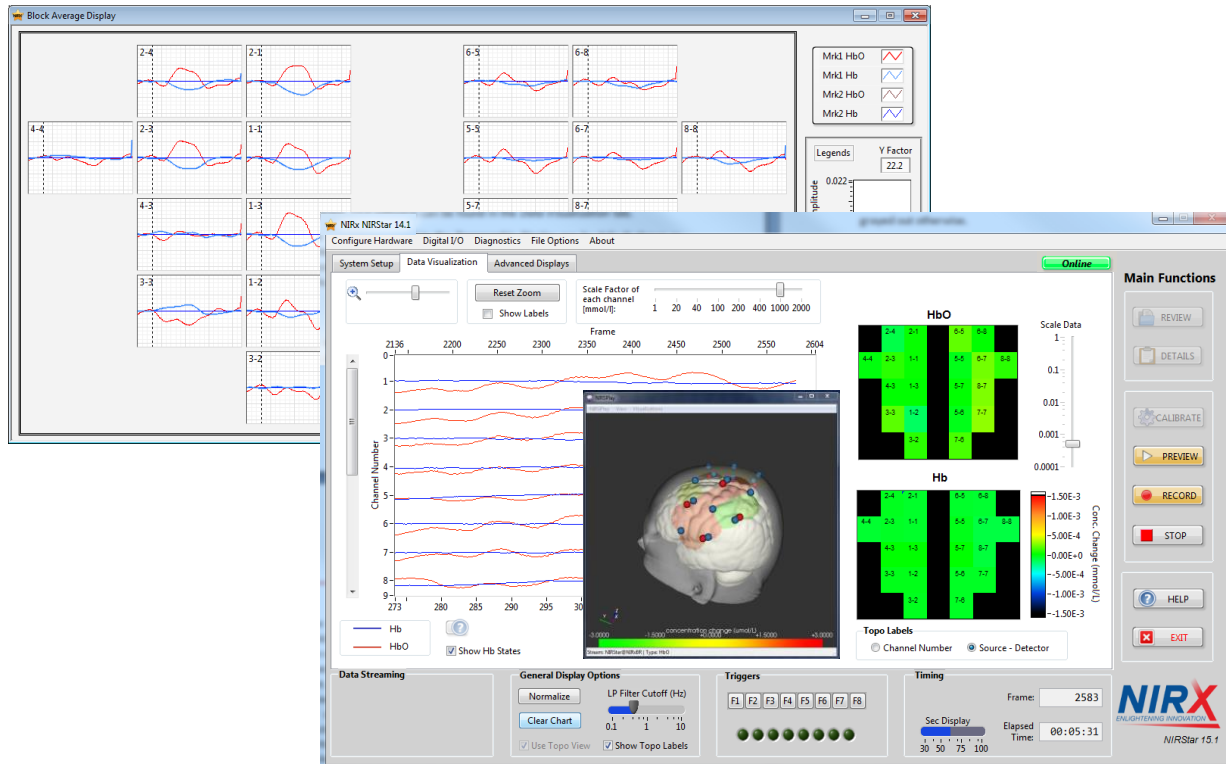


# NIRX

ENLIGHTENING INNOVATION



# NIRStar™ 15.2

## User Manual

*For use with NIRx NIRSport™, NIRScout™ and NIRScoutX™ Imagers.*

**NIRx Medical Technologies LLC**

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NIRStar15-2\_Manual\_R10\_2018-08-16.doc



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# 1 Release Notes

## 1.1 General Remarks

The release of NIRStar 15.1 includes important new features, improvements/enhancements, bug fixes as well as minor changes. And 15.2 presents important bug fixes that were present in the release of 15.1. We recommend that all users of NIRx systems update to this newest version.

New functionalities are highlighted throughout the text by the following tag: **NEW FEATURE**

## 1.2 NIRStar15.2

### 1.2.1 Bug Fixes and Minor Changes

- Installer: new upgrade code was generated to avoid overwrite of NIRStar version 15.0.
- High Resolution: slightly decreased font size to allow for full message display on loading bar.
- High Resolution: disabled left- and right-click responses on the area for online plot legends.
- NIRSport: battery display now becomes invisible while a measurement is being performed.
- NIRSport: fixed Tandem issue of connecting the second device just before NIRStar startup.
- NIRScoutX+: compatibility with all 8 bits of trigger markers (i.e. 0-255) has been restored.
- NIRScoutX+: customized amplitudes and thresholds settings are already included in the release.
- NIRScoutX+: improved handling of forced minimum number of steps (=2) for laser systems.
- NIRScoutX+: when working with laser and APD, amplitudes are adjusted for static phantom.
- NIRScoutX+: removed alert concerning the necessity to connect all LED bundles to the system.
- Scan rate: fixed maximum sampling rate to 100Hz (instead of original 125Hz as in 15-1).
- Demodulation: reduced number of samples for phantom measures with NIRScout(X+) systems.
- Lab Streaming Layer: provide the device(s) serial number as part of hardware meta data.
- Settings: reset 'APD' and 'dual-tip' selection when switching between NIRSport and NIRScout.
- Diagnostics: wavelengths labels are now adapted to those currently used by the system.
- Diagnostics: adapt y-axis limits in case avalanche photodiode (APD) detectors are used.
- Calibration Details: do not show 'SD' labels if montage does not present short-distance channels.
- Data Visualization: trigger markers received at the same frame should not cause display issues.
- AtlasViewer: 'digpts.txt' file is now only created if probeInfo file from NIRSite (ICBM) is available.

## 1.3 NIRStar15.1

### 1.3.1 New Features

- Short-distance channels  
NIRStar15-1 presents intuitive and user-friendly set-up and control of short-distance channels. New controls and indicators have been incorporated to improve usability. (Section 5.1)
- Integration with NIRSPay  
An improved package for topographic rendering (NIRSPay) was integrated into NIRStar. It allows for real-time 3D plots with Lab Streaming Layer and montages from NIRSite. (Section 19 5.7.2)
- Receive triggers from LSL  
It is now possible to send triggers from Lab Streaming Layer to NIRStar to facilitate multi-modal integration and synchronization for offline data analysis. (Section 5.7.3)
- Higher sampling rate  
The current version provides the option to double up the switching frequency of NIRScout(X+) systems, thus reaching up to 100Hz scan rate. Please refer to your NIRx distributor. (Section 5.1)
- Hyperscan layout setup  
Predefined montages created for single-subject measures can now be automatically extended to hyperscanning. With a single button-click the hyperscan topolayout will be created. (Section 5.2)

### 1.3.2 Improvements/Enhancements

- Automated NIRSport re-initialization  
If NIRStar is launched after connecting the USB cable, but before proper device recognition, it will attempt reinitialization after ten seconds to prevent issuing a false report of low battery.
- Improved measurement stability  
The current version presents a significant improve on stability of measurements and thus allow for greater performance, which particularly concerns limited resources (e.g. Microsoft Surface).
- Improved display of short-channels  
Available short-distance channels for online and offline visualization (e.g. review mode) can now be easily identified from its dedicated label (“SD”) in place of original detector number.
- Unique probeInfo for predefined montages  
Simplified creation of predefined montages by requesting a single probeInfo file. Either from nirsLAB, NIRSite or for short-distance, the settings will be adapted accordingly. (Section 5.2)
- Meta-data for Lab Streaming Layer  
Information about current hardware configuration in NIRStar as well as 2D and 3D coordinates from the probeInfo file are now also passed to LSL during NIRStar initialization.

### 1.3.3 Bug Fixes and Minor Changes

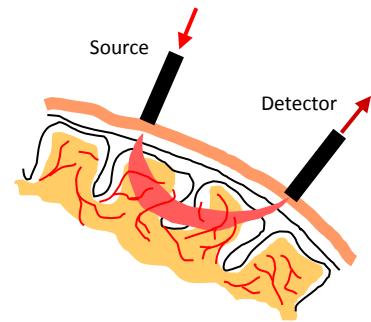
- Tandem operation: short-detector bundles are split between Primary and Secondary devices.
- Laser operation: new minimum limit of two steps of illumination pattern to respect safety limits.
- Topo Layout: automatic correction for layouts with short-distance channels created in NIRSite.
- [Hb] Parameters: inter-optode distance is automatically adapted for short-distance channels.
- Software Development Kit: it will be disabled in case the user increases the switching frequency.
- Topographic rendering: probeInfo files saved from recent nirsLAB versions now work as well.
- Topographic rendering: OpenGL renderer checkbox that allows for fixing invisible head plots.
- Battery display: loading hardware configuration file does not yield low-battery alert anymore.
- Calibration: cross-talk and dark-noise alerts are now displayed upon calibration completion.
- Details: loaded files now also adapt dark-noise threshold for hardware with APD or dual-tip.
- File options: export file to Homer2 format (offline and online) is compatible with short-channels.
- File options: Homer2 conversion now includes 'digpts.txt' file for compatibility with AtlasViewer.
- Lab Streaming Layer: improved error handling during LSL stream set up (NIRStar initialization).
- Lab Streaming Layer: option to select whether to stream flagged saturated data (with NaN's).
- Error handling: error reports are automatically generated by NIRStar in case of system crash.
- Header file: comprehensive information related to short-distance channels is now included.
- Header file: fixed Channel Masking by including single channel per virtual detector available.
- Config file: fixed number of detectors saved in case short-distance channels are enabled.

## 2 Introduction

### 2.1 NIRS Fundamentals

Near-infrared spectroscopy (NIRS) of brain function employs low-energy optical radiation for measuring absorption changes in sub-surface tissues, in order to infer local concentration changes of oxy- and deoxy-hemoglobin as correlates of functional brain activity.

Each measurement channel is formed by an optical emitter ('source') and a receiver ('detector') placed on the tissue surface. Because of the scattering (light diffusing) properties of the tissue, a portion of the received light will travel through deep tissue structures, where it may interact with tissue chromophores such as hemoglobin. The penetration depth and shape of the probing volume is a complex function of the source-detector distance and other aspects of the measurement geometry, and is also affected by the local tissue optical properties. As a general rule, measured cortical NIRS signals are estimated to originate from an area centered between the source and detector, and from a tissue depth no more than about half the source-detector distance (see



**Figure 1. Principle of simple nearest-neighbor NIRS**

Figure 1). Optical signals are heavily damped by biological tissue; the intensity will decrease several orders of magnitude over a few cm. The ideal source-detector distance is therefore a trade-off between achieving the greatest possible sensing depth while maintaining a sufficient signal quality (signal-to-noise ratio). Generally, a distance of 30-35 mm is considered optimal, and the sensing depth into the adult human head is on the order of 15-25 mm.

To achieve spatial mapping (or imaging) of brain activity, arrays of multiple source-detector pairs are placed over the area of interest. The NIRS imaging equipment developed by NIRx employs a unique measurement strategy in which EACH source channel forms a measurement channel with EACH detector channel. Therefore, a setup with X sources (S) and Y detectors (D) will always produce X\*Y measurement channels. This is true irrespective of the source-detector arrangement or distances; however, only the channels that have S-D separation distances within a certain upper limit will produce signals having usable amplitudes and noise levels.

Because of this scheme, there is no restriction on how to place sources and detectors over the tissue. This affords a maximum of freedom and flexibility in realizing any desired experiment, but at the same time it demands that the user pay careful attention to experimental planning and take a few data-quality assurance steps during setup and also in the subsequent signal analysis.

To allow this degree of flexibility, NIRx imagers require a calibration operation prior to each experiment, during which the signal for each S-D combination is optimized. Depending on the amount of light reaching a given detector from a given source, the detector's light sensitivity is electronically adjusted to provide the optimal amount of signal amplification and therefore the best possible signal quality. This

process is performed automatically during the calibration process initiated by the control software, as described in detail in Section 7.1.

## 2.2 Intended Readership

Familiarity with this document is strongly recommended for operators of the NIRx NIRS imaging devices including the NIRScout™ product family and the NIRSport™, to avoid instrument misuse that potentially can lead to hardware malfunction or data corruption.

We furthermore recommend this document to any user concerned with planning experiments or with analyzing data from NIRScout, NIRScoutX, NIRScoutX+ and NIRSport measurements.



Important notes and alerts are indicated with this symbol throughout the document.

## 2.3 Related Documents

The following user manuals and documents may contain additional information pertinent to the subject matter of this manual:

- NIRx NIRScout-NIRScoutX-NIRScoutX+ User Guide
- NIRx NIRSport User Guide
- nirsLAB user manual
- NIRStim user manual
- NIRSite user manual
- NIRSPay user manual
- NIRx API Design Document for the Real-Time NIRS Data Streaming Software Development Kit (SDK)
- NAVI (Near-infrared Analysis, Visualization, and Imaging) User Guide
- NIRx fNIRS Measurement Caps User Manual
- NIRx Trigger Communication

## 2.4 Problem Reporting Instructions

To reach out to our technical support, or to report errors or omissions in the documentation please contact NIRx.

E-mail: [support@nirx.net](mailto:support@nirx.net)

Web: <http://www.nirx.net/nirx-help-center>

## 3 Installation

### 3.1 System Recommendations

The NIRStar 15.2 software performance is maximized with the following system configuration:

- Windows 7, 8 or 10 (32 or 64 bit)
- Preferably USB 2.0 (if only 3.0 is available, please make sure to have all Windows drivers up to date)
- 8GB of RAM minimum
- At least 2.0 GB of hard-disk space
- Minimum of 1024×768 pixel screen resolution (higher suggested)
- Graphics adapter with more than 256 colors (at least 65k colors recommended)
- .NET Framework 3.5 installed (newer versions may present compatibility issues. If running on Windows 8: <http://windows.microsoft.com/en-us/windows-8/net-framework-windows-8>)
- Visual C++ Redistributable Package for Visual Studio 2013 x86: [Microsoft download link](#)



Please note that certain measurement configurations (especially high frame rates with large numbers of channels) and display capabilities (3D displays) may require computational performance exceeding these specification.

### 3.2 Download and Updates

To obtain the software and to check for updates, please access the [NIRx Help Center](#) in our website.

NIRStar can be downloaded in an optimized version for two different screen resolutions:

- High Resolution: 1900×1200 pixels
- Low Resolution: 1200×768 pixels

Both versions are downloadable either as an *Installer* (\*.exe) or as a *Build* (\*.zip). As several additional software components (*e.g.*, National Instruments™ drivers and the LabView™ Runtime Environment 2012) are needed to run NIRStar, these are included into the *Installer* package (~1.9 GB). After an initial complete installation of all required components has been performed, it is sufficient to install the *Build* versions (~67 MB) of further revisions of the software.

### 3.3 Setup

Please follow the on-screen instructions during the installation process and do not change the default installation paths.



When executing NIRStar for the first time, a firewall alert may be displayed by the operating system. This firewall permission should be granted to allow full NIRStar functionality.



### 3.4 Additional Software Requirements

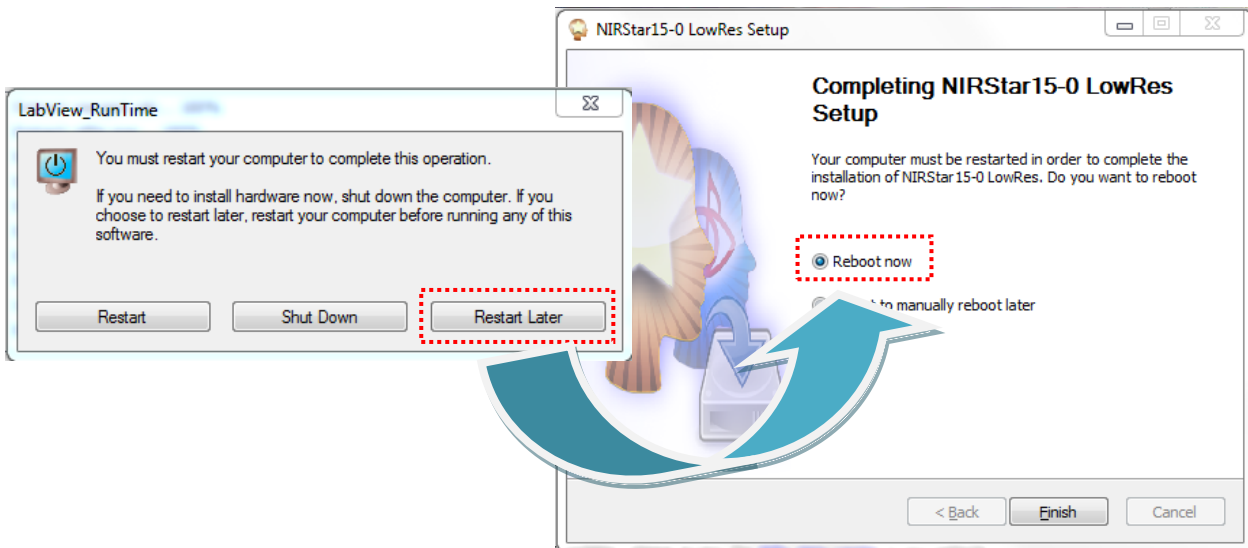
Some NIRStar features, such as the ‘NIRStim’ experimental control software and the ‘Topographic Rendering’ capabilities, used to require the installation of a separate software packages on NIRStar14-0.

