

## Application Note 254 Continuous Noninvasive Blood Pressure for Human MRI Applications

The NIBP-MRI is a wireless and noninvasive physiological monitoring system that tracks blood pressure, using Pulse-Decomposition Analysis (PDA) technology, as well as heart rate.

NIBP-MRI operates passively at a low constant coupling pressure of 40 mmHg. After being provided a calibrated blood pressure reading, the device tracks blood pressure by analyzing the timing and amplitudes of the primary left ventricular ejection pulse as well as the arterial pulse reflections, at the thumb, middle phalange of the middle finger, at the wrist, or upper arm. The system provides relative, real-time, beat-to-beat pressure measurement values during magnetic resonance imaging.

### EQUIPMENT

Components required for NIBP measurements:

#### Included with the NIBP-MRI:

Component	Function
<b>NIBP-MRI</b>	Emperical Technology Inc., <i>CareTaker</i> unit - Amplifier and transducer that processes the BP data from the sensor.
<b>NIBP-MRI-CAL</b>	Calibration unit for the NIBP-MRI. Will be used to take an initial, independent BP reading that will be entered into the <i>CareTaker</i> GUI.
<b>NIBP-DA-OUT</b>	USB D/A converter. Provides an analog output signal from the NIBP-MRI unit for plotting real-time signals using <i>AcqKnowledge/MP</i> system.
<b>CBL102</b>	Cable: 3.5 mm to BNC-M. Used to transfer signal from the D/A to the HLT100C or AMI100D. Mates with the CBL106.
<b>CBL106</b>	Cable: BNC-F to 2 mm pin plug. Used to transfer the signal from the D/A to the HLT100C/AMI100D. Mates with the CBL102.
<b>INISO</b> or <b>INISOA</b>	Input Signal Isolated Adaptor used in conjunction with the HLT100C or AMI100D. Used to provide optimal isolation for improved subject safety. Has a 3.5 mm plug input, RJ11 output jack.

#### Also required but *not included* with the NIBP-MRI:

Component	Function
<b>HLT100C</b> or <b>AMI100D</b>	All high level output transducers interface to an MP system through this device. Used in conjunction with the UIM100C. Has RJ11 input jack.
<b>MP160/MP150</b>	The core signal processing unit of the <i>AcqKnowledge</i> acquisition system.
<b>UIM100C</b>	The signal interface module to the MP150. Mates with the HLT100C/AMI100D. (Not used with the MP160 System. The MP160 connects directly to the HLT100C/AMI100D)

### Tips on setup

- The ONLY thing in the MRI chamber with the subject is the bladder sensor, the splint/tape (if needed), and the plastic hose leading out from the chamber into the control room. The *CareTaker* black box should be in the control room with all the other equipment.
- A separate BP unit can be used to obtain initial calibration values; however, as a precaution, make sure it is compatible with MRI environments—the gauss fields can get strong and wreck havoc on electronic devices exposed to it. For a unit that is **NOT MR Safe**, take measurements outside the MRI chamber.

**MR Safe** - an item that poses no known hazards in all MRI environments. Using the terminology, “MR Safe” items are non-conducting, non-metallic, and non-magnetic items such as a plastic Petri dish. An item may be determined to be MR Safe by providing a scientifically based rationale rather than test data.

**HARDWARE SETUP**

Figure 1a shows recommended hook-up of the various components for NIBP readings. The NIBP-MRI transducer attaches to the subject and a length of tube is passed through the waveguide to the control room. The tubing and sensor are plastic and MR Safe.

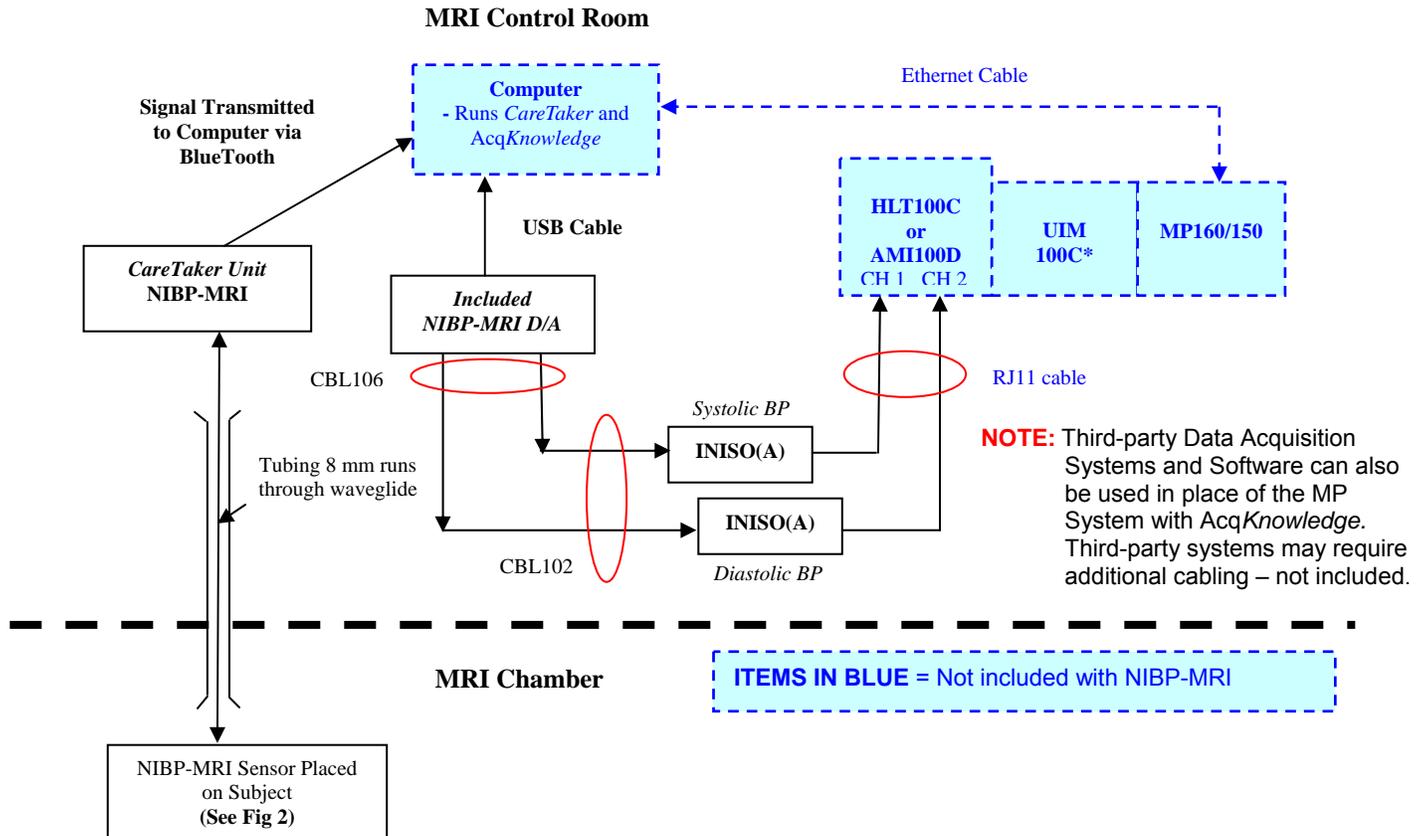


Figure 1a: Nominal Equipment Configuration

\*UIM100C is used with MP150 only. [Newer model MP160 units connect directly to the HLT100C or AMI100D.](#)

SuperLab and E-Prime systems generate signals when presenting a stimulus (visual, auditory, etc.) to a subject. These signals provide synchronization to data collected by an MP system.

