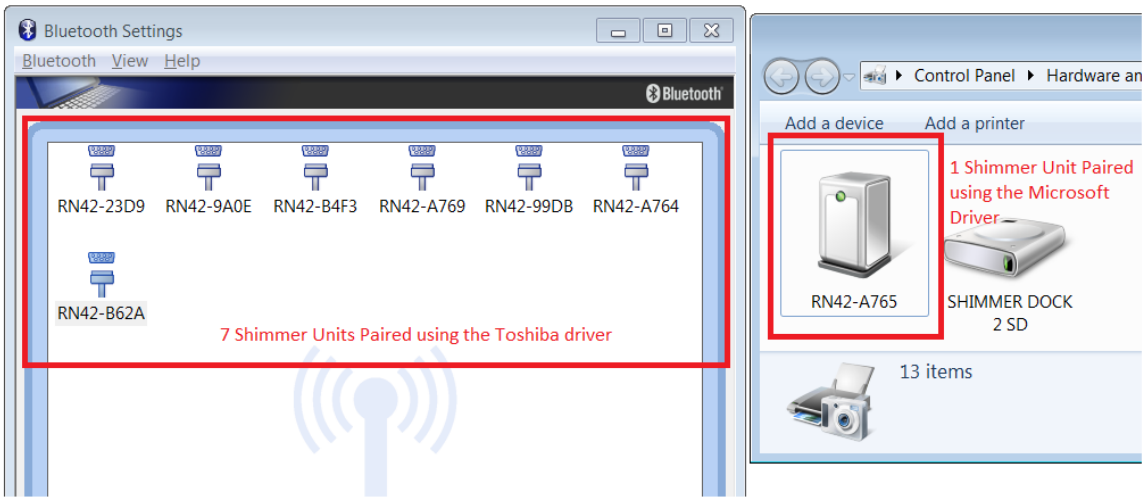


Figure 13-2: Pairing with Multiple Bluetooth Dongles

When using more than 7 Shimmer units ensure that a maximum of 7 are paired and used with one driver and the others are paired and used with the other driver. To avoid confusion it is advised that each device is paired with only one driver as demonstrated in Figure 13-2.

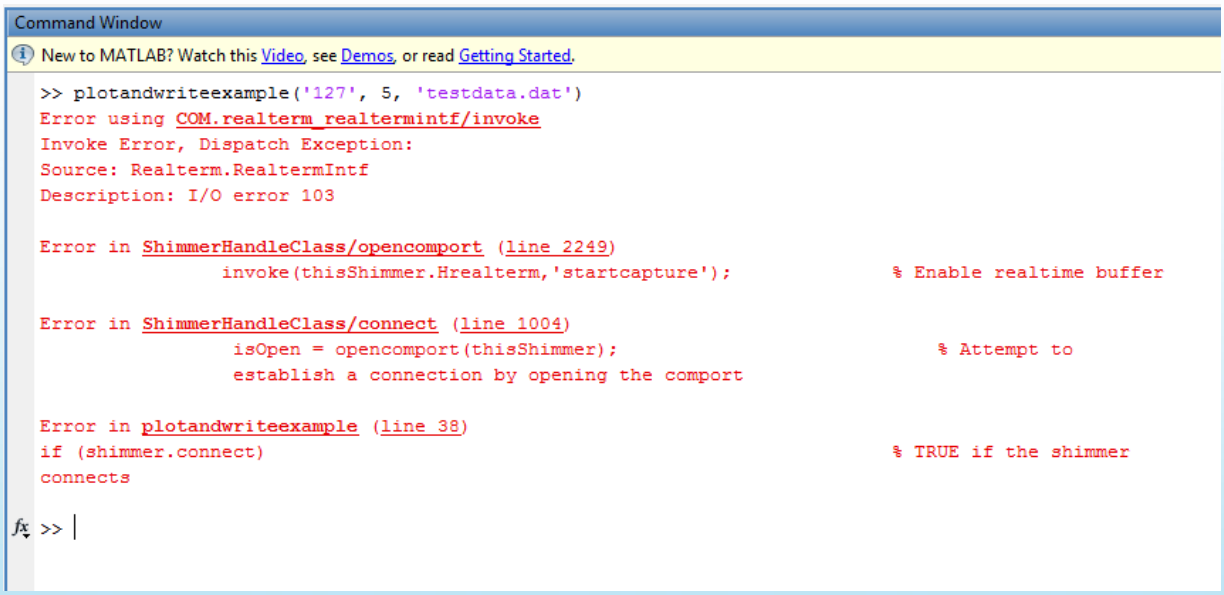
13.3. Known Bugs

See Readme.txt for known/fixed bugs.

13.4. Troubleshoot

I/O Error 103

Problem: Every time I run example functions I receive an I/O error 103 as illustrated below.



Solution: Ensure that your current working directory contains a folder called realtermBuffer and that you have permission to write to that folder.

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USA – Boston, MA.
Asia – Kuala Lumpur, Malaysia.

Web: www.ShimmerSensing.com
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