Starting on NIRStar14-1, the software installer (LowRes/HighRes) already comprehends all the additional packages and toolboxes that may be needed to run any feature available on the acquisition software. The installers will be automatically prompted to the user during installation of NIRStar (Figure 2).



**Figure 2. Additional software installers automatically prompted to the user during installation**

Please note that, at the end of the installation of *LabView Run-time*, one should click on “Restart Later”, as shown in Figure 3, because the main installation process of NIRStar has not finished yet.



**Figure 3. After the installation of LabView\_Runtime, please choose “Restart later”.**

Please only choose the option “Reboot now” on the finish page of the installation of NIRStar.

## 4 Overview

Welcome to NIRStar! NIRStar is designed to function as a multiplatform instrument controlling environment that offers maximum flexibility to support the many investigational paradigms that the NIRx line of NIRSport and NIRScout functional imaging systems can explore. Whether your aim is to perform mobile studies with the NIRSport or high density hyperscanning measurements with the NIRScoutX, NIRStar gives you a wealth of system control and real-time display capabilities that are designed to maximize the investigational opportunities accessible with NIRS.

Principal features of NIRStar include:

- Automated instrument recognition upon software startup.
- Ability to run full or partial sensing configurations.
- Tandem operation for all instrument types.
- Programmable source control to support multisite brain studies (e.g., left and right hemispheres).
- Automated logging of input triggers from 3<sup>rd</sup> party devices.
- Programmable specification of output triggers to 3<sup>rd</sup> party devices (NIRScoutX only).
- User-controlled manual trigger input.
- NIRStim™ integrated stimulation software
- Real-time data streaming to 3<sup>rd</sup> party devices (requires NIRx SDK).
- Multiple real-time display screens.
- Montage viewing options: Glass view, optode locations and standard EEG positions (international 10-10 system).
- Sensor registration onto anatomical displays (scalp, cortical, MNI brain).
- Real-time updates of hemodynamic response to event related protocols.
- Real-time hyperscanning topographic displays ( $Hb_{deoxy}$ ,  $Hb_{oxy}$ ,  $Hb_{total}$ ).
- Multiple system check displays to ensure data quality.
- Programmable display capability to highlight preselected sensor locations.
- Automated gain adjustment to maximize dynamic range of measurement.
- On-line frequency filtering of displayed results.

- User GUI for specification of custom optode configurations.
- Automated helpful suggestions to facilitate system use.
- Real-time system status reporting display.
- User directed comment box for information logging.
- Up to 4-wavelength laser operation (optional equipment required).
- Predefined montages for fast sensor-system setup.
- Online (acquisition) /Offline (data review) Modes.
- Export to Homer2 and AtlasViewer.
- Integration with Lab Streaming Layer (send data and receive triggers).
- External acquisition control (e.g. calibrate, start, stop, exit) and triggering.
- Short-distance measurements user-friendly set up and visualization.

**Functional Features of NIRStar:**

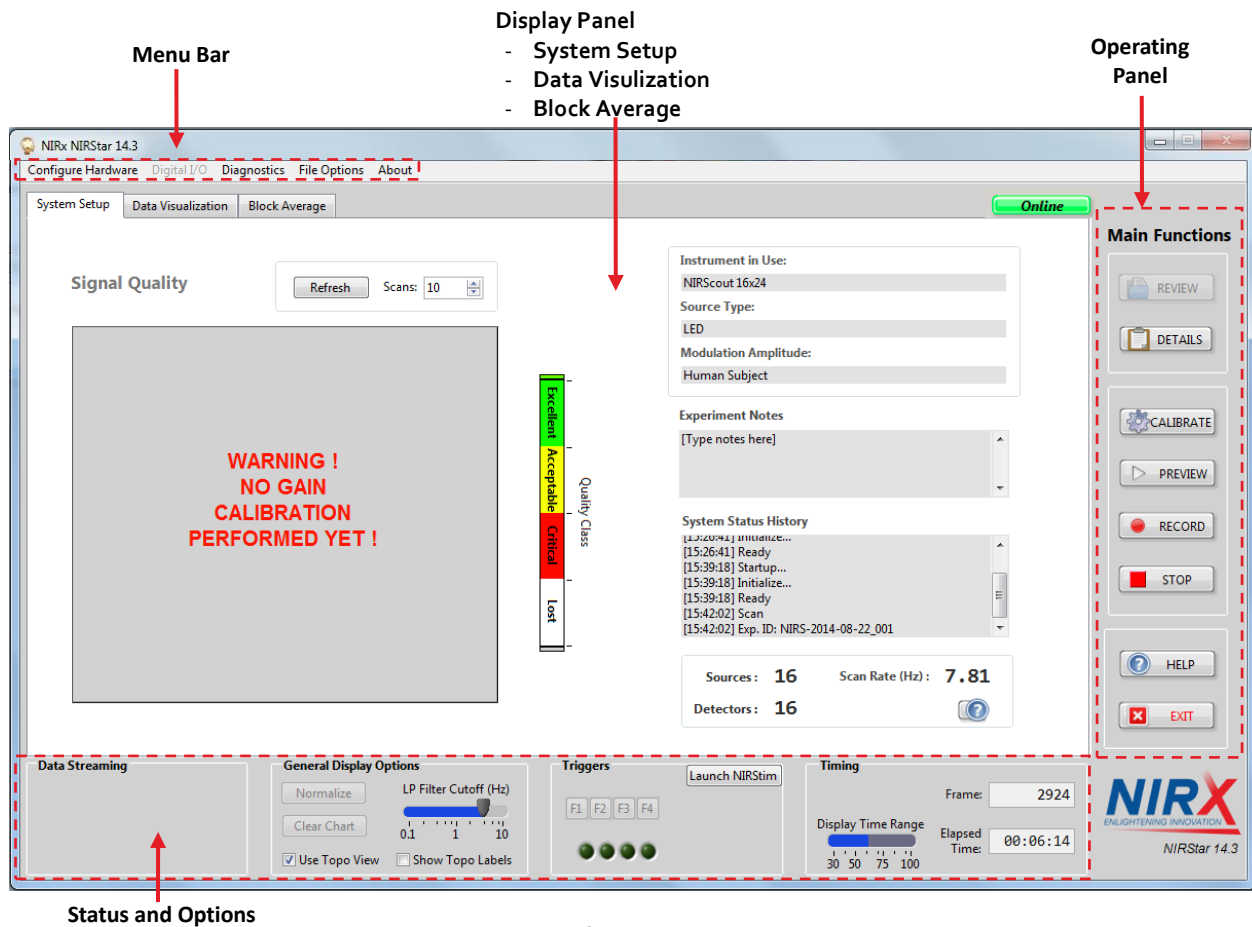
The NIRStar software screen, shown in Figure 4, is subdivided into four principal functional components. All screen elements are arranged to provide a workflow that generally progresses from top to bottom and from left to right.

**i. Menu Bar:**

The *Menu Bar* at the top of the software screen allows access to several configuration and status functions of the imager along with tools for system diagnostics and specification of data path. A principal control feature is the *Configure Hardware* menu described in Section 5. A description of the other menu items can be found in Section 6.

**ii. Display Panel:**

The *Display Panel* provides visual information about the instrument status and measured signals. Display information is accessed through three different tabs.



**Figure 4. Software GUI overview**

- **System Setup:** The *System Setup* tab is the default view when starting the software. Display features report on the general configuration of the system and of the particular optical setup. Information displayed includes the system configuration (number of sources and detectors), scan rate, and current system status. Also accessible is information on optical signal quality for each channel prior to initiating a scan. Please refer to Section 7.8 for detailed description of the *System Setup* tab and its use.
- Various real-time views of the measured data are accessible through the *Data Visualization* and *Block Average* tabs. A detailed description of data visualization and recording can be found in Section 10. For details about the Advanced Displays, please see Section 17.

The user may manually switch between the three tabs at any time during a scan.

### **iii. Operating Panel:**

The *Operating Panel* provides control for system calibration and elements of data recording (see right-hand side of Figure 4). Detailed information about the Operating Panel and its functions can be found in Section 7.

### **iv. Status and Options Bar:**

Positioned below the *Display Panel* are controls for additional display options along with status indicators related to use of triggers, elapsed recording time and data streaming. A detailed description of these functions is provided in Section 10.

## 5 Hardware Configuration

All hardware settings and experimental configurations of the instrument are controlled in the *Configure Hardware* item in the *Menu Bar*. The *Hardware Configuration* user interface (Figure 5) is subdivided into several tabs whose functions are described subsequently. All settings specified in *Hardware Configuration* are automatically saved and will be applied during subsequent calls of the software, until they are again modified.

### 5.1 Hardware Specification

The *Hardware Specification* feature accounts for the different types of imaging devices and different individual configurations supported by NIRStar. With the USB cable connected to the imager and the imager in the 'on' position, launching NIRStar will cause the software to automatically identify the imager type (*i.e.*, NIRSport, NIRScout, NIRScoutX). Because some system types are scalable, it is important that the hardware specifications listed in this section matches the hardware configuration present in the connected device. Hardware specification is made by indicating the number of detector cards (each having 4 input connectors), and number of LEDs (sources) available. Each LED driver card can support either one or two, 8-element connector cables. Shown in Table 1 is a summary of the maximum configurations supported by the different imager systems.

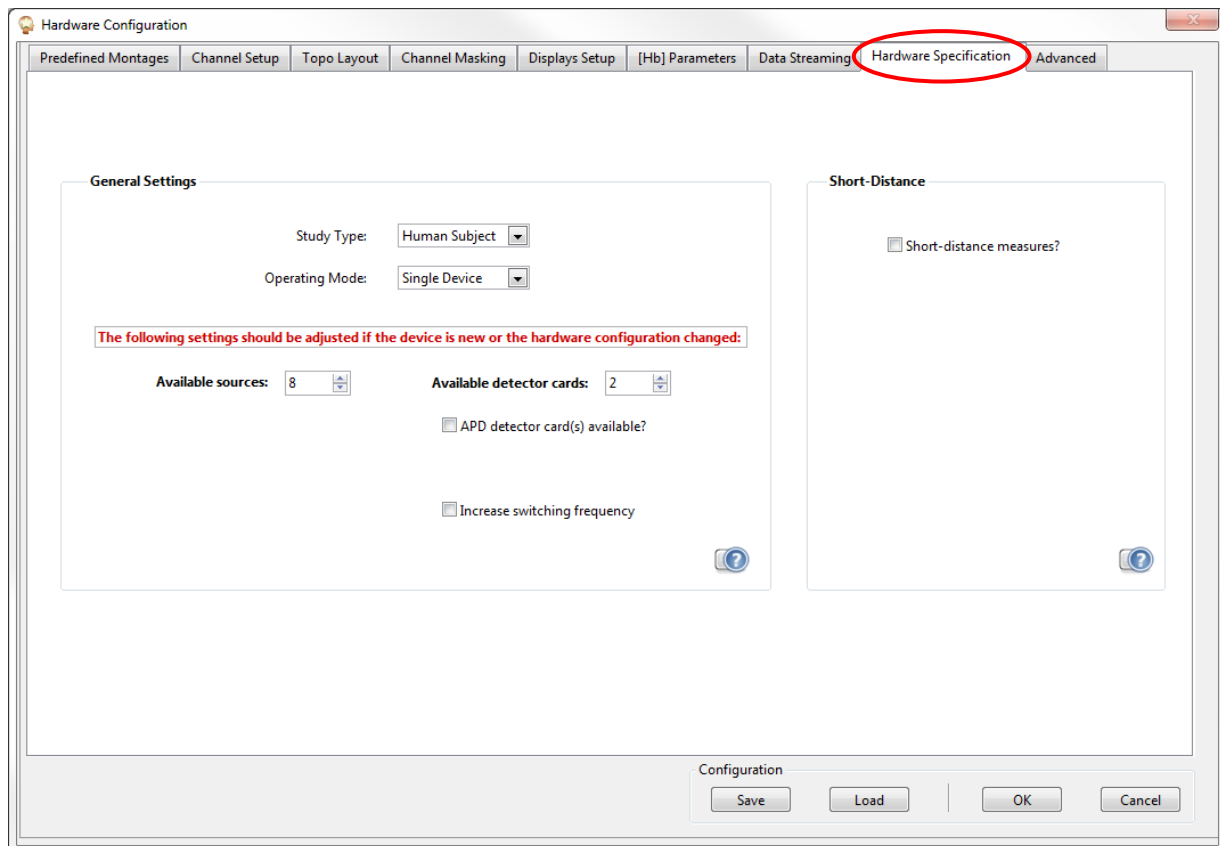


Figure 5. Hardware Specification. Use this interface to define the hardware configuration for the instrument in use.

## General Settings

**Table 1. Maximum number of source and detector configurations for different device types**

Device	Maximum number of detector cards	Maximum number of sources	Resulting maximum number of channels
NIRScout	6	16	384
NIRScoutX	8	64	2048
NIRSport	N/A (pre-set to 8 detector <b>channels</b> )	N/A (pre-set to 8)	64

**Study Type:** Sets the LED intensity to pre-defined power levels. For system performance evaluation using the static phantom, this should be set to ‘Phantom’ (40% LED power level); for all physiologic experiments, please use the setting ‘Human Subject’ (full LED power). This feature is only available for NIRScout and NIRscout Extended devices. NIRSport devices employ an automated LED intensity adjustment feature (see Section 16.1.3).

**Operation Mode:** In addition to the different instrument types, NIRStar will support operating each either as a single unit or as a Tandem system. Clicking the down arrow in the ‘Operating Mode’ check box will allow specification of either a single device or tandem mode. See Section 16 for a detailed description of this capability.

**Available Sources:** Specify the number of source driver channels *physically installed in the system*. Adjust this setting according to your system configuration initially after installing NIRStar and whenever the hardware configuration of the system is changed (*e.g.*, upgrading number of source channels).



It is necessary to set the correct *Hardware Specification* when

- executing NIRStar for the first time after installation or software upgrade, or
- changing the hardware (*i.e.*, the number of detector cards or LED drivers).

The settings will be stored automatically. Unless system hardware is changed, it is generally not necessary to recheck/configure the *Hardware Specification* during normal use of the system.



The *Hardware Specification* tab should NOT be used to limit the number of sources and/or detectors to a value less than number physically present. The numbers used for a selected measurement are specified in the *Channel Setup* tab (Section 5.3).



The NIRStar software assumes a consecutive order of the optodes connected to the instrument. Please make certain that the detector and LED optodes are installed following the system assignment specifications listed in the imager user’s manual.

**Available Detector Cards:** Specify the number of detector cards *physically installed in the system*. Adjust this setting according to your system configuration initially after installing NIRStar and whenever the hardware configuration of the system is changed (*e.g.*, upgrading number of detector cards).

**APD Detector Card(s) Available:** Please check this box in case your NIRScout system presents avalanche photodiode (APD) detector cards. The dark-noise threshold (Section 8.2) will be adjusted accordingly.

**Increase switching frequency (NEW FEATURE):** This doubles up the switching frequency of your NIRScout system, thus reaching sampling rates of up to 125Hz. It is password-protected: please refer to your NIRx distributor for further information on pricing and requirements to enable this option.

## Short-Distance

### NEW FEATURE

Figure 6. Controls for set up of short distance measures once the latter is enabled.

**Short-Distance Measures:** This checkbox enables the control of measurements with short-distance channels. By enabling this option, further controls become visible for set up of the hardware (Figure 6).



Please do NOT select this option if you do not have the short-distance prototype connected.

If enabled, this option will completely change the way raw data are stored by NIRStar.

**No. of bundles:** Number of short-distance bundles connected to the system. Each bundle is expected to be connected (coupled) to a single detector probe. Please note that, while working in Tandem mode or in Hyperscanning, only even numbers of bundles are allowed.

**Detectors connected to bundles:** Identifies the detectors to which the short-distance bundles should be connected and will also point to the last detector(s) according to hardware settings. In case of Tandem or Hyperscanning, it will identify the last detector(s) of each device and each subject, respectively.

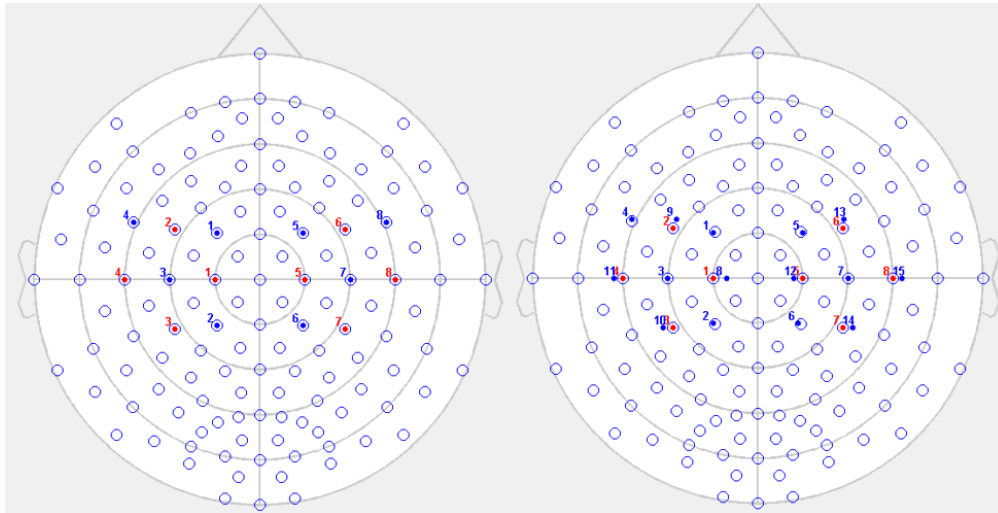
**Inter-optode distance (mm):** For purposes of online estimation of concentration changes, you may set up the hardware inter-optode distance of short-distance channels. By default, this value is set to 8mm.