- The STP100C is the interface needed between SuperLab/E-Prime and the MP systems.
- The SCR signal should interface to an EDA100C module.

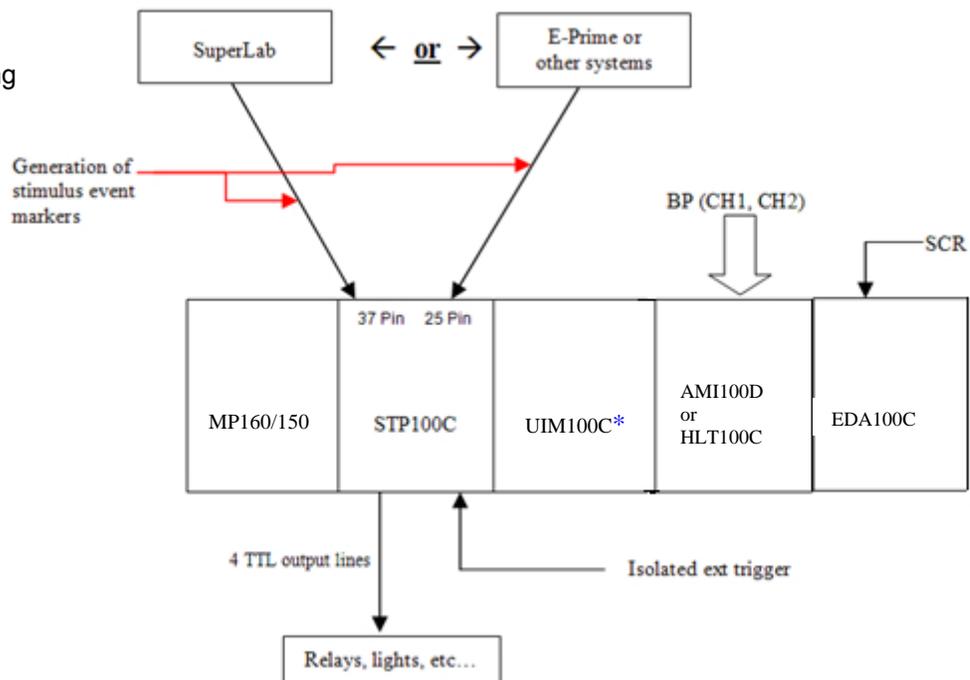


Figure 1b: Equipment Configuration for the interface of SuperLab or E-Prime to MP160/150 System

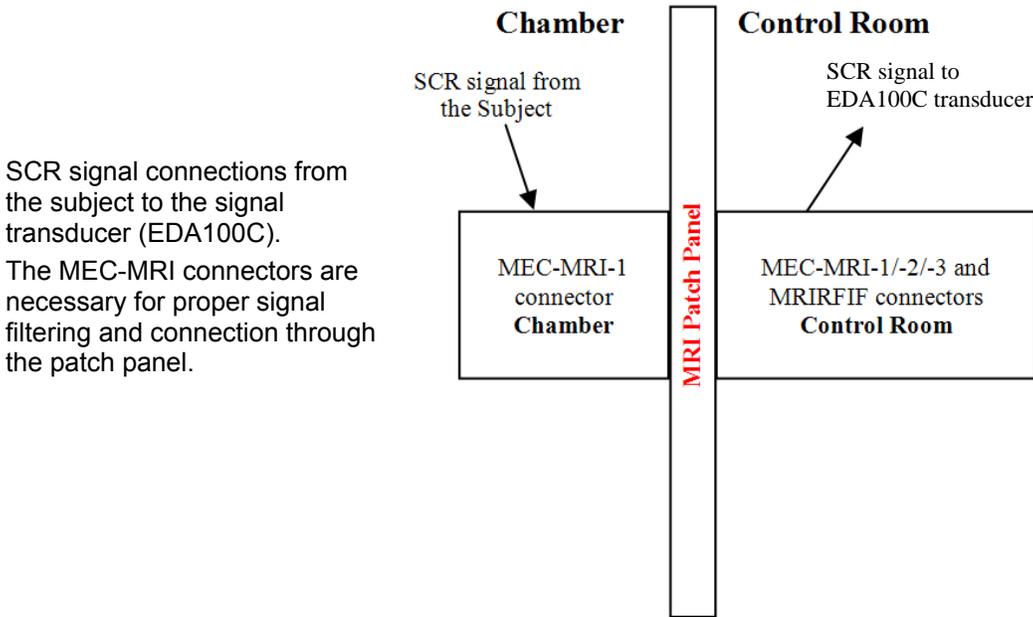


Figure 1c: Equipment Configuration for MRI

Referring to Figure 1a, commands and data between the NIBP-MRI *CareTaker* unit and the computer are transmitted via BlueTooth to the computer's COM port whereas commands and data transfer between the MP160/150 and the computer are accomplished through a network cable. The D/A output is necessary to route the Systolic/Diastolic signals to *AcqKnowledge* for plotting and data analyses.

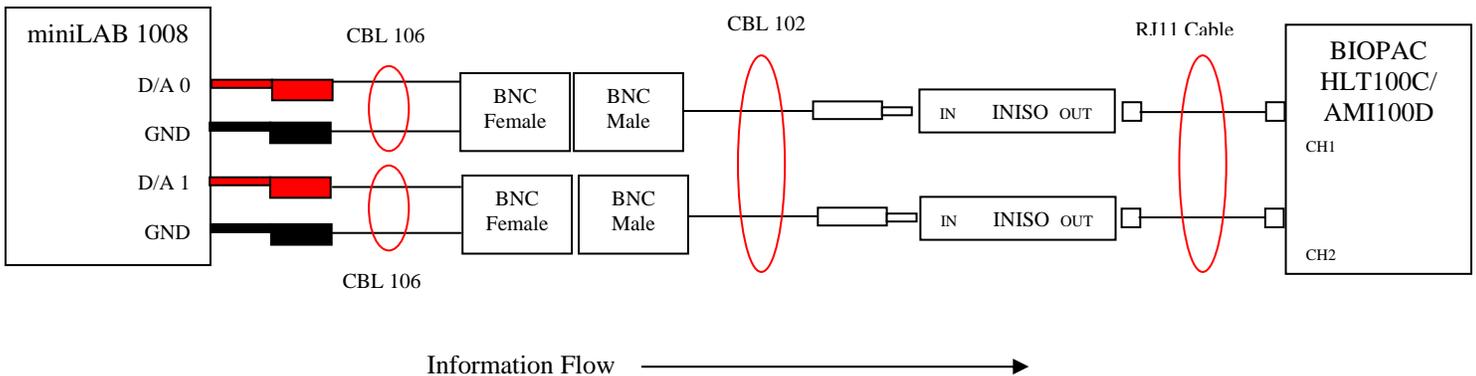


Figure 1d: Wiring schematic from minLAB 1008 D/A outputs to BIOPAC HLT100C/AMI100D CH1, CH2 inputs

**SUBJECT SETUP**

Ideal sensor placement varies by subject and protocol, see Table 1.