## Short-Distance Files

If the coupler that allows for short-distance measures is being used and the corresponding settings in hardware specification have been done, most of the files saved by NIRStar will be changed accordingly. Since the short-distance coupler provides the capability of splitting a single detector optode into eight different positions of the cap, corresponding adjustments in the data should be done to allow the user to proceed with data analysis in the usual way. Analysis software packages typically expect that an optode will be located on a single position. Therefore, the data corresponding to the optode(s) that have been split in different positions must be replicated.

For example, if the original montage consisted of 8 sources and 8 detectors, but the last detector has been split into 8 different positions for short-distance measures, all files stored by NIRStar will now be adjusted as if there were 8 sources and 15 detectors in the measurement. By doing so, the user is able to create e.g. probeInfo file that presents all short-distance positions and therefore allows for usual analysis.



**Figure 7. Layout examples for Motor\_8x8 predefined montage: Standard (left) and ShortDistance (right).**

Figure 7 illustrates an example of 2D layout representation for the predefined Motor\_8x8 montage. One can see that the original layout consisted of 8 sources and 8 detectors with positions based on the international system. The short-distance layout now presents 8 sources and 15 detectors, from which the last 8 detectors (numbered 8-15) have now been placed shortly apart from each source available in the montage in order to allow for short-distance measurements in each location of interest. This has been accomplished based on the prototype that allows for splitting the last detector available (#8, Figure 7 left) in eight different positions (#8-15, Figure 7 right).



### LEGACY NOTE

NIRStar15-0 expected two different probeInfo files (Standard and ShortDistance) for the same montage. Starting in 15-1, these are treated as separated montages. If one intends to create a layout with short-distance bundles, this will expect a single and exclusive probeInfo file, which will then be copied into the dataset folder for offline data analysis purposes.

## 5.2 Predefined Montages

NIRStar provides a quick setup of the hardware configuration according to the desired experiment design to be chosen under the tab *Predefined Montages* of the Hardware Configuration.

The tabs *Channel Setup* ( 5.3), *Topo Layout* ( 5.4) and *Channel Masking* ( 5.5) are automatically updated to the configuration that corresponds to the chosen layout, **if** the required number of sources and/or detectors does not exceed the limits set in the Hardware Specification tab (see Section 5.1).

Moreover, a picture of the chosen layout is displayed for the user, where the positions of each source and detector on the 10-10 standard NIRx cap is shown to the user (Figure 8).

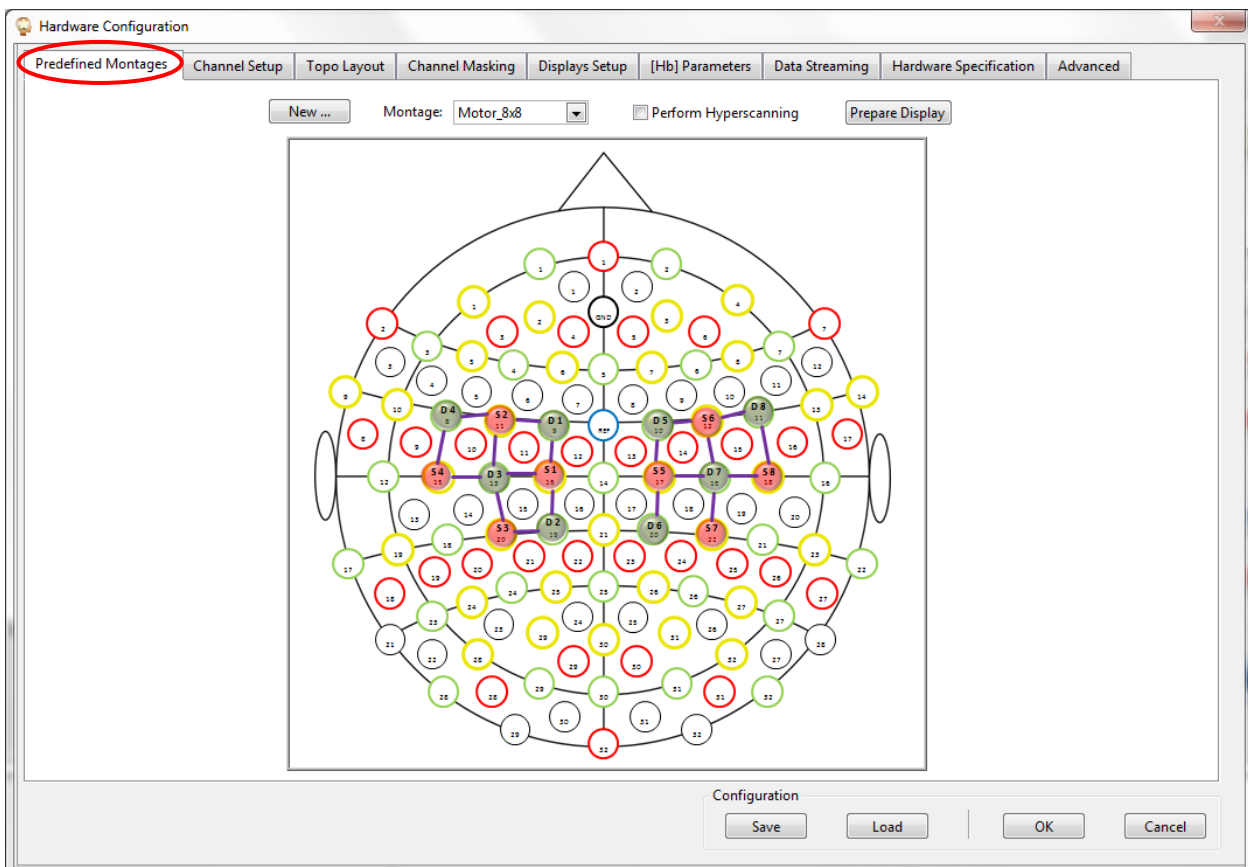


Figure 8. Montage Motor\_8x8 has been chosen under Predefined Montages tab and cap layout is displayed.

The option “Perform Hyperscanning” allows to expand the chosen configuration for two subjects if the number of sources and detectors required are available (please refer to Section 20 for more information on Hyperscanning requirements).

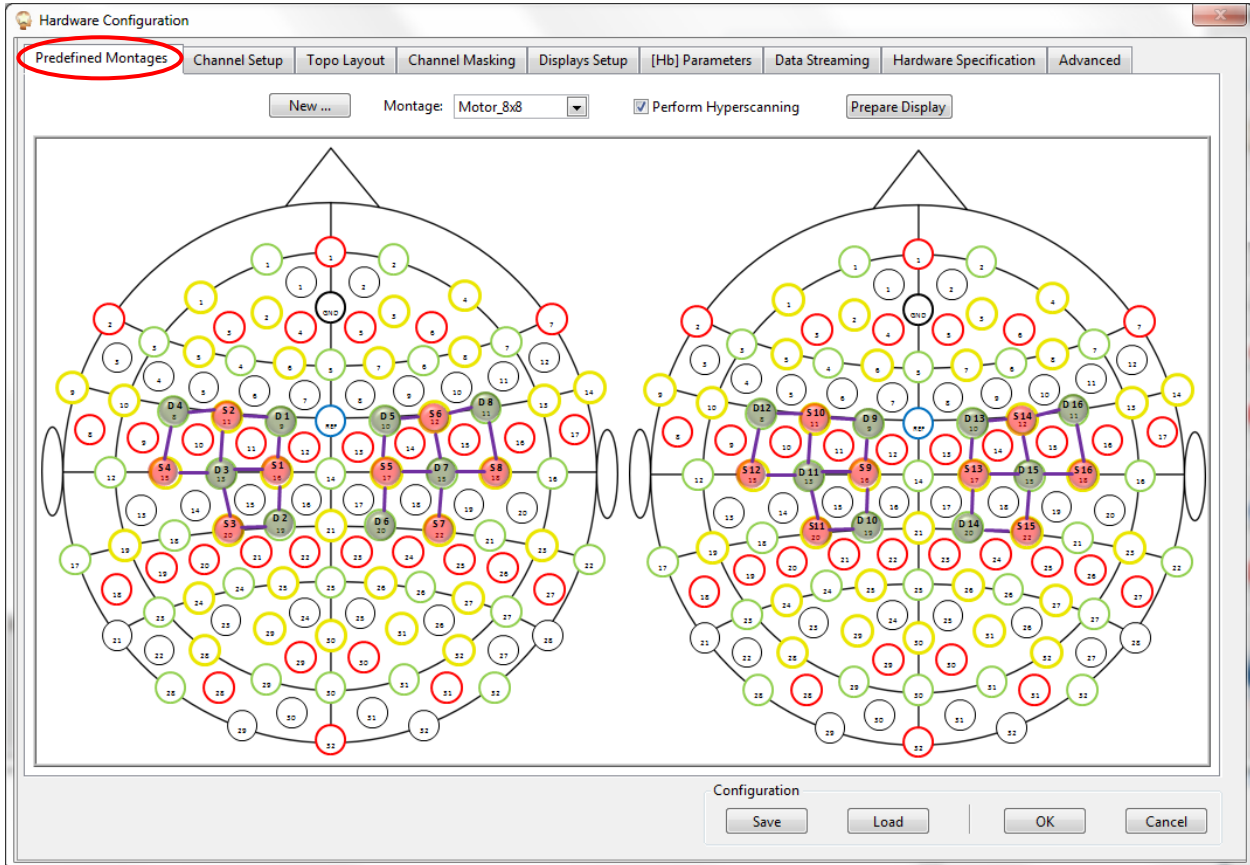
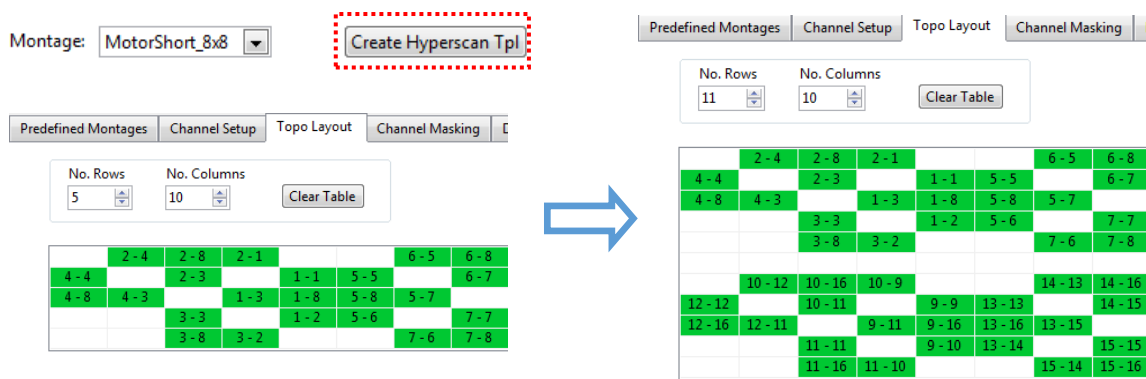


Figure 9. The sources and detectors positions for Motor\_8x8 are shown for Hyperscanning (two subjects).

**NEW FEATURE**

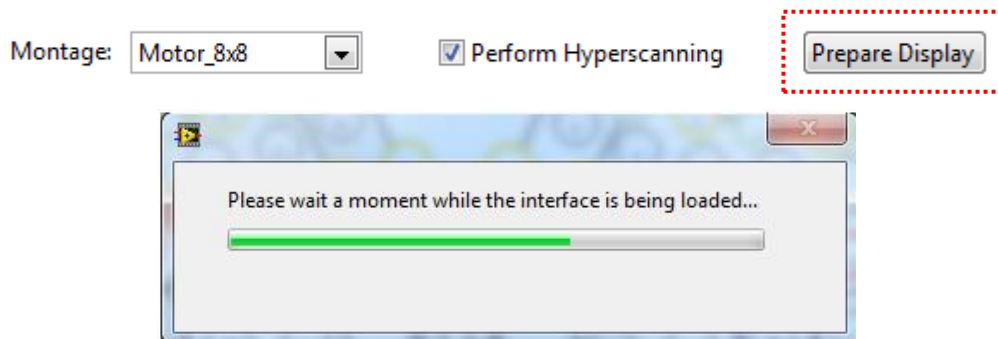
If the chosen predefined montage does not contain a topo layout for hyperscanning, NIRStar will rather provide the user with the option to automatically create this layout, as shown in Figure 10. It essentially attempts to replicate the current pattern by adapting the labels and creating new columns or rows.

Please note however that if the result exceeds the size restrictions for topo layout (20 rows and 15 columns), it will not be possible to create it and the user will be informed to do it manually. Otherwise, if the operation succeeds, the “Perform Hyperscanning” checkbox will now be available in the screen.

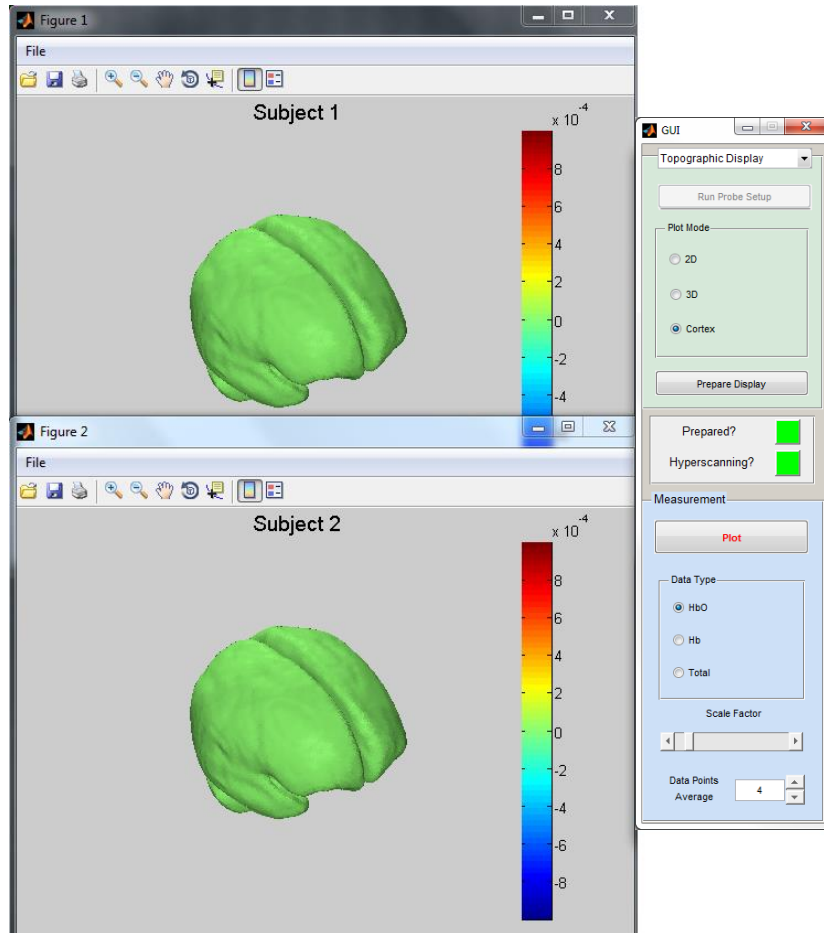


**Figure 10. Original single-subject Topo Layout (left) and Hyperscan topo layout created by NIRStar (right).**

Once the desired configuration has been chosen, the user also has the option to automatically launch the Built-in Topographic Rendering (see section 18) already having the corresponding Probe Setup file loaded and the Cortex display(s) available (Figure 12). This can be done by clicking on “Prepare Display”:



**Figure 11. ‘Prepare Display’ button (top) and loading bar (bottom) that appears while the interface is**



**Figure 12. GUI interface successfully loaded and Cortex figures (Subject 1 and 2) displayed.**

In other words, only using the Predefined Montage tab, the user is able to completely configure the system for the experiment (given that the Hardware Specification tab has been previously set), select whether one or two subjects will be measured and also to load and display the Cortex plot(s) to be used to plot in real-time the data collected by the measurement.

This can be achieved on NIRStar with the following montages available from the drop-down menu:

Motor_8x4	Motor_8x8	Motor_16x16
Occipital_8x8	OccMotor_16x16	OccPrefr_16x16
Prefrontal_8x8	PrfMotor_16x16	More on <a href="#">NIRx Help Center</a>

In addition to these, NIRStar allows its users to add their own montages by clicking on “New...”. By doing this, a form pops up and the user is requested to enter the montage name and the corresponding number of sources and detectors, in addition to check the configuration files to be loaded (Figure 13).