In Figure 2a, the sensor is placed at the brachial artery of the subject under test and the subject is seated comfortably with the arm elevated to be horizontally coplanar with the heart. The elevated arm will have the *CareTaker*™ pressure transducer placed over the brachial artery near the elbow joint. Note that a board splint placed under the arm is used to force the brachial artery close to the skin surface for optimal transducer sensing.

- The brachial artery is one of three locations for BP recordings inside the MRI. [Click for setup video.](#)



Figure 2a: Displays the arm position, attachment of an arm splint and the pressure transducer

**Tips on applying the bladder sensor**

- A. Since no two vascular systems are alike, a hierarchical procedure will allow the user to determine proper sensor attachment.
  - Table 1 delineates the choices
  - **Refer to Appendix D for attachment procedure and confirmation of signal quality.**



Figure 2b: Sensor placement on the thumb

Choice Rank	Location	Rationale
1 <sup>st</sup>	thumb	a) unobtrusive and comfortable location (Fig 2b) b) stays warm as it is fed directly by radial artery c) motion tolerant
2 <sup>nd</sup>	middle finger (middle digit)	a) unobtrusive and comfortable location b) motion tolerant c) fingers tend to get colder faster than the thumb due to fingers being fed by multiple divisions of brachial artery. d) See CareTaker™ manual for location
3 <sup>rd</sup>	arm at elbow joint (brachial artery) (un-splinted)  <i>See Note B</i>	a) provides the strongest pulse and works on almost anybody b) must secure the sensor with extra Velcro band around the arm to prevent the sensor from pulling way from the artery.
4 <sup>th</sup>	arm at elbow joint (brachial artery) (splinted)  <i>See Note B</i>	a) has attributes of #3 but arm is rigidly held at 180° by non-ferrous board or splint. b) splint will push the brachial artery closer to the skin surface for better pulse detection. c) arm could be subject to fatigue and discomfort after awhile.

Table 1: Choices in sensor placement

- B. If a subject's poor circulation on the finger prevents good BP measurements, try attaching the bladder sensor to the brachial artery. Generally there are issues with small-framed females in getting strong BP measurements through the finger. The arm may be the most reliable way to get good measurements.
  1. "Splint" or immobilize the arm, from shoulder to wrist, in order to "push" the artery closer to the skin surface and to keep it there.
    - a. Use the BIOPAC splint stabilizer for NIBP-MRI.
      - As an alternative, the reader can create a splint but using only non-ferrous materials, for example, plastic or wood.
    - b. Use tape between the bicep and shoulder to bind the upper arm to the splint and use tape about 3-4 cm below the wrist to bind the lower arm to the splint. Velcro® (or similar) adhesive or hospital-type tape. Velcro is easy to remove and is reusable.
  2. Fingers placed over the area on the elbow joint can sense the point of well defined pulsations, which indicated the brachial artery has been located and that is where the bladder should be placed. Use tape to attach the bladder or use Velcro®.
  3. To make the subject feel comfortable with the splint, use foam blocks as support; place the foam underneath the splint so that the arm is level and not tilted downward (assuming the subject is supine).

**SOFTWARE SETUP**

Complete the following steps to prepare for taking BP measurements.

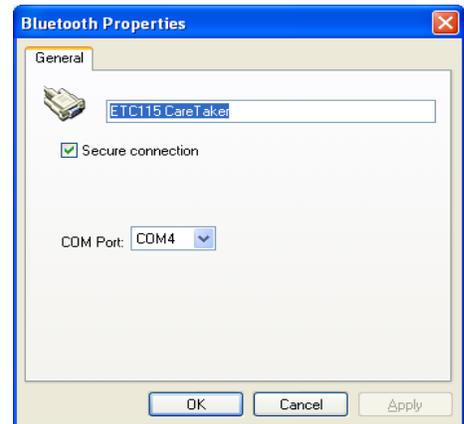
1. Ensure that the BlueTooth device is active on the computer.

Follow the manufacturer's instructions for installing the BlueTooth software. **Refer to Appendix C for the appropriate Bluetooth installation pass-codes.**

The following icon should be visible on the system tray:



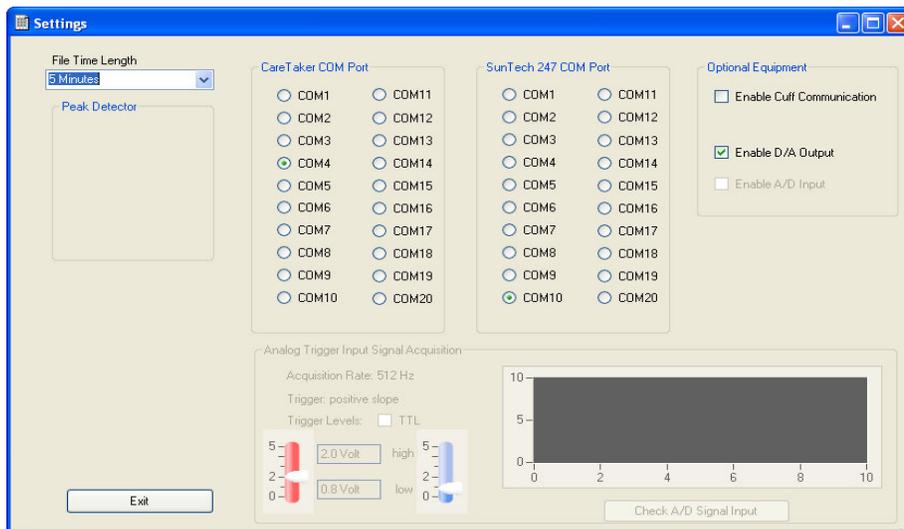
Generate the *Properties* window and note the COM port assignment which will be needed for the *CareTaker* device:



2. Settings within the *CareTaker* software.

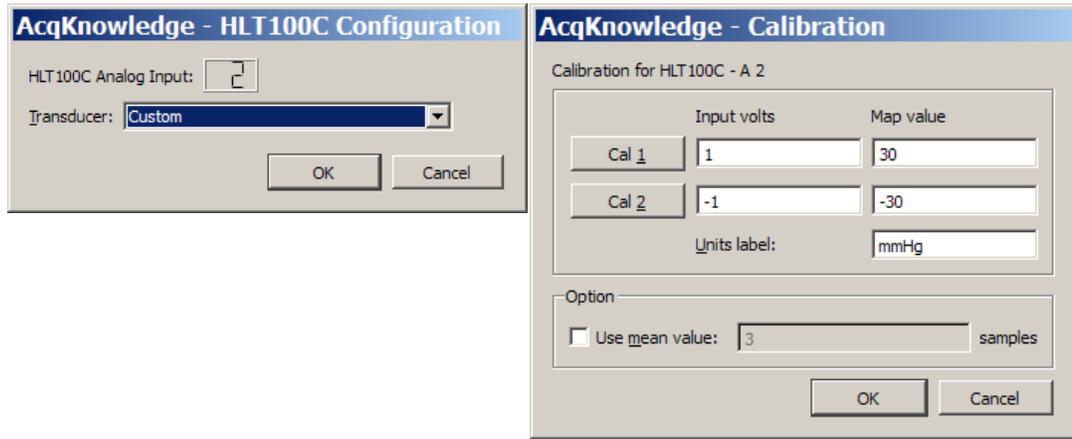
The software will have System tab on the GUI; click on the Systems tab to generate the following window:

- In this example, the port setting is on COM4 which matches that for the computer.



Referring to Figure 3a, check the box to route the data stream to the D/A module as indicated by the dashed red arrow so the data may be routed to *AcqKnowledge* for plotting and analysis. If communication problems occur, refer to [APPENDIX B](#)—Connection between the *CareTaker* program and the D/A board.

3. Set up the Recording Channels in *AcqKnowledge*.
  - a. Using the graph window menu, the two recording channels in **NIBP.gtl** are established through:  
**MP160/150 > Set Up Data Acquisition > Channels....**
  - b. To apply the HLT100C/AMI100D transducer to the input channels use the following:  
**MP160/150 > Set Up Data Acquisition > Channels... > Add New Module > HLT100C - A1/A2 > "Custom" Transducer (or Add New Module > AMI100D...**  
The following windows are generated for the user to set up scaling for the custom transducers for each channel. The setup for Channel 2 is shown:



c. Each channel should have the following Calibration settings for the proper systolic and diastolic scaling:

CH 1 - Systolic:	Cal 1 Input volts: 1	Map value: 50	Units label: mmHg
	Cal 1 Input volts: -1	Map value: -50	
CH 2 - Diastolic:	Cal 1 Input volts: 1	Map value: 30	Units label: mmHg
	Cal 1 Input volts: -1	Map value: -30	

**DATA COLLECTION**

**Tip: see APPENDIX A—Checklist for tasks to prepare for good data collection.**

- A. Click Connect *CareTaker*. The program will establish communications with the *CareTaker* Bluetooth enabled transmitter/receiver.
- B. When connection is established and the transducer is secured on the subject, press the "Manual Calibration" button (see Figure 3a) to generate a calibration window (Figure 3b).
  - To enter initial calibrate numbers the NIBP-MRI-CAL is used. It is a simple stand-alone blood pressure device, which is MRI compatible. The cuff is placed around the subject's other arm and following the manufacturer's instructions, an average blood pressure systolic and diastolic values are obtained. Those numbers are then entered into the Calibration window. The NIBP-MRI-CAL unit connects to the subject and a length of tubing passes back through the waveguide to the control unit that is located in the control room.
  - After clicking OK (Figure 3b), the sensor will inflate to a pressure until it starts to sense the BP systolic/diastolic values. After the calibrate mode is complete, the *CareTaker* unit will process the BP data in a manner similar to that shown in Figure 3a.

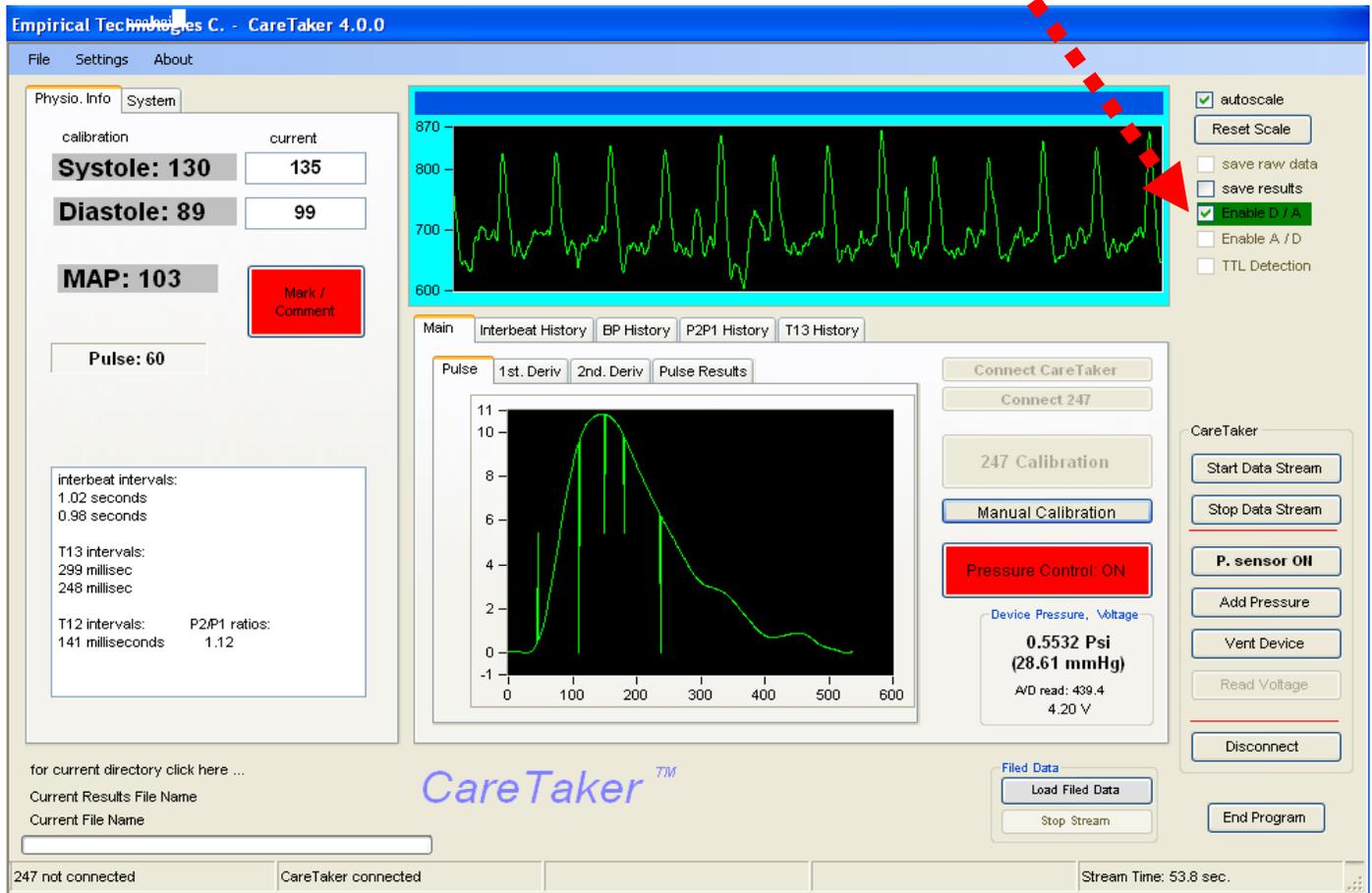


Figure 3a: Display screen of CareTaker processing blood pressure data stream



Figure 3b: Calibration dialog box

The NIBP-MRI device is controlled from and streams data to the software running on a PC computer. Communication is wireless using the Bluetooth transmission protocol. The device weighs  $\pm 114$  grams and runs for about 12 hours on a single battery charge. Since the device tracks pulse reflections that stem from the central arteries, it appears to be capable of tracking central blood pressure.