**Figure 13.** “Create new Montage” form that appears by clicking “New...”.

Here, the user may enter the desired montage name, the number of sources and detectors, and which additional files (TopoLayout, ProbeInfo and head models) they would like to add to this montage. Please note that “Standard TopoLayout (.tpl)” file is always selected and cannot be changed, because at least this file should be available in order to set up the hardware configuration properly.



For more information on how to create a Topo Layout (.tpl) file, please refer to section 5.4. The ProbeInfo file (\_probeInfo.mat) creation is explained on nirsLAB and NIRSite manuals.

The number of sources and detectors will be combined into the final montage name to be displayed in the drop-down menu. For example, if one wants to define a montage called *Empathy* making use of 8 sources and 8 detectors, the drop-down menu will list it as *Empathy\_8x8*, in which the first number represents the sources and the latter the detectors (Figure 14).

If a Standard Head Model (optimal resolution: **543x549**) or a Hyperscan Head Model (optimal resolution: **540x1008**) is not uploaded to the software, the layout of the cap will not be displayed. Instead, there will be a message that says “**No layout available to be displayed.**”.

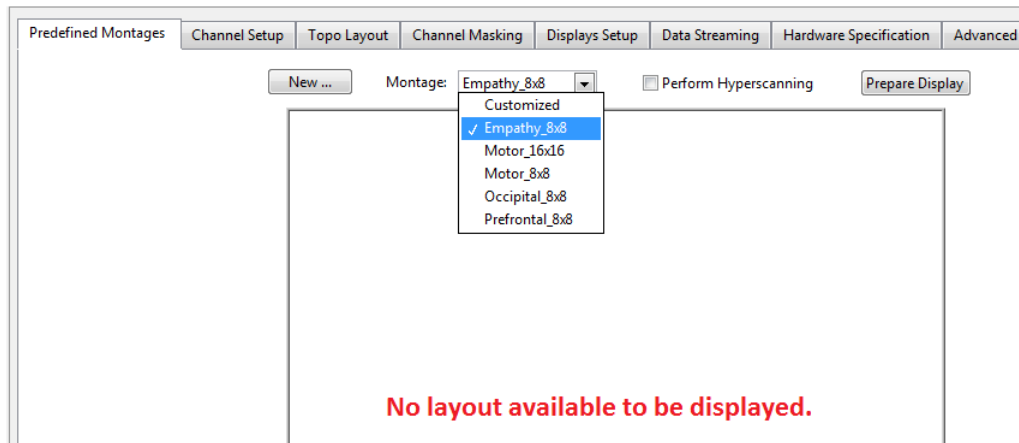


Figure 14. Upon completion, the Montage drop-down menu list is updated and now shows *Empathy\_8x8*.

This message will also be displayed in the case that “Customized” Montage is chosen, which may happen either manually or when the user changes any setting of the Hardware Configuration, because this will result on a different configuration than the previously selected Montage.

### 5.3 Channel Setup

In the *Channel Setup* tab (see, Figure 15) the user can define the number of measurement channels and the illumination sequence to be used in a specific experimental protocol.

#### Number of Sources

Sets the number of physical illumination positions used in the experiment. The maximum number of sources is determined by the number of available sources specified in Section 5.1.

#### Number of Steps

Sets the number of rows in the illumination pattern matrix. As explained below, the number of rows cannot exceed the number of columns.

#### Number of Detectors

Sets the number of detection positions used for the experiment. The maximum number of detectors is determined by the number of detector cards available, as explained in Section 5.1.

#### Illumination Pattern

The NIRStar software provides the user with the ability to specify illumination sequences. The illumination pattern graphic identified under the Channel Setup tab indicates the illumination sequence used in the experiment, *i.e.*, the order in which the sources are turned on during each scan. Each column of the matrix represents a source (in consecutive order from left to right, starting with source no. 1), and the rows represent sequential steps in the scanning process, from top to bottom. The individual

elements of the matrix may be toggled by left-clicks of the mouse. A highlighted dot in the matrix position row  $x$  / column  $y$  signifies that the source no.  $y$  is activated in the  $x^{\text{th}}$  step of the scanning sequence. The default pattern is a square matrix with the main diagonal highlighted, *i.e.*, all sources light up in consecutive order. Figure 15 shows the default illumination pattern for a 16-source measurement, resulting in 16 illumination steps and a scan rate of 3.906 Hz. Because the illumination duration per source is always constant, the overall scan rate depends on the number of scan steps, according to

$$f_{\text{scan}} = 62.5 \text{ Hz} \div (\text{no. of steps}).$$

In the formula above, 62.5Hz represents the default switching frequency of NIRx devices. This may be increased to 125Hz with the password-protected checkbox in Hardware Specification (section 5.1).



For EARLIER SOFTWARE VERSIONS (up to NIRStar 12.4) the scan rate was given as:

$$f_{\text{scan}} = 62.5 \text{ Hz} / (\text{no. of steps} + 2)$$

**LEGACY NOTE**

Starting with Vers. 13.0 NIRStar was optimized to provide increased scan rates.

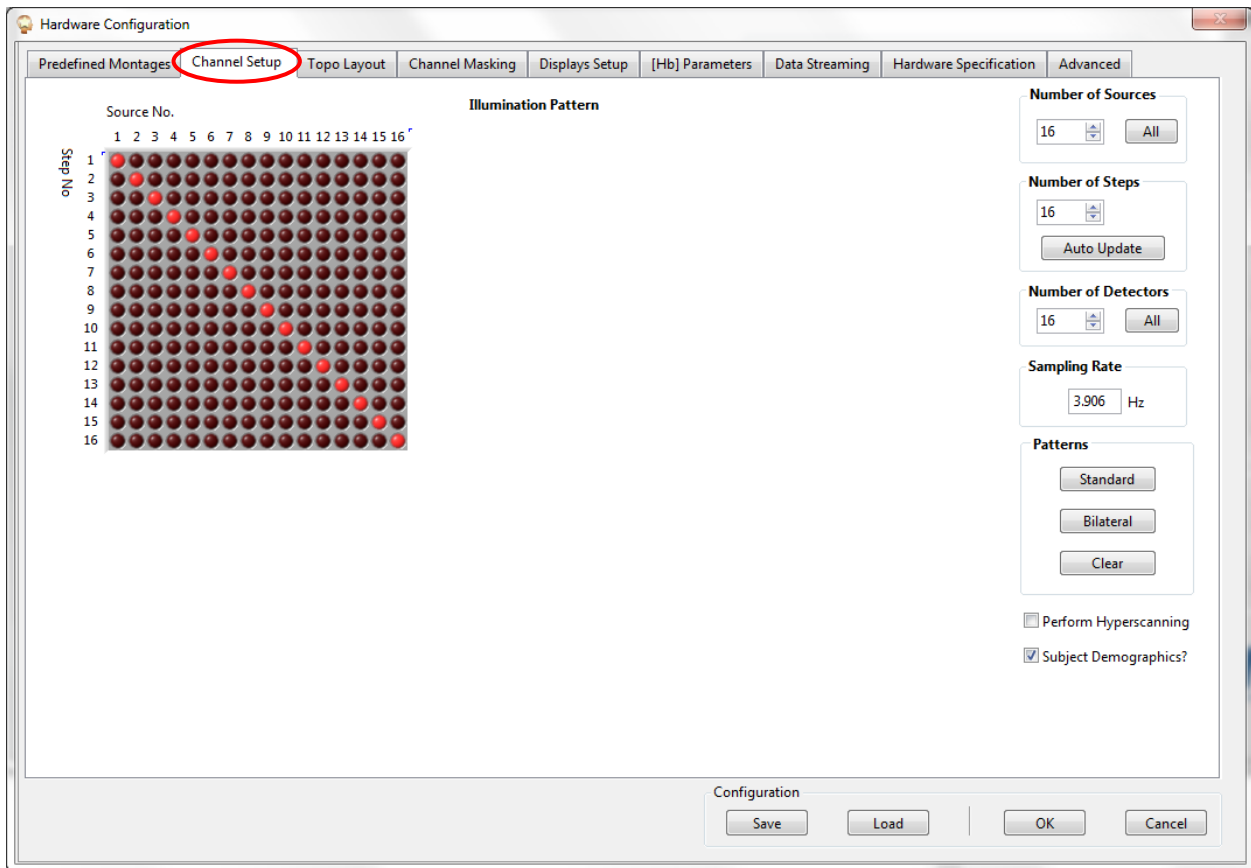


Figure 15. Illumination Setup: A standard pattern for 16 sources



There are some general guidelines to consider when setting up the illumination sequence:

- A 'scan' is defined as the process of performing the illumination sequence once. The number of rows in the illumination pattern is equal to the number of steps per scan. A scan may also be referred to as a 'frame'. The number of scans performed per second determines the acquisition rate, or scan rate, *i.e.*, the number of NIRS data sets acquired per second.
- A source cannot be switched on more than once per scan (*i.e.*, there can be only one highlighted dot in each column).
- The number of steps cannot exceed the number of sources.
- Multiple sources may be activated during the same step (*i.e.*, parallel illumination of different areas). This reduces the number of steps and increases the scan rate (see below).
- It is permissible to specify that a source never gets switched on in any step (by leaving the appropriate column empty), but this is not recommended and it will generate an alert message.

### Auto Update

Empty rows are ignored by the software and are removed from the illumination pattern. To visualize this effect when specifying an illumination pattern, the user may click the *Auto Update* button.

If there are empty columns in the final LED pattern, an alert will be generated to warn you to the fact. It is possible to ignore this alert. Nevertheless, we suggest that in this case you reduce the number of sources and define a fully populated LED pattern.

### Patterns

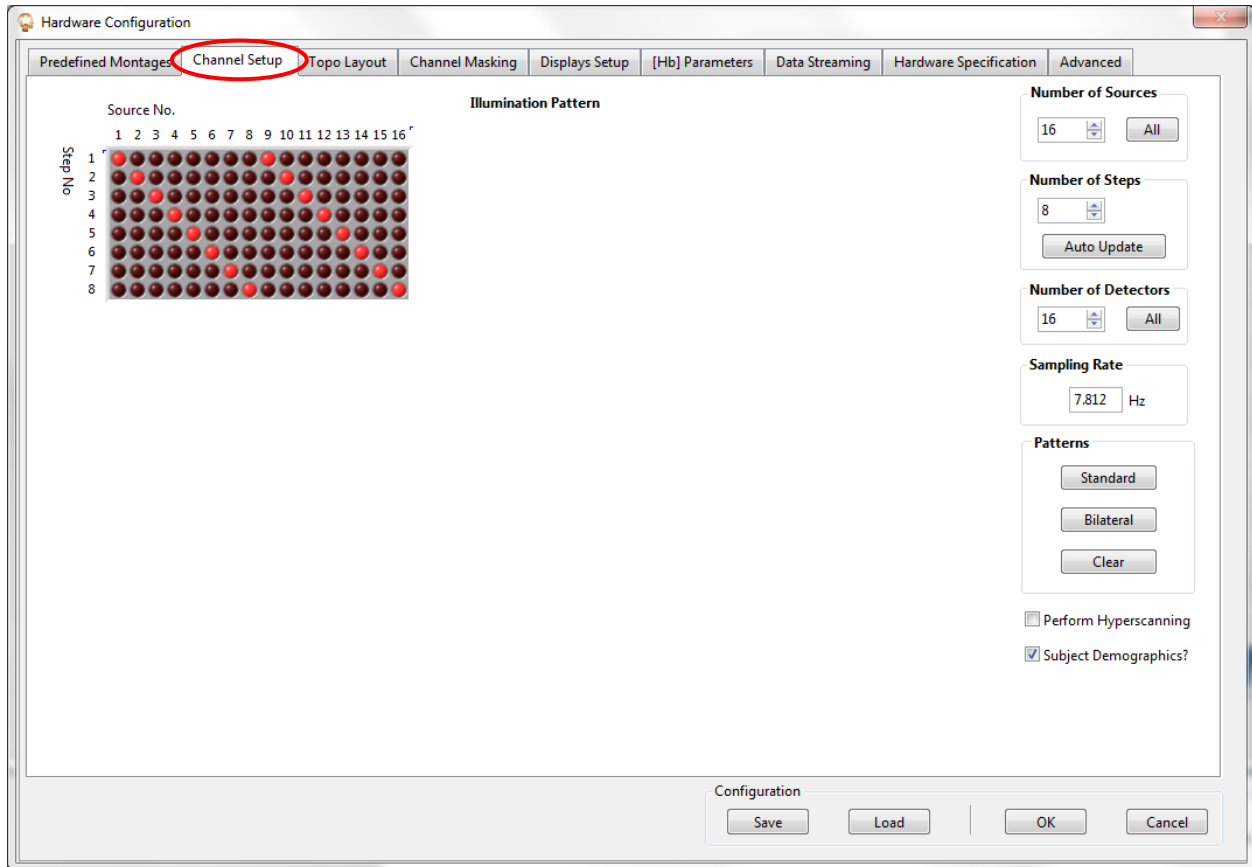
The *Standard* pattern (sources along the main diagonal) can always be restored by clicking the *Standard* button in the *Patterns* region.

For even numbers of sources, the basic dual-source parallel illumination scheme shown in Figure 16 is generated by selecting *Bilateral* in the *Patterns* section, achieving about twice the standard scan rate.

*Clear* empties the illumination matrix.

## Parallel Illumination

For a given number of sources, the number of steps may be reduced, and the scan rate increased, by turning on more than one source per step (*i.e.*, highlight more than one dot per row). Figure 16 shows the case of a scan sequence in which two LEDs are switched on at the same time, *i.e.*, 1 & 9, 2 & 10, 3 & 11, *etc.*



**Figure 16. Illumination Setup: An example for a bilateral setup for 16 sources**



When employing parallel illumination, care should be taken to avoid optical cross-talk. Therefore, sources activated during the same step should be located so that no detector receives light from both sources simultaneously.

To avoid optical cross talk, a sufficient distance (a minimum of ~6 cm) should be maintained between the paired sources. This is easiest to achieve by performing a parallel scan of well-separated brain areas (*e.g.*, left and right hemisphere).

### Parallel illumination considerations

Per LED driver card a maximum number of four sources may be used for simultaneous (parallel) illumination; this satisfies the most commonly encountered experimental situations. Trying to use a larger number of sources within the same cycle will cause an alert:

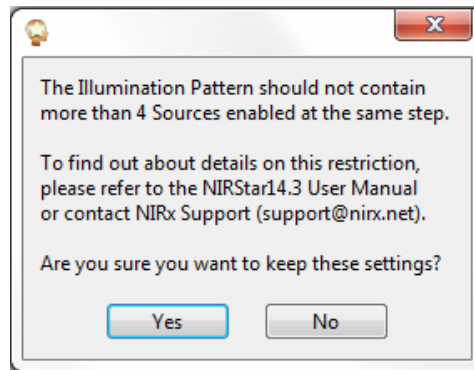


Figure 17. Alert issued for large number of parallel sources.

While it is possible to use more than four sources per card in parallel it may be necessary to limit the overall power consumption of the electronics by either reducing the light intensity, lowering the scan rate, or both.



If it is desired to use more than four sources per driver card in parallel please reach out to technical support to assist with the proper instrument setup.



The hardware is internally protected against undue power consumption. As a result, choosing an inappropriately high number of parallel sources may result in protective LED shutdown and, as a result, severe data corruption.

### Hyperscanning

Enables the Hyperscanning capability. See Section 20 for a complete description.

### Subject Demographics

When checked, a dialog for entering subject demographic information will appear prior to starting the recording (see Section 11).

### 5.4 Topographic Layout Editor ('Topo Layout')

NIRStar offers different ways of topographic data mapping. The 'Topo Layout' editor described here and shown in Figure 18 offers simplified, schematic mapping of the channels onto a geometric, rectilinear pattern. For advanced anatomical mapping capabilities, please refer to Sections 17.1 and 20.

The pattern defined under 'Topo Layout' determines the channel arrangement for both the real-time display (Section 10) of the hemodynamic changes and the block average display (Section 17.3).