The digital sensor features a miniaturized design based on a piezo-electric sensor and proprietary pulsation-exteriorization as well as electronic filtering and amplification techniques.

The device's signal quality is sufficiently high as to allow detailed contour analysis of the radial or digital pulse shape, which is influenced by factors such as systolic and diastolic blood pressure, arterial distensibility and the pressure impedance effects of artery/arteriole interfaces. Specifically, it makes the resolution of the component pulse structure of the radial/digital pulse envelope possible.

Data is streamed to the MP system. The data is plotted in real time by AcqKnowledge on a beat-to-beat basis, as shown in Figure 4 after the CareTaker software starts to analyze the data and the waveform trace in the CareTaker display window turns blue.

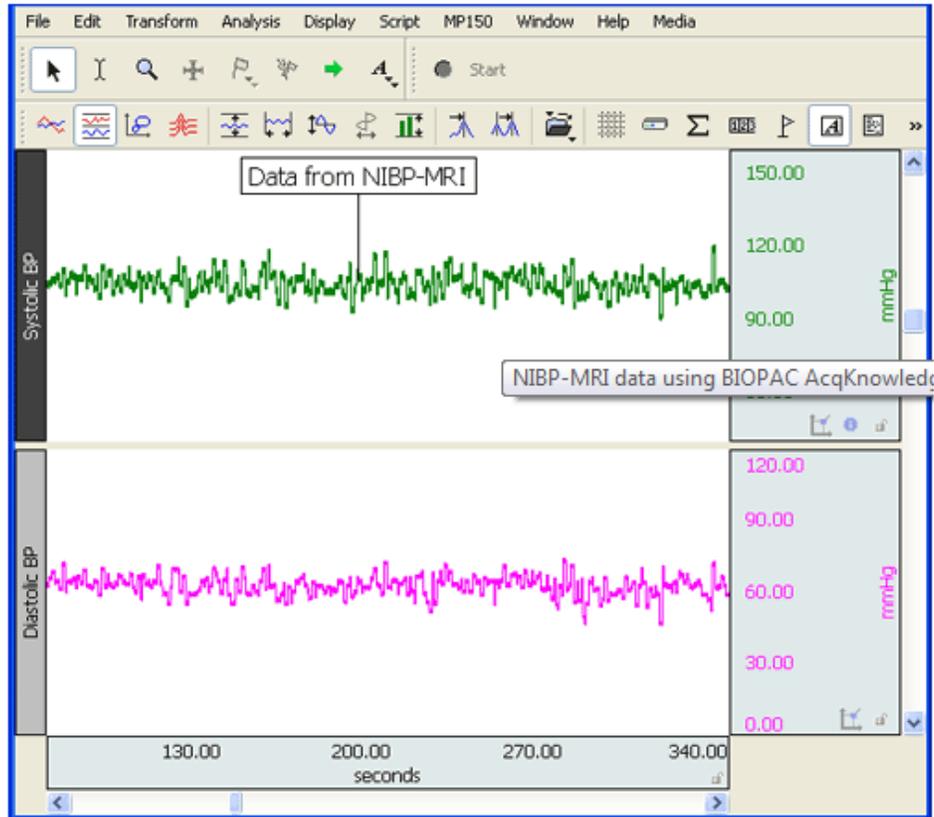


Figure 4: Systolic and Diastolic data from the *CareTaker* device as processed through *AcqKnowledge*

## APPENDIX A—Checklist

### Summary:

1. Establish Bluetooth connection.
2. Invoke *CareTaker* - establish settings.
3. Place sensor on subject.
4. Get initial calibration numbers for *CareTaker*.
5. Invoke *AcqKnowledge*.
6. Send data stream from *CareTaker* (press "Start Data Stream").
7. Acquire data with *AcqKnowledge* (press "Start").

This checklist can be changed to specific protocol or procedures; however, one thing MUST NOT change:

**Always start the Bluetooth connection before invoking *CareTaker*!**

### Detailed:

1. Make sure all the cable connections between HLT100C/AMI100D and the D/A box are in place.
2. Establish Bluetooth connection first - *CareTaker* won't work properly if the connection is absent.
3. Launch the *CareTaker* software (generate the *CareTaker* window)
  - a. Under the "Settings > COM Ports and other Settings"
    - i. Click the radio button on the COM port that matches the one the Bluetooth device is using.
    - ii. Click the checkbox "Enable D/A"
    - iii. Exit that Settings window and make sure that the "Enable D/A" is checked on the main window.
  - b. Check "autoscale" on the main window, it will allow autoscaling to occur in the graph as BP measurements are acquired.
4. Press the "Connect *CareTaker*" button
  - The Pressure Control box should turn green
  - The "Manual Calibration" button should be active (not grayed-out)
  - a. Press the "Start Data Stream" button and look for the *CareTaker* unit to acquire noise across the top graph screen. Once noise is displayed, click the "Stop Data Stream" button. This is just to make sure that the *CareTaker* unit and computer are "talking" to each other.

5. Additional check: In the start menu select "Measurement Computing > Instacal"
  - a. This will generate a window that is specific to the D/A box. There should be visible a "tree-structure" of connected devices: PC Board List
    - |--- Universal Serial Bus
    - |--- Board# 0 - miniLab 1008 (serial# whatever-is-listed)
 The miniLab Board should be listed as the first board (i.e. Board#0).
  - b. Within this window, select from the menu "Install > Configure", this will generate a sub-window
  - c. Within the Configure window, click the "Test LED" button.
    - If the LED flashes, the computer is cognizant of the presence of the D/A board.
  - d. After testing LED, close the Configure window.
  - e. Go to the menu "Test > Analog."
    - An oscilloscope-type window will appear and one should see the D/A board acquiring noise. This is expected and again shows that the board is working properly.
  - f. Click OK to dismiss this window.
6. Once the sensor is on the subject (see Tips under Setup), click on "Manual Calibration."
  - a. A dialog window will be generated to enter initial Systolic and Diastolic numbers. Use a separate BP unit on the subject's other arm to obtain the required values. This is a temporary measurement just to get an initial number to put into the CareTaker dialog box.
  - b. After entering the number, press "OK." A "thermometer" or "progress bar" will be generated, showing how CareTaker is pumping the sensor bladder to get initial BP readings. The black CareTaker box will likely make AUDIBLE SOUND as it is pumping air into the bladder.
  - c. The top graph window in CareTaker will start displaying BP data. The border of the graph window indicates status:
    - RED** CareTaker is adjusting the measurement
    - GREEN** CareTaker has stable BP readings
7. Once good BP readings from CareTaker have been obtained, launch *AcqKnowledge* (generate a graph file).
  - a. Press the "Start Data Stream" button on the CareTaker window; data will now be sent to the D/A box (which will send data to the *AcqKnowledge* HLT100C/AMI100D unit)
  - b. Press "Start" on *AcqKnowledge*; data from CareTaker will now be received and plotted on *AcqKnowledge* graph window.
  - c. If the scaling on the *AcqKnowledge* graph window is done properly, new acquired waveform values in time should reflect the values displayed on the CareTaker window under the "current" text boxes showing real-time Systolic and Diastolic pressures.