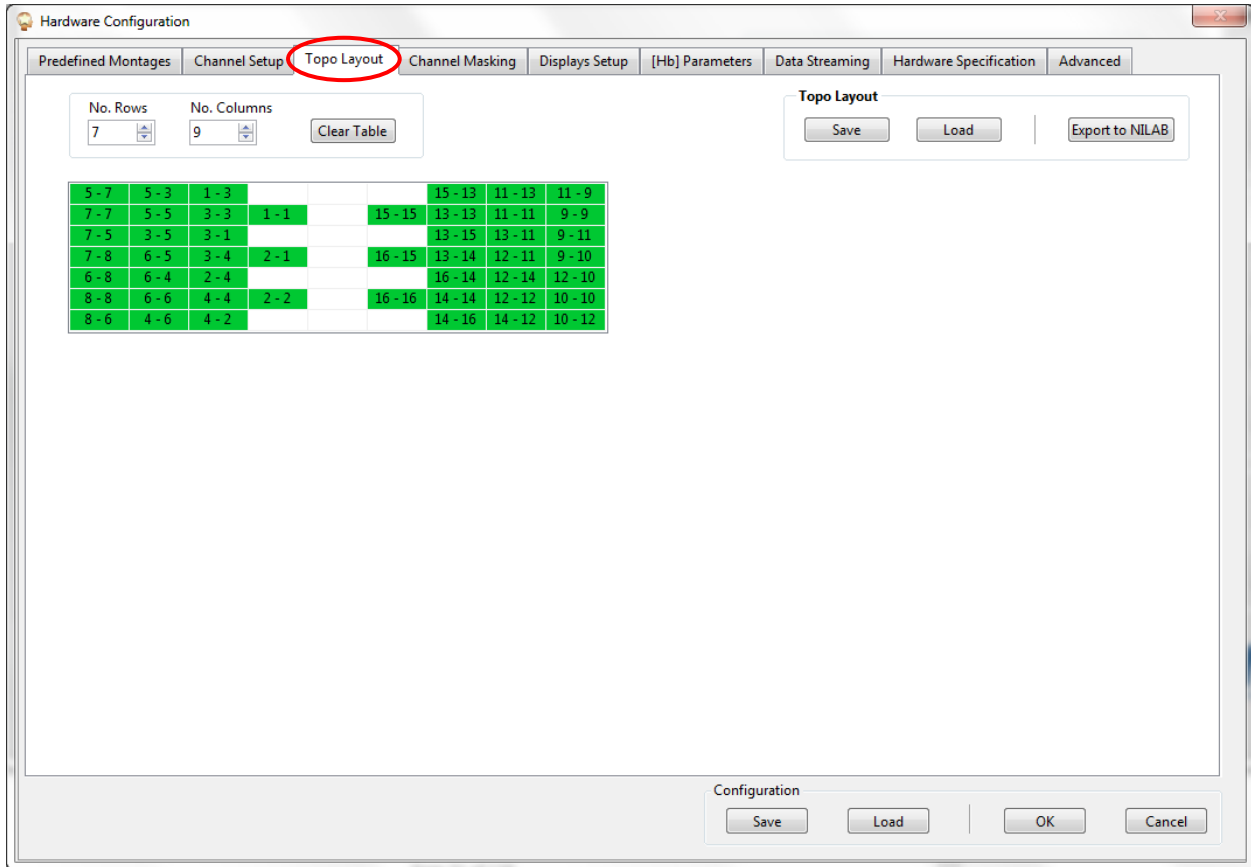
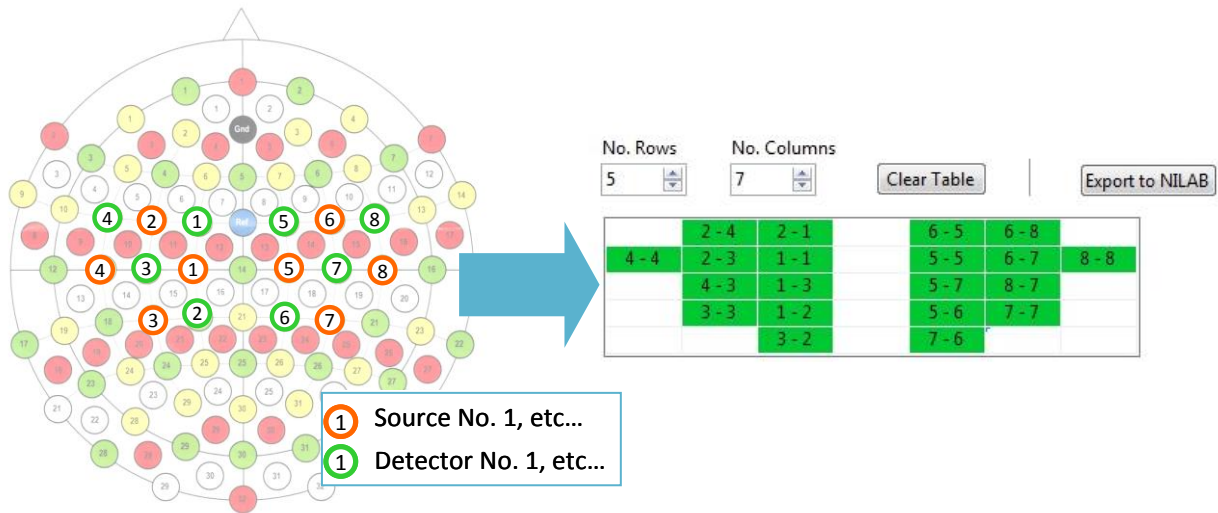


Figure 18. The topographic layout editor tab. Shown is the example of a 16-Source / 16-Detector measurement

The Layout Editor offers a convenient way of specifying the spatial arrangement of specific source-detector-combinations ('channels'). As illustrated in Figure 18 and in Figure 19, the physical layout on the head (in this example, referenced to the international 10-10 system) is transferred to a tabular rectilinear view. The channel formed by Source X and Detector Y is identified by the String X-Y in the appropriate field.

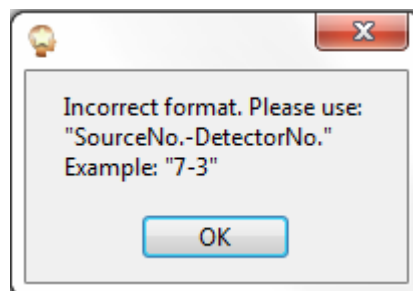


**Figure 19. Example configuration illustrating how to translate a physical source-detector arrangement on the head to the topographic layout. The physical setup is shown in relation to the positions of the EEG 10-10 system. Each neighboring source-detector combination forms a measurement channel. For example, the channel defined by source 2 and detector 4 would be positioned top left in the topographic layout.**

To define the layout, click on a cell of the table and enter the specific channel identifier. A channel is defined by specifying first the source number, followed by a minus sign, followed by the detector number. If the format requirement "Source No. - Detector No." is not met, an error message is displayed as shown in Figure 20. The number of rows and the number of columns can be adjusted by using the appropriate fields in the upper left corner of the *Topo Layout* user interface.



Please refer to Appendix B for a simple algorithm on how to generate a rectilinear abstraction for most any real-world probe arrangement.



**Figure 20. Error message for an inappropriate format of the source-detector definition.**

The Topo Layout matrix can have up to 20 rows and 15 columns, for a maximum of 300 cells. However, the largest array that the real-time Block Average display function can display is 15×10, so a maximum of 150 channels can be simultaneously viewed during the data collection process. (Note, however, that neither the number of channels you include in the layout nor the number of channels in the real-time Block Average display has any effect on the number of columns of data in the .wl1 and .wl2 output files that NIRStar generates.)

The specified topography pattern is automatically saved when exiting from the *Hardware Configuration* user interface, and it is automatically retrieved the next time that interface is entered.

The *Export to NILAB* button (upper right corner of the *Topo Layout* user interface) saves the topographic setup to a binary MATLAB file for easy import into the NILAB topographic data analysis suite.



If no Topographic Layout is defined (*i.e.*, if the table is empty) and the *Use Topo View* checkbox is activated, then no channels are displayed in the corresponding plots. Please uncheck the *Use Topo View* checkbox to obtain a source-detector view. Please also check for an empty Channel Masking matrix (see Section 5.5) that might have been automatically updated. This also can cause the channel display to be empty.



A specified topographic layout is erased when the hardware configuration (*e.g.* number of either sources or detectors) is changed.

### 5.4.1 Save or Load a Topographic Layout

A specified topographic map may be saved for later use. Likewise, a saved layout may be loaded for use or re-editing. Both *Save* and *Load* functions are available in the *Topo Layout* tab. Clicking on either button (upper right corner of the user interface) brings up a navigator window, in which the user selects a desired location and specifies a filename (Figure 21). The file is in ASCII text format, with the default filename extension ‘tpl’.

This function is not to be confused with the *Configuration Load/Save* feature (see Section 5.9), which is used to store and recall the entire instrument setup, including the layout and also all other configuration settings (*i.e.*, no. of sources, no. of detectors, LED pattern, *etc.*).

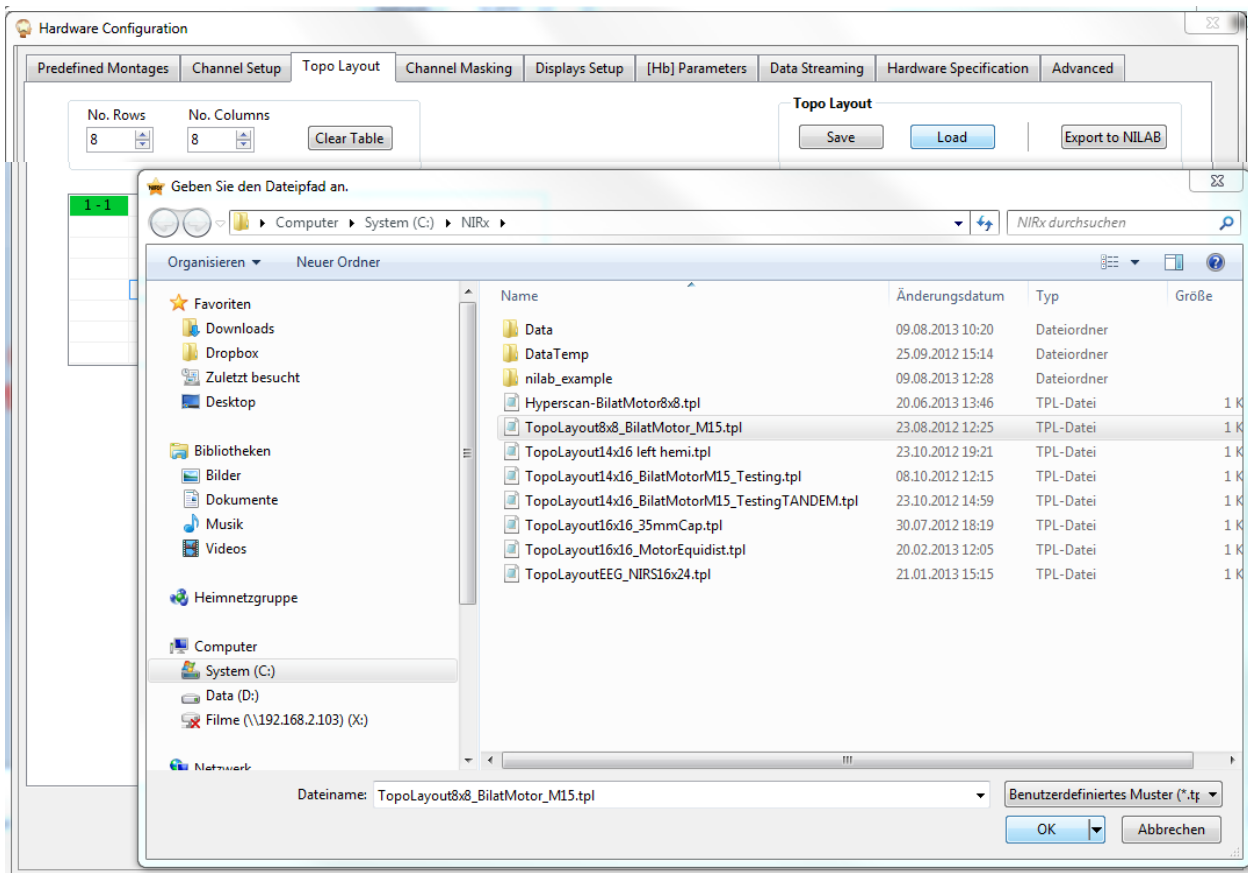


Figure 21. Save/Load Dialog for storing and recalling topographic layout patterns

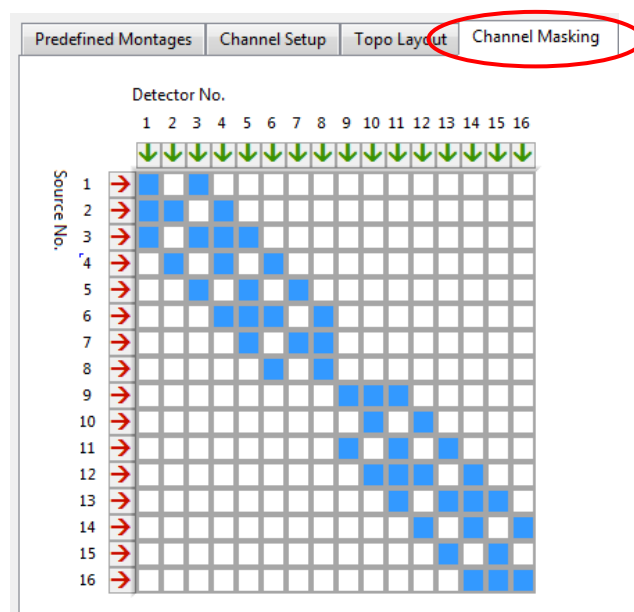
## 5.5 Channel Masking

The *Channel Masking* tab is used for selection of specific source-detector-combinations (*i.e.*, measurement channels) for display in the time-series plots (see section 10). Typically, these will be channels that are expected to yield good data quality based on the sensor separation distance being less than  $\sim 3.5$  cm. Rows represent sources, and columns represent detectors. Selected channels are marked by filled squares, and will appear in plots. Unchecked (white) boxes mark those channels which are excluded from plots. (This is the reason why no time series are displayed if the Channel masking matrix is empty, as indicated in Section 5.4.)

When a *Topo Layout* is specified (see Section 5.4), each measurement channel that the user includes is automatically selected in the Channel Masking matrix, as these are assumed to be the channels of interest. However, the user may modify the Channel Masking after the Topo Layout has been defined. Figure 22 shows the *Channel Masking* pattern that corresponds to the *Topo Layout* example in Section 5.4.

The boxes marked with red rightward-pointing arrows are used to select/de-select complete rows (*i.e.*, all detectors for a specific source). The boxes marked with green downward-pointing arrows are used to select/de-select complete columns (*i.e.*, all sources for a specific detector).

The masking options also allow the user to select or clear all channels. Use the *Apply Topo Layout* button in the *Channel Masking* tab to create a mask that displays all of the channels in the currently specified topographic layout (see Section 5.4). The 'Auto' function masks out all channels that have a signal level, in Volts, below the specified value (default = 0.1 V). To use this functionality, a gain calibration has to be performed first.



**Figure 22. Channel Masking: The pattern shown was automatically adopted from the Topo Layout (see Section 5.4)**





Only channels that are included in the *Channel Masking* matrix are shown in the trace plot display.



By default, Channel Masking affects **ONLY** the display, **NOT** the recorded data (*i.e.*, ALL channels are recorded). However, the user can force NIRStar to save data for **ONLY** the channels highlighted in the Channel Masking matrix, by placing a mark in the 'Mask saved data?' checkbox.

## 5.6 [Hb] Parameters

NIRStar provides the user with the possibility of setting the modified Beer-Lambert law parameters that will be used for the online computation of oxygenated and deoxygenated forms of hemoglobin. These parameters are: extinction coefficients, differential pathlength factor, source-detector separation and baseline, as illustrated in Figure 23. Please note that these will not affect the data stored by NIRStar.

The screenshot shows the 'Hardware Configuration' dialog box with the '[Hb] Parameters' tab selected. The main content area is titled 'Modified Beer-Lambert Law (mBLL)' and contains four sub-sections:

- Absorption Coefficients:** A table with columns for HbR and HbO, and rows for 760 and 850 nm. The values are:
 

	HbR	HbO
760	3.56624	1.34956
850	1.59211	2.43657
	0	0
	0	0

 Reference: <http://omlc.org/spectra/hemoglobin/>
- Differential Pathlength Factor (DPF):** A 'Subject Age' dropdown set to 30, and a table with columns for 760 and 850 nm, and rows for 760 and 850 nm. The values are:
 

	760	850
760	6.2966	
850	5.23433	
	0	
	0	

 Reference: 10.1117/1.JBO.18.10.105004
- Source-Detector Separation:** A checkbox 'Equidistant channels?' is checked, and a 'Distance (mm)' input field is set to 30.
- Baseline:** A 'Length (sec)' dropdown is set to 120.

At the bottom of the dialog, there are buttons for 'Save', 'Load', 'OK', and 'Cancel'.

Figure 23. Modified Beer-Lambert law parameters for online calculation of hemodynamic changes

### **5.6.1 Absorption Coefficients**

Depending on the wavelengths that are available in your NIRx system, NIRStar will automatically retrieve the extinction coefficients that have been tabulated by Scott Prahl based on data from W.B. Gratzler and N. Kollias and are available on the following link: <http://omlc.org/spectra/hemoglobin/summary.html>

The resulting absorption coefficients, which are displayed in NIRStar, are calculated by multiplying the extinction coefficient values provided by 2.303, as described in: <http://omlc.org/spectra/hemoglobin/>

However, if one would like to use different absorption coefficients for the modified Beer-Lambert law than those provided by Scott Prahl, the absorption coefficients fields under [Hb] Parameters are editable.

### **5.6.2 Differential Pathlength Factor (DPF)**

The differential pathlength factor accounts for the actual distance that the light travels from the emitter to the detector due to the scattering properties of the tissues in between. Therefore, these values not only depend on the wavelengths used, but also to the subject age as well as cortical region of interest.

Recently, F. Scholkmann and M. Wolf published a general equation to calculate the DPF of the frontal human head according to the wavelength and age. We have incorporated this equation for the online hemodynamic computation to allow for more precise hemodynamic values.

The wavelengths are retrieved automatically and the user is able to enter the subject age (default value is 30 years) to compute the corresponding DPF based on this equation. And the user is also allowed to edit these values, if desired.

### **5.6.3 Source-Detector Separation**

NIRStar allows the user to enter individual source-detector pair distances for the channels enabled in the Channel Masking tab (Figure 24) in the case that non-equidistant source-detector separation values should be considered.

By default, all source-detector separations are considered equidistant (30mm). Unchecking the 'Equidistant channels?' box allows editing source-detector separation distances for individual channels (Figure 24). Please note that, if short-channels (section 5.1) are included in the channel masking, these will automatically have the inter-optode distance set by default to 8mm or the value chosen by the user.

The estimated concentration changes scale linearly with the presumed source-detector distance. Therefore, specifying too short a distance will underestimate, and specifying too long a distance will overestimate the displayed amplitude. In cases where non-equal-distances are employed (e.g., 10-10 system positions) this may cause imprecise amplitude estimates if the actual channel distances are not entered in the Source-Detector Separation feature. For qualitative real-time display purposes these uncertainties are usually uncritical. Please note, however, that any offline or real-time analysis relying on quantitative amplitude estimates should take into account source-detector distances variation.

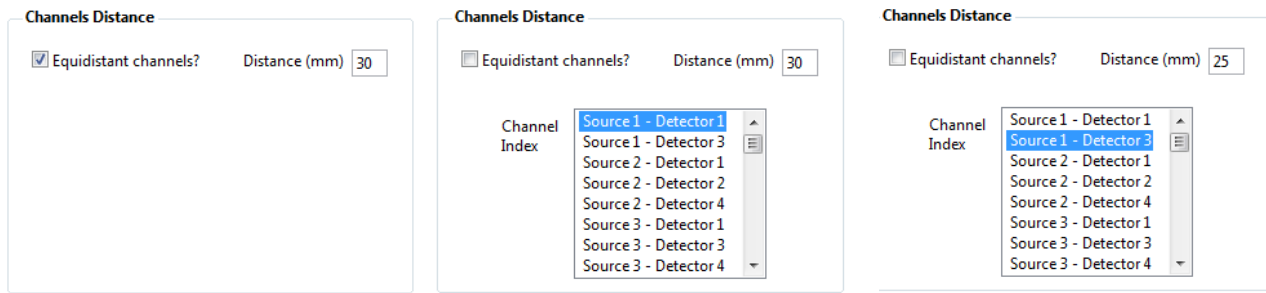


Figure 24. Specification of the source-detector separation

### 5.6.4 Baseline

NIRx instruments are continuous-wave systems and therefore measure concentration changes in relation to a baseline. For the real-time hemodynamics computation in NIRStar, a shifting baseline is employed. By default, the baseline will be calculated from the mean of the last 120s of data collected. For the first 120s of data collection, NIRStar will then take into account the number of data points currently available, i.e. it is a building baseline. The user is also allowed to enter the number of seconds to be considered for the baseline, in case shorter or greater periods should be preferred.

## 5.7 Data Streaming

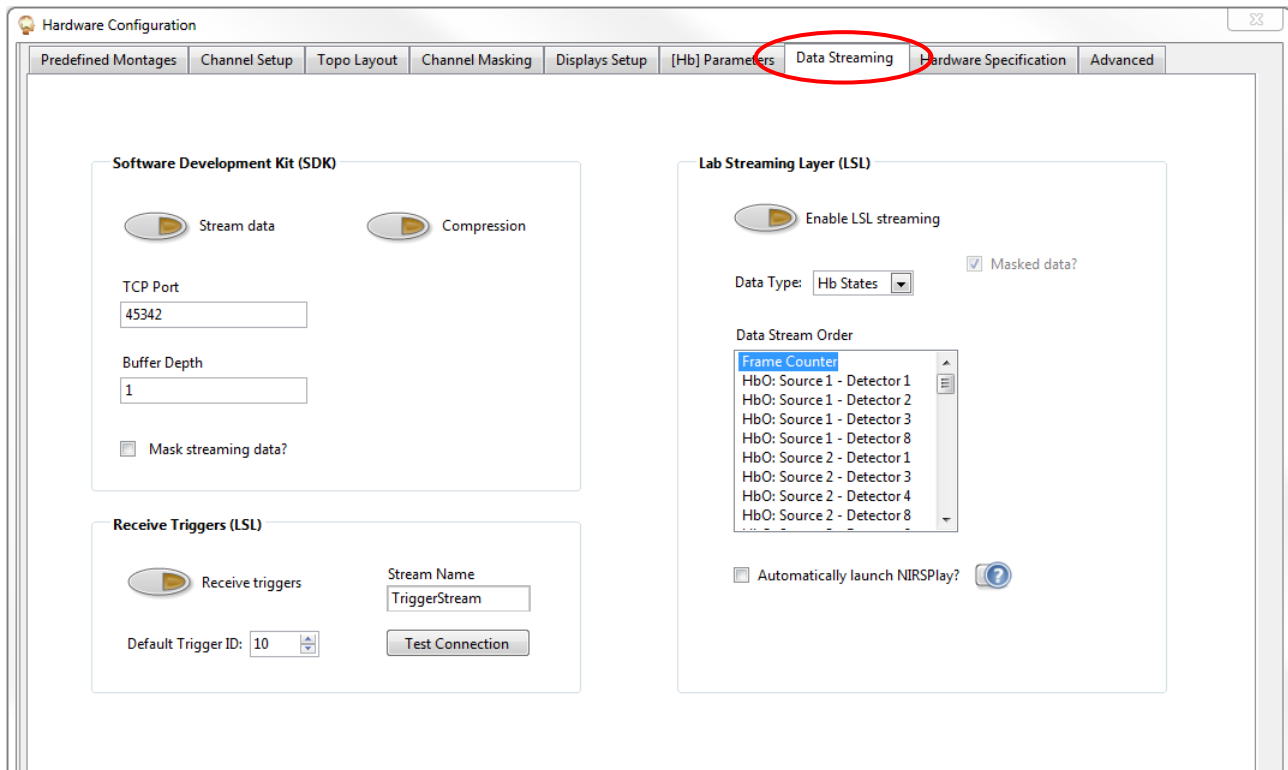
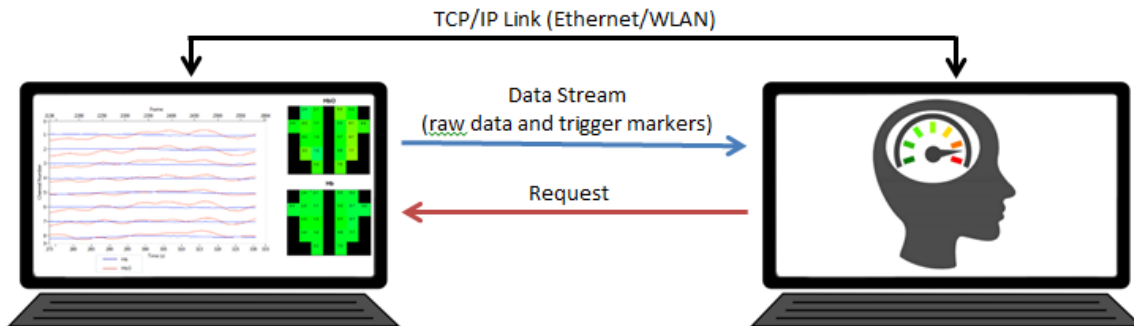


Figure 25: Options available for data streaming: (i) Software Development Kit (SDK); (ii) Lab Streaming Layer (LSL); and (iii) Receive Triggers (LSL).

### 5.7.1 Software Development Kit (SDK)

The NIRStar software includes a real-time data streaming facility, which allows the software to act as a server for transmitting the acquired NIRS data in real time to another computer via TCP/IP (see Figure 26). In addition to streaming possibilities with Lab Streaming Layer, NIRx provides an optional software development kit (SDK) that enables users to build client software for receiving the data.



**Figure 26: Conceptual schematic of real-time NIRS data streaming using NIRStar and the NIRx SDK**

Provided with the SDK are several sample codes written in MATLAB, LabVIEW, and C for demonstration and testing and to act as a development basis for user-specific applications. For more information, please refer to the SDK documentation as listed in Section 2.3.

The Data Streaming tab in NIRStar's Hardware Configuration dialog, shown in Figure 25, provides the following functions for configuring the data streaming process with SDK:

#### Stream Data

Pushing this button enables NIRStar's function as a server to publish data over the network. When the streaming function is enabled several status lights become visible in the lower left corner of the main Window (see Figure 25).



Please note that SDK is not compatible with the increased switching frequency mode. If this option is enabled, the controls relevant to SDK will become disabled.



Please also note that stream of every single frame recorded is only possible for:

No. of Steps  $\geq$  7

Fewer Steps require data averaging prior to stream: 1 Step -> average over 8 last frames collected; 2-3 Steps -> 4 frames; 4 Steps -> 3 frames; 5-6 Steps -> 2 frames.

## Compression

Data may be compressed before transmission in case of Bandwidth limitations.

## TCP Port

The protocol requires server and client to agree on a TCP/IP port number. By default this number is set to 45342 and needs to be changed only if this address is already being assigned to another process. Whichever port number is specified in NIRStar must be used by the client side to be able to receive the data.

## Buffer Depth

In case the available bandwidth for the TCP/IP connection is severely limited, the data may be buffered to improve the streaming performance and to avoid buffer overflow. Buffer Depth specifies the number of scans that are buffered before being transmitted.

The minimum number and default for this parameter is '1' (for measurements with no. of Steps  $\geq$  8). In this case, each scan is transmitted immediately after acquisition.



Please note that buffering the data stream is *required* for no. of steps  $<$  8, due to an internal buffer for data acquisition in NIRStar. The expected value for Buffer Depth in these cases (i.e. Illumination Pattern (section 5.3) resulting on fewer steps than 8) will be automatically set by the software. The user does *not* need to do it manually.

## Mask Streaming Data

By default, NIRStar transmits the data of all channels, *i.e.*, all source-detector combinations. If only a subset of channels is required by the client software, the *Mask Streaming Data* option may be checked, in which case only those channels are transmitted that are highlighted in the *Channel Masking* interface (see Figure 22). This option may be used to improve the streaming performance, or to relieve the receiving software of some computational burden.

## Data Streaming Status

If data streaming is selected, several status indicators are displayed in the lower left corner of the NIRStar main screen (see Figure 25).

- Connected:** Lights up upon successful TCP/IP link of client software to the NIRStar server
- Acquiring:** Lights up once NIRStar starts scanning, *i.e.*, during a *Preview* or a *Recording*
- Transmitting:** Lit as long as data are transmitted from the server to the client (prerequisites are lit *Connected* and *Acquiring* indicators)
- Compressed:** Indicates that data compression is used

**Overflow:** Warns of a data overflow in case the client is not able to receive the data transmitted by the server (*i.e.*, broken data flow).

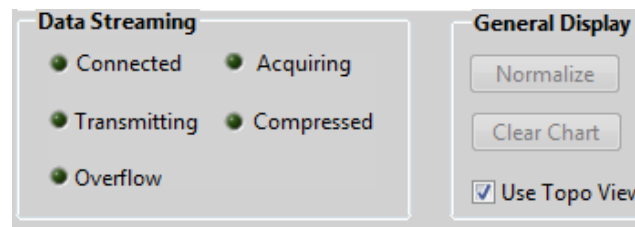


Figure 27. Data Streaming status display

### 5.7.2 Lab Streaming Layer (LSL)

Lab Streaming Layer is protocol that consists of a collection of libraries and tools that allow for real-time data and triggering streaming as well as multi-modal time-synchronization. The communication can be controlled using different programming languages (C, C++, Python, Java, C#, Matlab) and under different platforms (Mac, Windows, Unix). It is available in GitHub (<https://github.com/sccn/labstreaminglayer>), where one can find libraries to communicate with several modalities from different manufacturers, e.g. EEG, Eye-Tracking and Virtual Reality.

In face of the great range of possibilities that LSL offers for multi-modal integration and synchronization, we have incorporated its protocol into NIRStar as a further data streaming capability (Figure 25). Some examples on how to receive data are provided by LSL developers in the GitHub under the following link: <https://github.com/sccn/labstreaminglayer/blob/master/LSL/liblsl-Matlab/examples/ReceiveData.m>

#### Enable LSL Streaming

The streaming based on LSL protocol can be activated in NIRStar by clicking on “Enable LSL streaming”. Once enabled, recorded data and trigger information will be automatically streamed to LSL. Also, during NIRStar initialization, current hardware settings and montage coordinates are provided to LSL as well.

#### Data Type

Using this drop-down menu, the user can select whether to stream the raw data or the concentration changes (“Hb States”), as calculated in real-time by NIRStar. There is also an option to stream both raw data and hemodynamic changes (“Both”). Please note, however, it is currently only possible to stream the masked data, *i.e.* the channels enabled in the Channel Masking tab (section 5.5).

#### Data Stream Order

As illustrated in Figure 25, additional information on the data stream order corresponding to the data type chosen and the channel masking settings are displayed to the user. The first information streamed to LSL will always be a frame counter to facilitate data synchronization. This is followed by the current

measured data point of all masked channels for the first wavelength (e.g. 760nm) and then for the second (e.g. 850nm). Or, respectively, for HbO and Hb data, in case “Hb States” has been selected.

### Stream saturated frames as NaN’s

This checkbox is only visible for NIRSport systems. Eventual data points with detector saturation (section 16.1.3) are by default replaced with NaN values. It is however possible to also stream the original, non-flagged values, by unselecting this checkbox. Please note that doing it is not recommendable, as one will not be able to identify which portion of the data is not reliable (i.e. non-physiological saturated data).

### Automatically launch NIRSPplay

NIRStar15-1 provides an additional visualization tool (NIRSPplay, see section 19) that obtains the Hb States data sent over the LSL protocol. Thus, this checkbox enables the automatic launch of NIRSPplay during the next NIRStar initialization. Please note however that LSL streaming must be enabled and the Data Type needs to be set to Hb States, as shown in Figure 28.

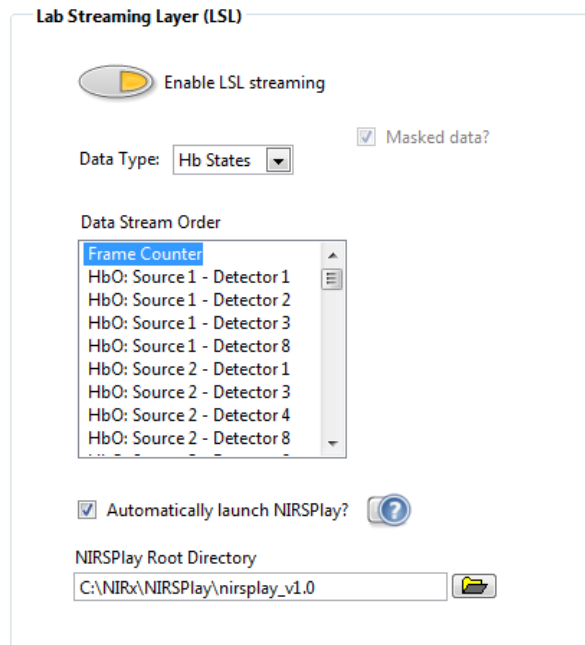


Figure 28. Example of LSL set up allowing for automatic launch of NIRSPplay.

### NIRSPplay Root Directory

By enabling the automatic launch of NIRSPplay, this field becomes visible to allow the user to set the local path to the NIRSPplay root directory. The default path points to the version 1.0 of NIRSPplay, but the user is able to change it e.g. in case further versions are released before the next NIRStar release is available.

### 5.7.3 Receive Triggers (LSL)

#### NEW FEATURE

In addition to send data and triggers information over the LSL, NIRStar can also receive trigger markers and time stamps using the same protocol, as shown in Figure 29.

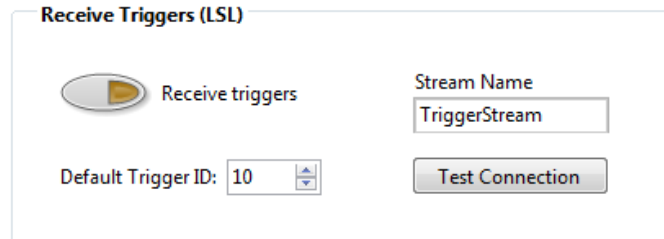


Figure 29. Setup controls to receive triggers from LSL.

#### Receive triggers

Please click on “Receive triggers” to enable this capability and then follow the settings explained below for its fine adjustment.

#### Default Trigger ID

The trigger information is expected to be received by NIRStar as an integer corresponding to one of the markers available in the system (e.g. for NIRSport between 1 and 15, and NIRScoutX+ up to 255). In case NIRStar receives an unexpected trigger format (e.g. string), its corresponding time stamp will be stored with the trigger marker defined in this field. By default, as shown in Figure 29, this value is set to 10.