**APPENDIX B—Connection between the CareTaker program and the D/A board**

The connection between the CareTaker program and the MCC D/A board (Measurement Computing Corp.) is predicated on the program finding and using the dynamic linked library: DaqLib.dll.

When the user clicks on the check box:  Enable D/A Output there is an assumption by the program that the file is in a set location and if not discovered, the following message is displayed:



How the program discovers this file is dependent on the version of the program. Table B1 delineates the discovery method. Figures B1, B2 show the way the user can specify the path to the dll file for versions 4.0.1.5 and later of the CareTaker program.

Version	Discovery Method	Potential Issues
4.0.1.5 and later	The user can click on a button as shown in Figure B1 to call up an editable text box and enter the exact path string leading to the dll file.	There is no "auto-discovery" mode so the user must manually search for and type in the path string.
4.0.1.4	The program expects to find the dll file at the following fixed location: C:\Program Files\Measurement Computing\DAQ\DaqLib.dll	If the path string deviates from the expected setting (for instance, using C:\Programs\Measurement... instead of C:\Program Files\Measurement...) the dll will NOT be found.

Table B1: DaqLib.dll discovery method used by two versions of CareTaker.

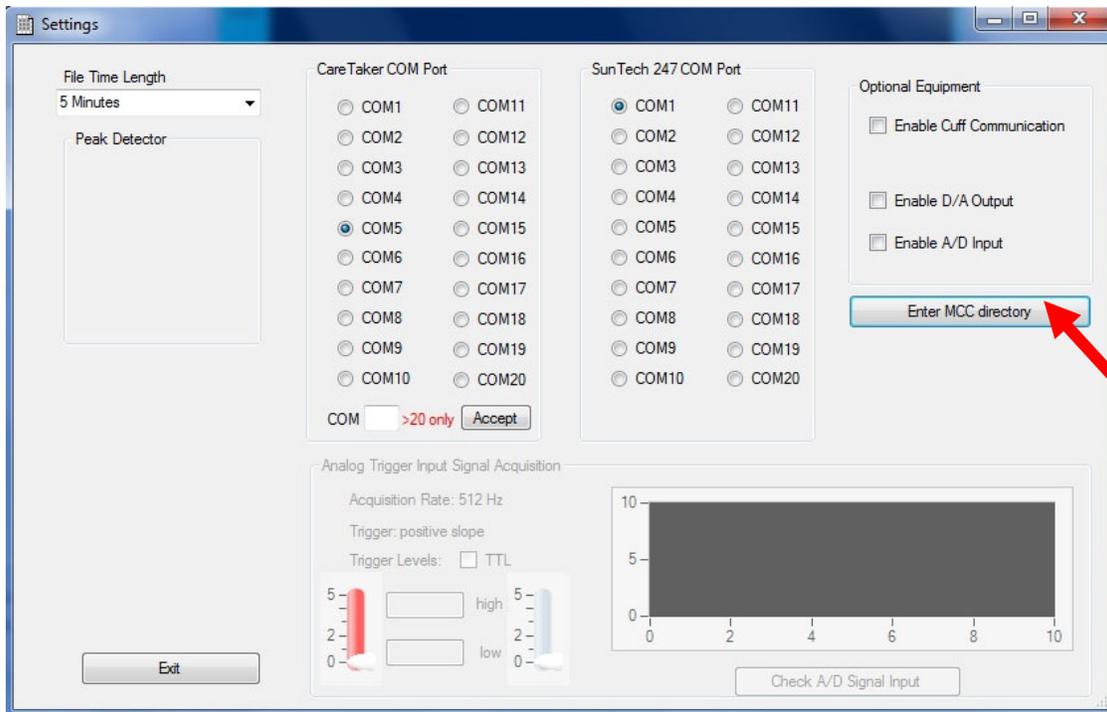


Figure B1: CareTaker Settings window. Red arrow indicates the button to click to open the editable directory text box.

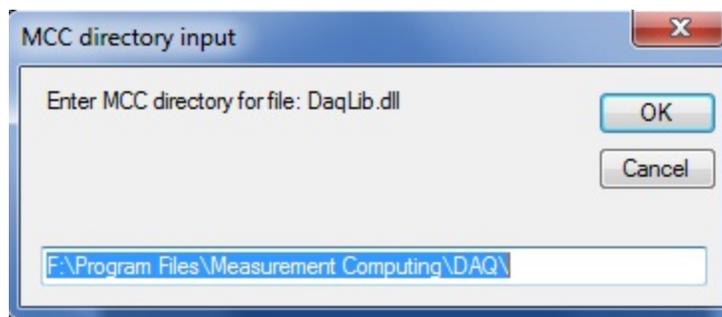
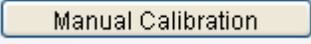
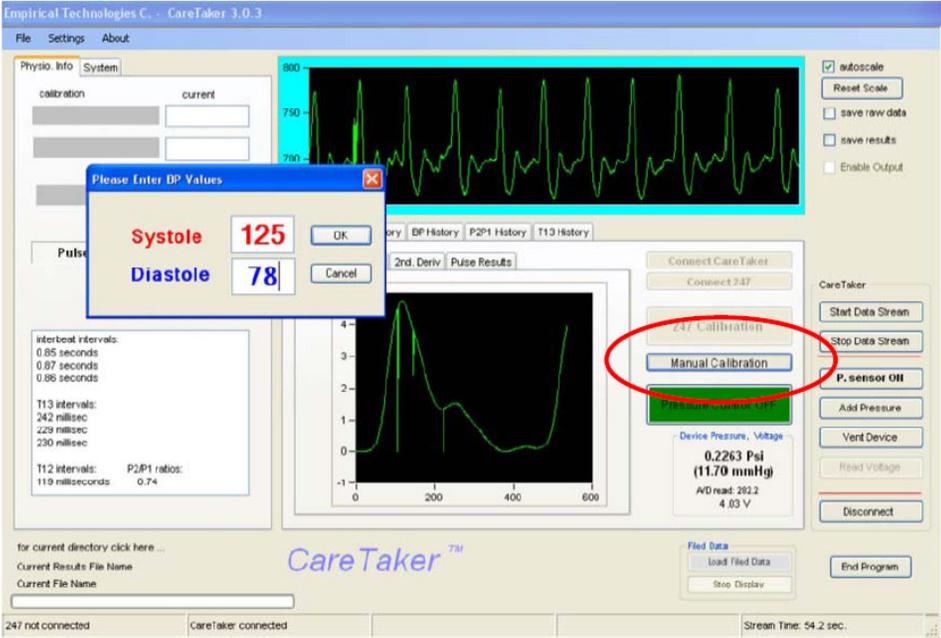