#### Stream Name

The communication with LSL is based on streams with respective names. Therefore, the user is expected to set up the name of the stream that will provide NIRStar with the expected trigger information.

#### Test Connection

To make sure that the stream name is correct and the stream outlet is already available, one may test the connection with it by clicking on this button. We recommend to test the stream connection before exiting the hardware configuration, otherwise an error may occur when starting the measurement (e.g. “LSL stream cannot be found”).

By clicking on this option, NIRStar will check to see whether the defined stream is available and inform the user about the result. In case of success, you may confirm the hardware settings and proceed with the measure. Otherwise, please double check the stream name and whether the outlet was created.



## 5.8 Advanced Setup

The *Advanced Setup* tab allows the user to change basic instrument parameters affecting timing, LED modulation, etc. These should be changed only by developers and professional staff, and are password-protected to prevent users from inadvertently changing parameters.

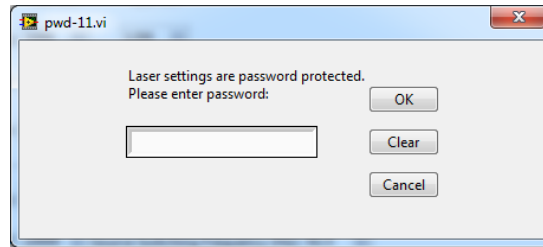


Figure 30. Password prompt for accessing the Advanced Options tab



Inappropriate *Advanced Setup* settings may severely interfere with data quality or may cause damage to the instrument!

## 5.9 Additional Functionality

After appropriate settings are entered in all tabs of the *Configure Hardware* window, the user has to click the *OK* button (lower right corner) to apply the system settings. Doing this automatically stores all settings, and they are automatically loaded the next time the software is started or the *Configure Hardware* menu item is opened.

Pressing the *Cancel* button purges all settings that have been either entered in the *Configure Hardware* window during the current session or automatically loaded when the menu item was opened.

In addition, the user may load specific configurations that were generated during previous sessions (*Load* button, lower right). If the user subsequently modifies a loaded configuration, the modifications may be saved by pressing the *Save* button (lower right). Then NIRStar will ask the user to specify an appropriate filename (e.g., "BilateralMotorLayoutS16xD16").

The *Load* and *Save* functions are convenient when the instrument is used for different experimental setups, as they allow multiple users to save and recall their specific experimental setups with minimal effort.

## 6 Additional Menu Bar Items

### 6.1 Digital I/O



This option is available only in conjunction with the NIRScoutX instrument series.

In addition to the capability of receiving digital input signals for the purpose of experiment timing that all NIRS instrument possess, NIRScout Extended systems also have the capability to send out hardware timing signals. This capability expands experimental design because in addition to receiving timing signals, in conjunction with NIRScoutX device the NIRStar software can also serve as the main control instance of the experimental setup.

Possible application examples include the orchestration of other devices included in the experimental paradigm, such as stimulus-generating equipment, *e.g.*, magnetic stimulation, electrical stimulation, *etc.* One particular example is the use of a pulsed laser source for combined optogenetics/NIRS studies. In this case, the TTL trigger input of a diode laser module (optional equipment NIRx DL-473, 473 nm 0...100mW optical power, fiber-coupled output) is connected to one of the NIRScoutX digital output lines. Whenever this port is in a 'high' state, the laser source will be activated, and optogenetic processes

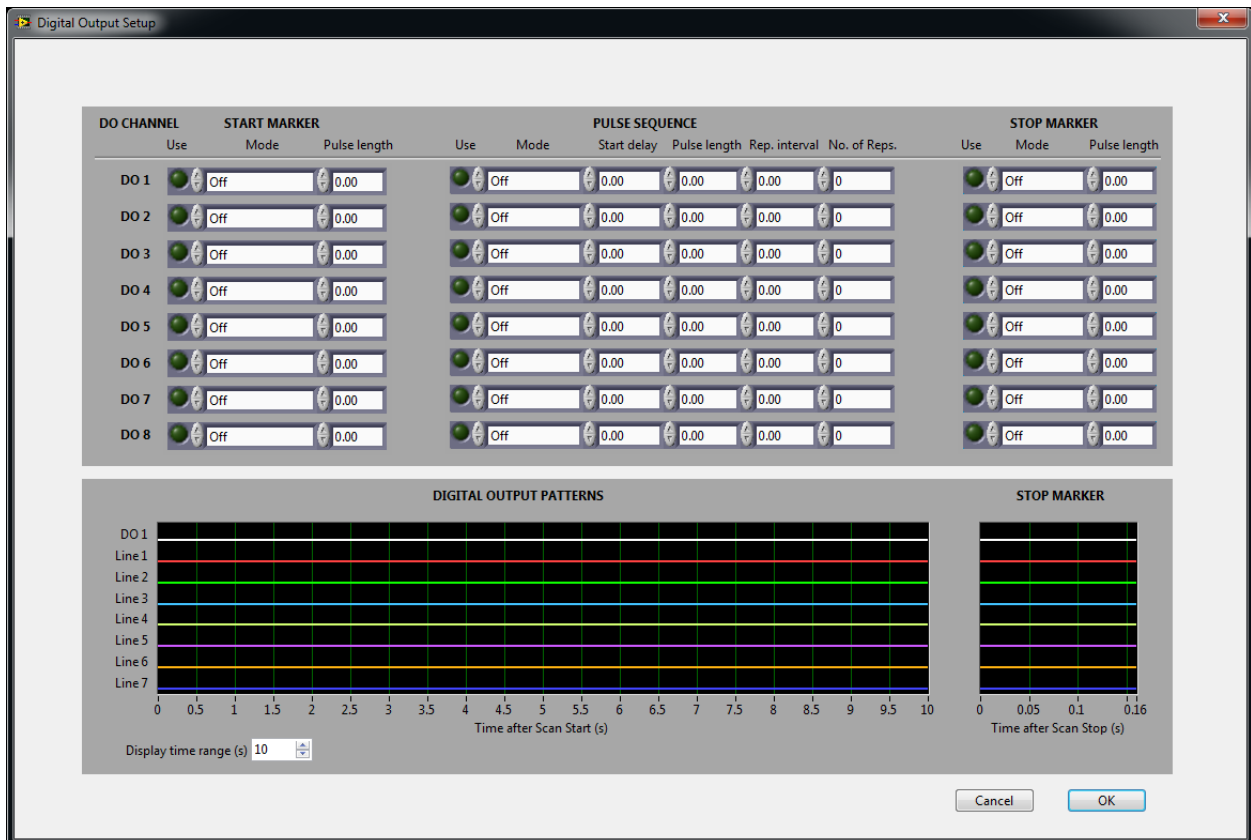


Figure 31. Digital I/O interface

may be initiated in the target tissue. This particular example demonstrates the measurement of NIRS activation following optogenetic stimulation. Other forms of tissue stimulation (magnetic, electric, thermal, etc.) may be considered.

The NIRStar digital I/O interface (Figure 31) provides programmable control of the timing and output states of the NIRScoutX system’s digital output port (for details of the hardware, connections, and signal specifications please refer to the NIRScoutX user manual).

Eight digital outputs (*i.e.*, DO 1...8) can be programmed to generate digital signal levels during the NIRS scan. The generated signals are meant to aid in coordinating the actions of other devices that are associated with the measurement: for example, if the experimental protocol entails displaying a visual stimulus to a study participant at pre-defined times and for pre-determined durations, then digital output signals can be used to turn the stimulus presentation system on and off.

The display shows a preview of the digital output patterns. All times are in seconds. For any channel, either a Start Marker or a pulse sequence (but not both) may be set.

The interface of the digital output pulse generation provides a precision of 10 ms, which is also the minimum duration that may be defined for a pulse, or an inter-pulse interval.

For the technical hardware specifications of the digital output port, please refer to the NIRScoutX hardware manual.

### 1) Start Marker

This digital I/O mode creates markers at the beginning of a scan. Available parameters are:

Use: Activate this channel to generate a Start Marker.

Mode: Select one of the following modes:

- Off: Inactive
- Pulse hi: create single high pulse
- Pulse lo: Create single low pulse
- Set hi: Output goes hi at start
- Set lo: Output goes low at start.
- Pulse length: Set the duration of Pulse Hi or Pulse Lo (otherwise ignored)

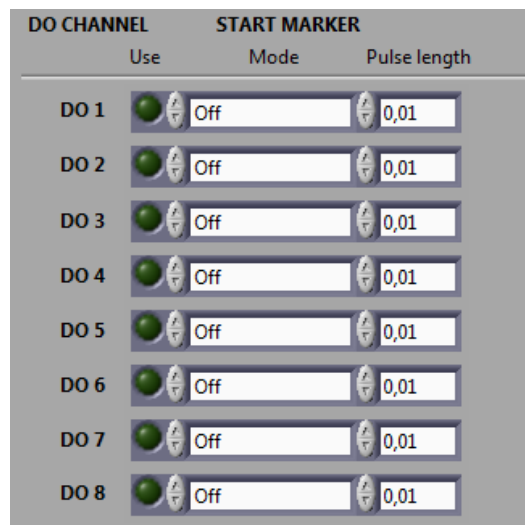


Figure 32. Start Marker section of the Digital I/O interface

## 2) Pulse Sequence

This digital I/O mode allows the user to generate finite pulse sequences. Available parameters are:

Use: Activate this channel to generate a pulse sequence. If activated, any Start Marker in this channel will be deactivated.

Mode: Select one of the following modes:

- Off: Inactive
- Pulse hi: Create train of high pulses
- Pulse lo: Create train of low pulses
- Set hi: Output goes hi after specified delay
- Set lo: Output goes low after specified delay

Start delay: defines the beginning of a pulse train or level change after scan start

Pulse length: Duration of [high|low] period for 'Pulse [hi|lo]'

Rep. Interval: Pulse-to-pulse time. Must be at least as long as the 'Pulse length'

No. of Reps.: Number of pulse steps (repetitions), after which the pulse train will stop.

## 3) Stop Marker

This digital I/O mode is used to create markers at the end of a scan. Available parameters are:

Use: Activate this channel to generate a Stop Marker.

Mode: Select one of the following modes:

- Off: Inactive
- Pulse hi: create single high pulse
- Pulse lo: Create single low pulse
- Set hi: Output goes hi at start
- Set lo: Output goes low at start.

Pulse length: Set the length of Pulse Hi or Pulse Lo (otherwise ignored)

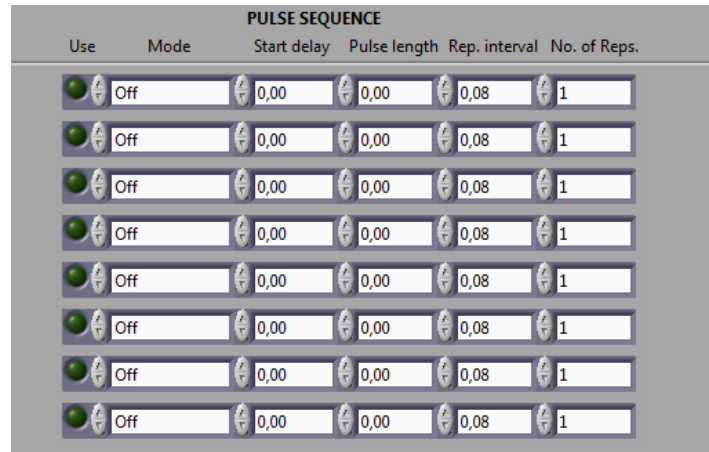
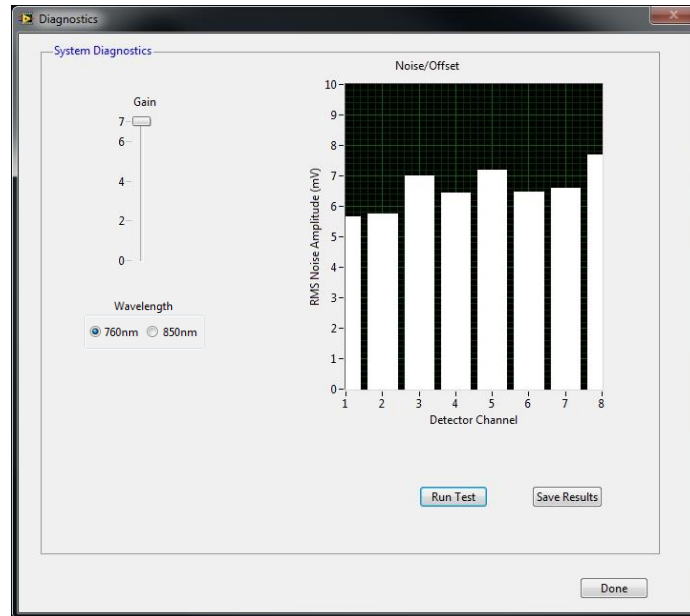


Figure 33. Pulse sequence section of the Digital I/O interface

## 6.2 Diagnostics

The diagnostics window is shown in Figure 34 below.



**Figure 34. Diagnostics window with dark noise test.**

This feature allows users to test the dark noise performance of each detector, at each gain setting, for both wavelengths.

The 'dark noise' characterizes a detector channel's sensitivity by evaluating the amplitude and variance of the detector reading if no input signal (*i.e.*, incident light) is present. The residual signal variation is caused by the fundamental noise of the light sensor and the electronics and is a measure of the optical sensitivity of the device. Increased noise values can be indicative of faulty hardware (sensor or subsequent electronics). The acceptable noise levels depend on the type of system used; for NIRScout systems, the noise should stay well below 0.1 mV for Gains 0-5, and below 1.0 mV for Gain 6. For Gain 7, less than 10 mV of noise is to be expected. Please see Section 16.1.4 for NIRSport considerations.



When performing a dark-noise test, it is **CRITICAL** that stray light be prevented from entering the optical detector fibers or the fiber ports on the detector cards. Fiber tips and open connectors must be optically well shielded from ambient light, by covering them with opaque materials (*e.g.*, heavy black cloth, black plastic foil, *etc.*).

Before running the dark noise test by clicking the *OK* button, ensure that the detector inputs are well shielded from ambient light. The bar graph displays the noise or offset level for each detector, in units of mV on the y-axis. The user can manually adjust the gain with the slider, in order to observe the gain-factor dependence of the noise (here, a noise level is defined as the root-mean-square (RMS) value of a sequence of detector readings).

After a dark noise test is performed, the results can be stored to disk by clicking on the *Save Results* button. A path and filename have to be specified in the dialog box that opens when the button is pressed. While the user can specify any Windows- and MATLAB-compatible filename, the software will automatically give the extensions .dn1 and .dn2 to the files containing data for the first and second wavelengths, respectively. The user specifies a name for the .dn1 file, and that same name is automatically given to the .dn2 file as well.

The .dn1 and .dn2 files can be read with a standard text editor. Each row contains noise data for a different gain value (Gain 0 in the first row, Gain 1 in the second, *etc.*), and each column contains noise data for a different detector (Detector 1 in the first column, Detector 2 in the second, *etc.*).

### 6.3 File Options

In the *File Options* pop-up window, the user can specify a data filename and storage location (see Figure 35). Detailed information about the formats of the files generated by a NIRS recording is provided in Section 13.

The NIRStar software can organize file directories and names automatically, according to the date and time of acquisition and the *Data Root Directory* specified in the *Options* dialog. This is done as follows:

#### Data Root directory

All data files are organized within `root_directory\...` where the location of `root_directory` can be specified by the user. By default, data are located under `C:\NIRx\Data\`.

#### Date directory

All data recorded on a specific day are collected in a subdirectory of `root_directory\...`, which is named according to the format `root_directory\yyyy-mm-dd`.

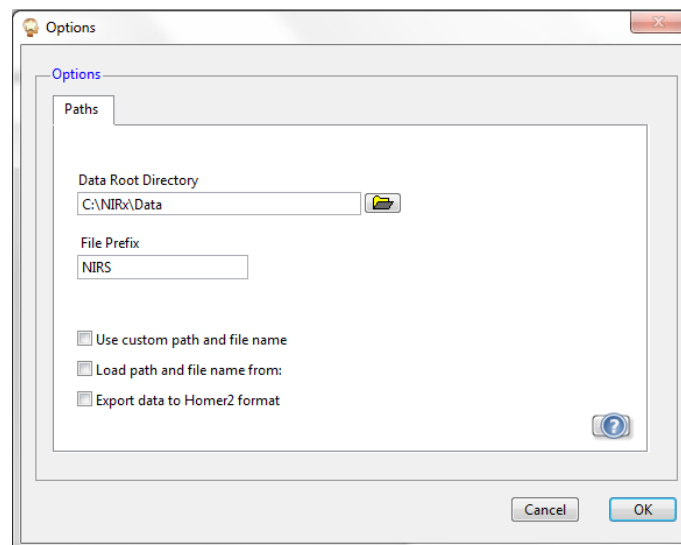


Figure 35. Options dialog

## Experiment directory

For each recorded experiment, a subdirectory is generated, within the appropriate date directory, whose name contains a date identifier and the running number for that day: `yyyy-mm-dd_xxx\`.