Figure B2: The editable directory text box with the default path string

**APPENDIX C—Bluetooth Installation Pass-codes**

CareTaker™ unit type	Bluetooth Pass Code
“Black-box” version of CareTaker Type the character string shown in the right column as is without quotes or any other characters.	default
“Display” version of CareTaker Type the character string shown in the right column as is without quotes or any other characters.	65536 or 055336

APPENDIX D—Sensor Attachment to a Subject

Guidance on Sensor Attachment and Signal Quality Metrics		
Step	Instruction and CareTaker UI Display <i>(Read the CareTaker manual for further explanations of the software tools and features)</i>	
1	<p><b>THIS IS IMPORTANT</b></p> <p>Deflate the pressure pad (bladder) completely!</p>	
2	<p><b>THIS IS THE MOST CRITICAL STEP</b></p> <p>Attach the sensor to the thumb. (1<sup>st</sup> choice of sensor placement – can try other choices if the thumb does not render satisfactory signals.)</p> <p>Wrap sensor around the thumb <b>snugly</b> but not tightly, as though you are wrapping a band-aid or a strip of gauze around a cut or scrape to the skin. Use the Velcro ends to secure the sensor.</p> <ul style="list-style-type: none"> <li>▪ <b>If the sensor is too tight, you risk occluding the vessel and losing the pulse signal.</b></li> <li>▪ <b>If the sensor is too loose, it will fail to detect a clean pulse signal.</b></li> </ul>	
3	Start CareTaker.	
4	Click on Manual Calibration button. (Section 12 of the CareTaker manual)	
5	In the text box that pops-up, enter initial Systole and Diastole values derived from external means.	

Guidance on Sensor Attachment and Signal Quality Metrics		
Step	Instruction and CareTaker UI Display <i>(Read the CareTaker manual for further explanations of the software tools and features)</i>	
6	Use three metrics to check whether an adequate BP measurement is being acquired: <ul style="list-style-type: none"> <li>- waveform appearance</li> <li>- pressure values</li> <li>- waveform ordinate axis values</li> </ul>	-----
6a	Check the appearance of the waveform: <ul style="list-style-type: none"> <li>- should look crisp, no fuzziness which is indicative of noise due to a loose attachment.</li> </ul>	
6b	Look at the device pressure value: <ul style="list-style-type: none"> <li>- should get around 40-50 mmHg values for attachments to thumbs or fingers.</li> <li>- should get around 70-80 mmHg for attachments to the arm (brachial artery).</li> </ul>	
6c	Look at the waveform display ordinate axis. <ul style="list-style-type: none"> <li>- should get at least 150-200 units peak-to-peak values for the Pulse Decomposition Algorithm to operate properly. The example shows &gt; 250 units.</li> </ul>	
7	If the quality metrics indicate an unsatisfactory signal, reapply the sensor or check for leaks within the sensor, tubing, or CareTaker device.	

**Appendix E – Smoothing of Blood Pressure Data**

When the drop-outs in systolic/diastolic waveforms are not too severe, and ideally rather narrow, a smoothing technique can be employed.

The key to mitigating the data drop-outs is to ensure that the averaging window bridges the drop-out. Figure E1 displays the concept and the following constraint can be used as a guideline:

$$w \geq 2 \cdot d$$

where:

w = averaging window width

d = drop-out width

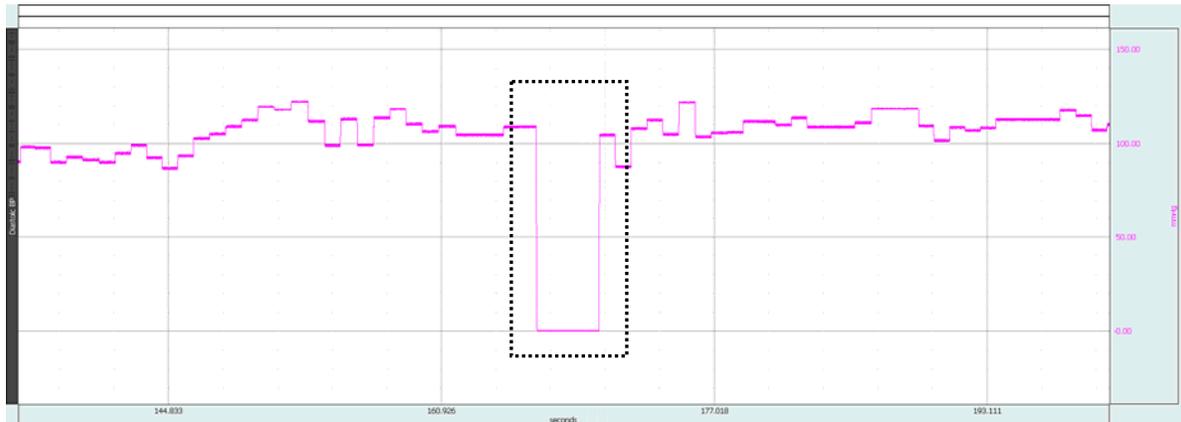


Figure E1: Averaging window. Width of window should be greater than the width of the widest drop-out.

The following table delineates the steps to smoothing systolic/diastolic waveforms from CareTaker.

Step	Transform/Analysis Tool	Goal
1	Edit > Duplicate Waveform	Duplicate the waveform of interest. Figure E2
2	Transform > Resample Waveform...	If necessary, reduce the number of sample points to 200 - 250 Samples/sec. Data is slowly varying. Figure E3
3a	Transform > Smoothing...	As shown in Figure E4, user has a choice of using the Median or Mean smoothing. Use Mean smoothing when noise appears in a Gaussian distribution around the mean of the signal. <u>Clearly</u> not the case here. Use Median smoothing if some data points appear completely aberrant and seem to be “wild flyers” in the data set. That definition could be applied here. For a given sequence of wave data, $x = \{x_1, x_2, \dots, x_n\}$ , Median value smoothing will sort the sequence and extract the median equivalent to the recommended NIST (National Institute of Standards and Technology) formula: $n$ is odd: median is the center element of the sorted list of $n$ items. $n$ is even: median is the mean of the center pair of elements of the sorted list of $n$ items.
3b	Selection of smoothing window	The gaps (or zero levels) in the example data appear to be around 500 – 700 samples, so 1400 samples are used to “bridge over” those zero levels. An averaging window less than the gap would only “average” closer to the zero; here, the attempt is to mitigate the “hole.”
4	Apply the smoothing transform	The data should show some mitigation of the drop-outs as shown in Figure E1 (lower graph) and Figure E5 (overlap)
5	Caveats	Long drop-outs may not “smooth-out” easily. This may lead some distortion of the waveform. This can be an iterative process whereby the smoothing window parameters will have to be varied in order to converge to acceptable results.

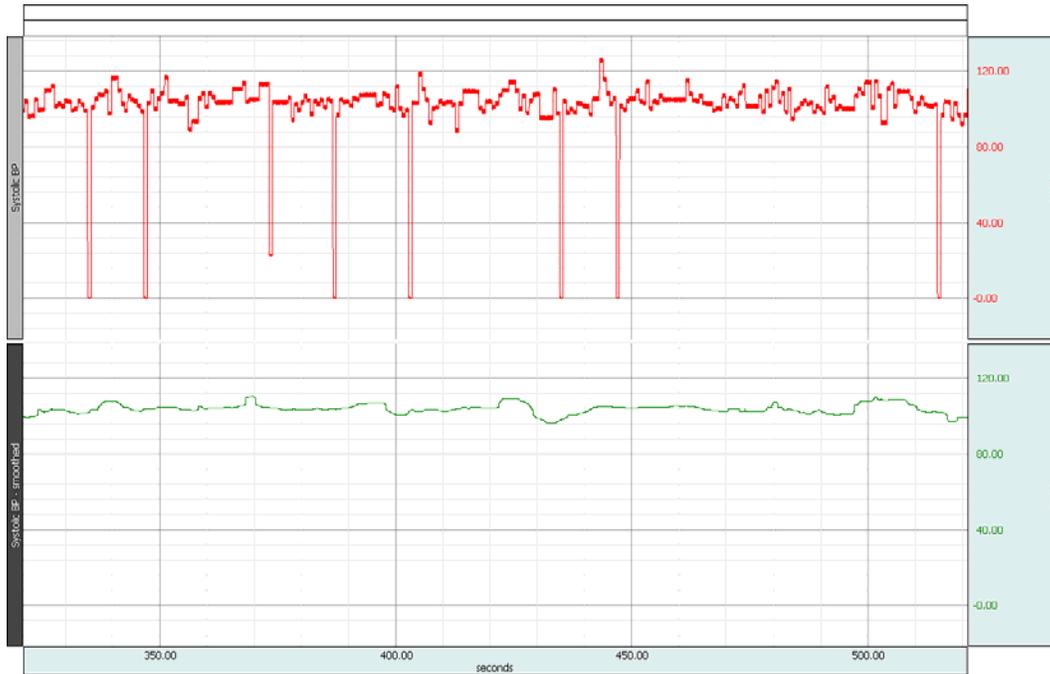


Figure E2: Top graph un-smoothed systolic data. Bottom graph, smoothed systolic data

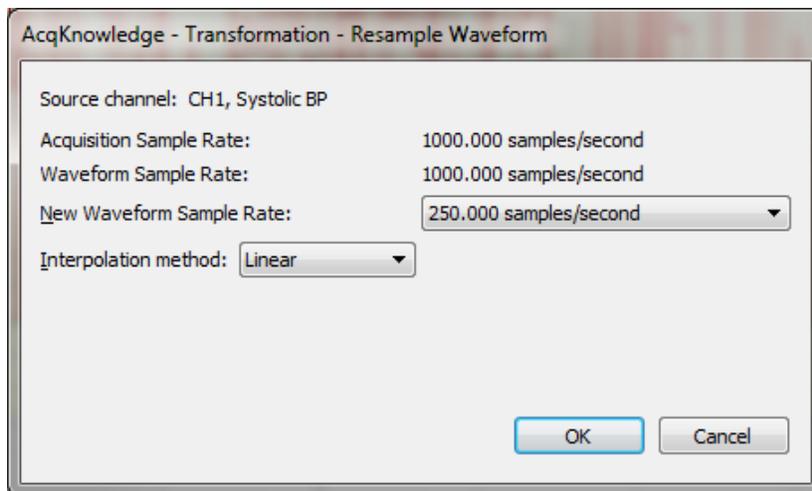


Figure E3: Transform UI used to re-sample the waveform

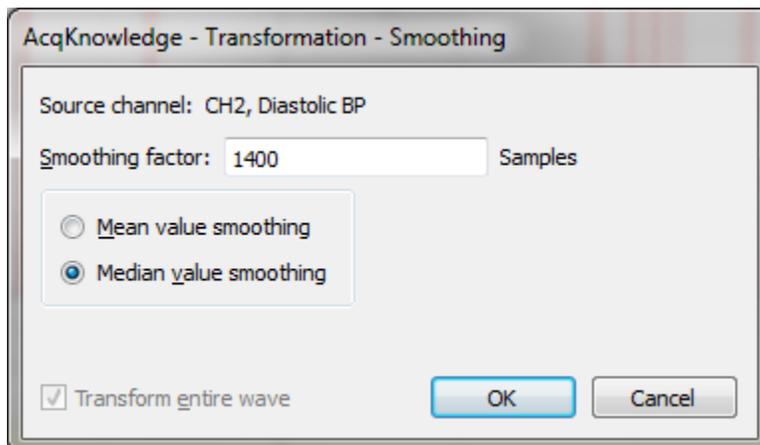


Figure E4: Smoothing parameters

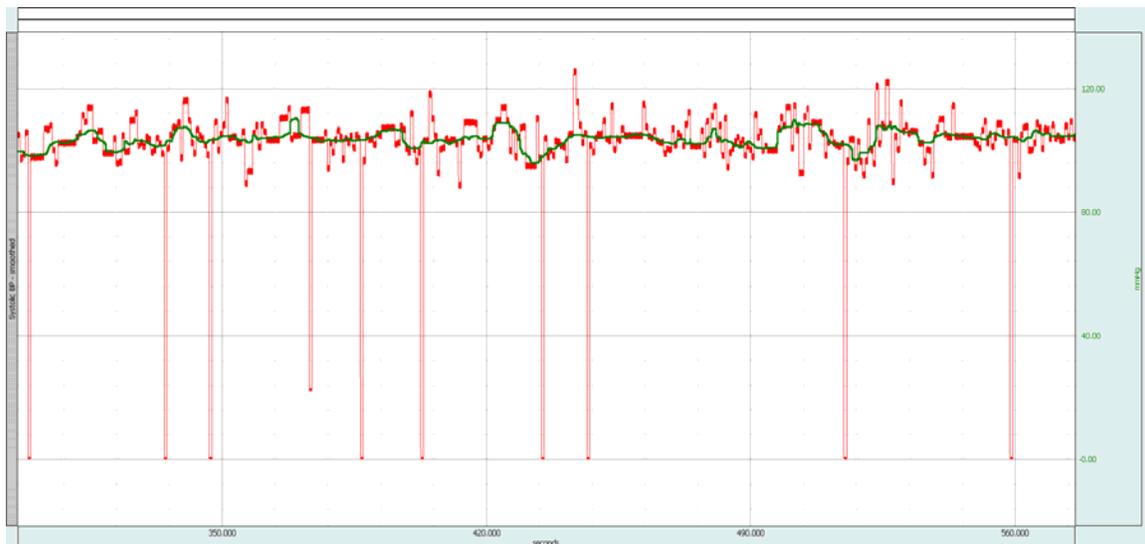


Figure E5: Smoothing of the BP data, overlap of the graphs in Figure E2:

- **Red** – original waveform,
- **Green** – smoothed waveform.
- Smoothing window: 1400 samples,
- Option: Median smoothing,
- Graph re-sampled to a rate of 200 S/s from the original sampled rate.