## File name

For each experiment, different files are generated (see section 13), all of which have identical filenames consisting of a prefix, a date identifier, and the running number of experiments recorded on that day. The files are distinguished by their file extensions and, in one case, a file suffix. The format for the file names is: `prefix-yyyy-mm-dd_xxx`. The prefix is 'NIRS' by default, but the user can specify a different prefix in the Options menu (see Figure 35).

## Custom File Naming

The option of using customized data file paths and names may be selected by clicking in the *Use custom path and file name* checkbox. The software will prompt the user to specify a path and a filename prefix every time the *Record* button is pressed.



The file dialog appears after starting the scan; therefore please note that you should allow some extra time in the experimental design to account for the time it takes the operator to specify a custom file path.

If no path or an invalid path is specified, the software will save the data to the standard location in the Data Root Directory.

## Load path and file name from:

A new option has been incorporated to allow the user to programmatically specify customized path and file name by using a text file with this information. When the checkbox is enabled, a field to specify the location and name of this text file becomes visible.

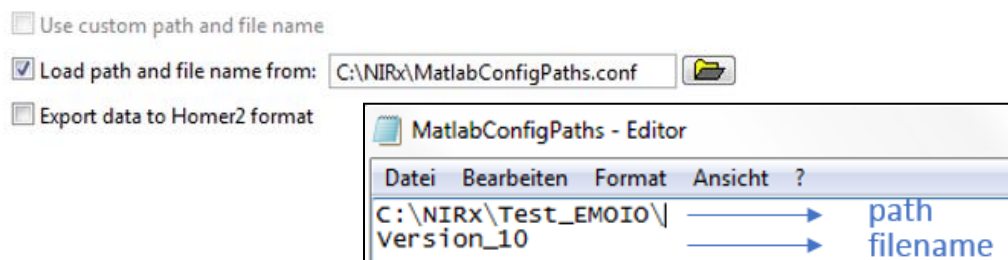


Figure 36. Load path and file name from text file example.

Figure 36 illustrates an example, in which the text file “MatlabConfigPaths.conf” defines the path (C:\NIRx\Test\_EMOIO\) and the file name (Version\_10) for the NIRS data to be stored. Please note that, the first line of the text file is expected to provide the path, and the second line is used for the filename.

### Export data to Homer2 format

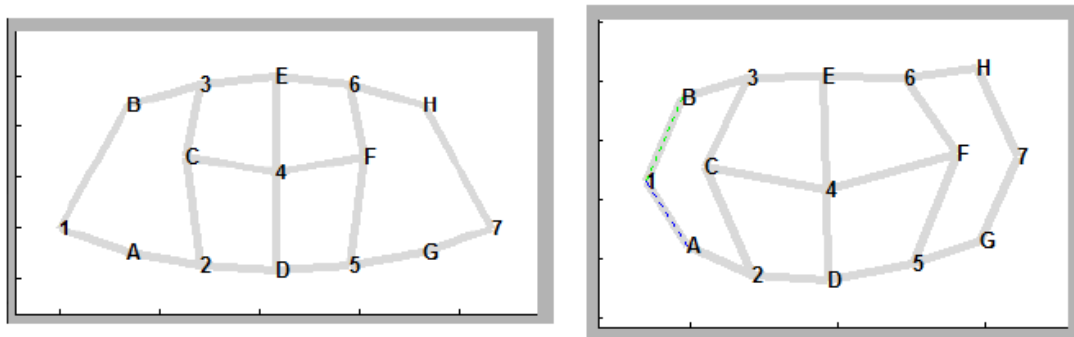
It is possible to export datasets into the format accepted by Homer2, which is a package available online free of charge that may be used to process and analyze fNIRS data. To enable this feature, please check the option “Export to Homer2 format” in the *File Options* window (Figure 35).

It is necessary to access the information from the Probe Setup (\*\_probeInfo.mat) file corresponding to the measurement. The probeInfo file can be automatically obtained from the Probe Setup interface, either under the Predefined Montages tab or the Displays Setup tab.

If the user has set up the probes and prepared the display for Topographic Rendering (see sections 18 and 19) before starting the measurement, the \*.nirs file (format expected by Homer2) will be automatically generated and saved along with the other files in the dataset folder.

Otherwise, the user will be prompted at the end of the experiment to choose the corresponding \*\_probeInfo.mat to the dataset just recorded. If the user selects a file that does not correspond to the saved dataset, the user will be once again prompted to select a new file.

NIRStar exports the 3D coordinates from the Probe Setup file to be used for Homer2. Up until 14-1, the 2D coordinates were used instead in order to provide with an optimal channels visualization. However, the 3D coordinates are necessary for a more accurate estimation of the inter-optode distances to be applied for the modified Beer-Lambert Law (mBLL) calculation in Homer2. Therefore, the channels display in Homer2 user interface will now be slightly distorted, as depicted in Figure 37 for Prefrontal8x8.



**Figure 37. Example of probes and channels display in Homer2 as previously based on 2D coordinates (left) and now slightly distorted as based in the 3D coordinates for accurate mBLL calculation (right).**

Starting on 15-1, NIRStar exports a digpts.txt file along with the \*.nirs file for each measurement. This is intended to allow for proper usage of AtlasViewer by providing the original coordinates for the montage along with some reference points. Therefore, after loading the processed data in AtlasViewer, the user can use the option “Register Atlas to Dig Points” to enable further capabilities, e.g. Hb data overlay.



## 6.4 About

Information about the software and copyright notices revision can be obtained through the *About* menu item, as shown in Figure 38.

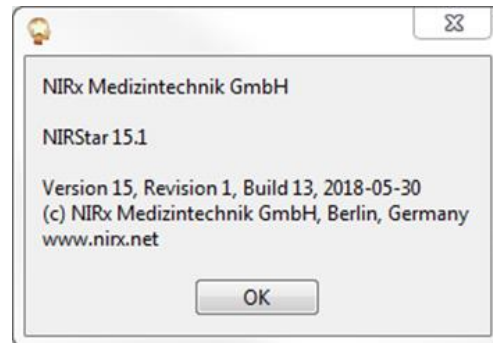


Figure 38. About dialog

## 7 Operating Panel

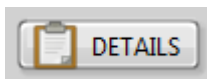
In this section, the functions of the main buttons are described. The order of the buttons on the mid-block (Sections 7.3 - 7.6) matches the usual sequence of operations during a data recording session.

### 7.1 Review



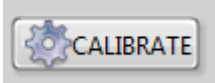
NIRStar provides the user with the capability of reviewing previously recorded datasets, which can be done by clicking on “Review”. Please note that this button will be only enabled if the NIRStar operating mode has been switched to offline. Detailed information on online/offline modes and also on the data reviewing feature may be found on Section 15.

### 7.2 Details



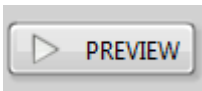
This option allows the user to visualize the details about the parameters obtained to calculate the signal quality of each masked channel (Gain, Level and Noise). These may be displayed either using a ‘traffic light’ metric (green, yellow, red) or the old-style scale from earlier versions. Please refer to Section 15.2 for more information about this feature.

### 7.3 Calibrate



A calibration procedure must be performed prior to each measurement. In this step the instrument determines the optimum gain (or signal amplification) for each source-detector combination. Gain levels are numbered from 0 to 7 (NIRScout Systems) or from 0 to 2 (NIRSport), with each step representing a 10-fold amplification factor. During calibration, the *Signal Quality* (see Section 8.1) will be updated to reflect the current gain settings and corresponding Level and Noise values. During the calibration, we perform 4 scans for each amplification step and calculate the signal mean to evaluate the current gain. The gain is deemed optimal if a channel's modulated raw signal falls between 0.4 V and 4.0 V.

### 7.4 Preview

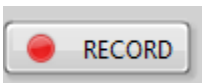


The *Preview* button initiates a preview scan without writing data to disk, for test measurements, inspection of the data quality, and display optimization. The test scan may be stopped by clicking the *Preview* button a second time, or by clicking the *Stop* button. "NOT RECORDING" alert will be displayed on the screen during a preview scan.



Data measured during the preview is not automatically saved to disk! But note that if the Record button is clicked during an ongoing preview, then the preview data will be saved.

### 7.5 Record



The *Record* button initiates a scan for which the data, gain settings, trigger events and various system settings get recorded. If first a test scan is initiated with the *Preview* button, and at some point afterwards during the scan the *Record* button is clicked, all data (*i.e.*, both preceding and following the instant that the *Record* button was pressed) will be saved.

### 7.6 Stop



Once recording has started, the only way to stop the scan is by using the *Stop* button. The *Stop* button terminates the ongoing scan.

### 7.7 Exit

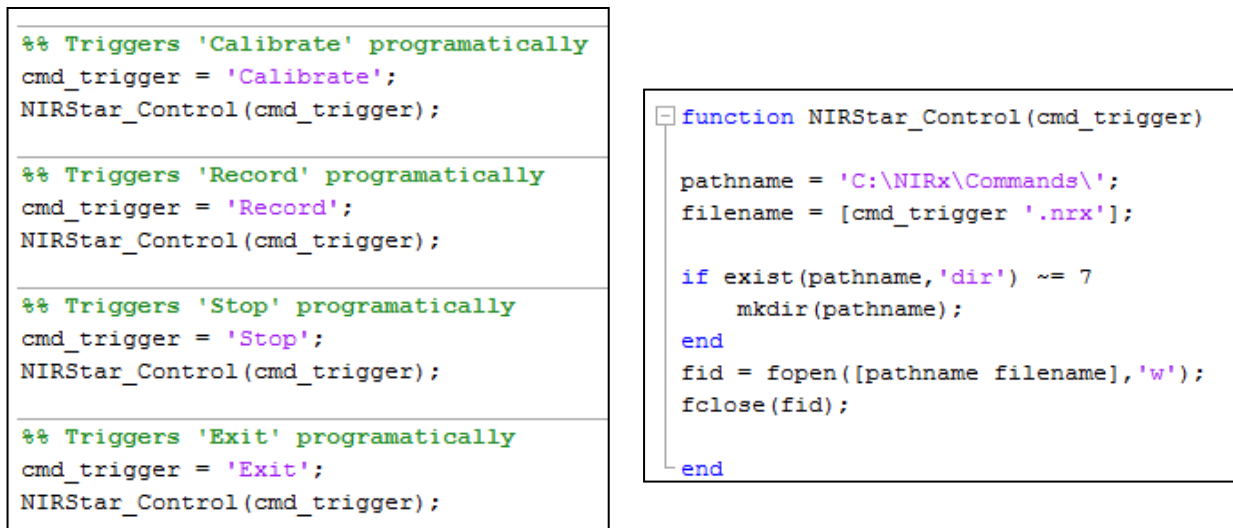


Clicking the *Exit* button is the ONLY way to implement a proper shutdown of the software, including correct handling of all used variables and data.

## 7.8 Remote Control

The most fundamental functions of the operating panel for instrument control (Calibrate, Record, Stop and Exit) can now be activated remotely and programmatically. This can be achieved by creating empty files with name corresponding to the desired operation (e.g. Calibrate) and extension “.nrx” and located in the path “C:\NIRx\Commands\”.

Figure 39 shows an example of code and function prototype implementation in Matlab. The function



```

%% Triggers 'Calibrate' programatically
cmd_trigger = 'Calibrate';
NIRStar_Control(cmd_trigger);

%% Triggers 'Record' programatically
cmd_trigger = 'Record';
NIRStar_Control(cmd_trigger);

%% Triggers 'Stop' programatically
cmd_trigger = 'Stop';
NIRStar_Control(cmd_trigger);

%% Triggers 'Exit' programatically
cmd_trigger = 'Exit';
NIRStar_Control(cmd_trigger);

function NIRStar_Control(cmd_trigger)

    pathname = 'C:\NIRx\Commands\';
    filename = [cmd_trigger '.nrx'];

    if exist(pathname,'dir') ~= 7
        mkdir(pathname);
    end
    fid = fopen([pathname filename], 'w');
    fclose(fid);

end

```

Figure 39. Example of Matlab code and function prototype that allows for NIRStar remote control.

*NIRStar\_Control* creates the file that will trigger the desired operation in NIRStar. On the left, four blocks illustrate how one can call this function by providing as input the name of the operation (i.e. ‘Calibrate’, ‘Record’, ‘Stop’ or ‘Exit’). After the operation is completed in NIRStar, the corresponding file is deleted.

## 8 System Setup

The *System Setup* tab is displayed when NIRStar is started. In a typical experiment and data recording setup, the user would first place the sources and detectors on the subject’s head, then calibrate the instrument, and then perform the data recording.

### 8.1 Signal Quality

Before recording data, a calibration has to be performed to automatically determine an appropriate amplification factor for each source-detector combination and to judge the signal quality. NIRStar provides a *Signal Quality* which labels the expected data quality for each channel according to a simplified ‘traffic-light’-style color-coded classification:

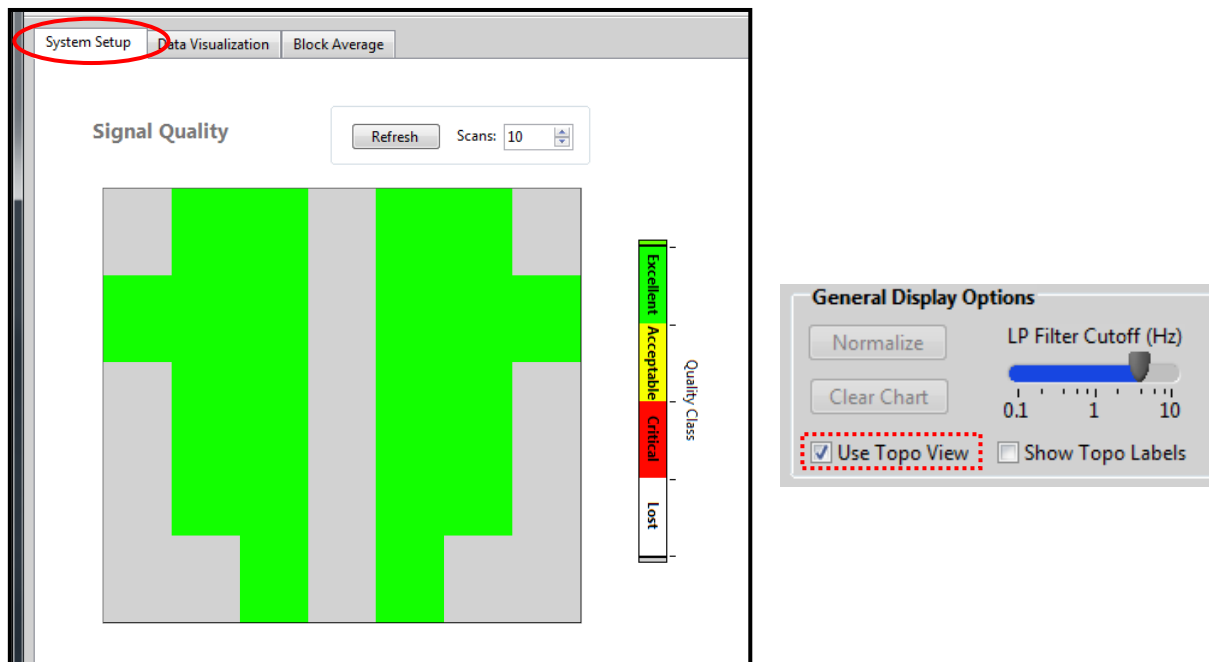


Figure 40. System Setup after calibration in topographic view (i.e. 'Use Topo View' is enabled).

**Excellent** – This level of signal quality usually permits a clear visibility of the cardiac fluctuations in the HbO signals (e.g., in the unfiltered *Preview* display) and is appropriate for the highest demands (e.g., single-trial/single-subject evaluation).

**Acceptable** – Basic physiological features such as the cardiac signal may not be discernible in the unprocessed display but the noise level generally still affords the extraction of neuro-activity through the use of appropriate statistical evaluation (e.g., filtering, event-related averaging, SPM, group averaging).

**Critical** – Signal quality is low and neuro-activation signatures may be obscured by signal noise. Most likely, insufficient coupling of light into/out of the tissue is the reason; please check and try to improve the preparation of the optode-tissue contact.

**Lost** – The signal is severely compromised to the point that no extraction of meaningful physiological information can be expected from this channel. Possible reasons include: Mis-placement of the optical probe, improper probe-tissue contact, loose or improper hardware connections.



If signal quality remains insufficient (especially, 'Lost' = white) despite efforts to improve skin-optode contact, and no obvious erroneous connection or placement of probe hardware, please check whether the hardware is working properly by running calibration and dark-noise tests with the static phantom supplied with NIRx imagers.

This classification is a combined metric that takes into account all features of the traditional setup display (Gain, Level, Noise, definitions on Section 8.2) at all wavelengths according to the table below.

Table 2. Look-up table for the calculation of the signal quality scale considering each of the indicators separately.

Signal Quality	NScout Gain [10 <sup>x</sup> ]	NSport Gain [10 <sup>x</sup> ]	Level [V]	Noise [%]
Excellent	1 - 6	0 - 2	0.09 - 1.40	< 2.5
Acceptable	7	3	0.03 - 0.09 1.40 - 2.50	2.5 - 7.5
Critical	0	-	0.01 - 0.03 > 2.50	> 7.5
Lost	-	-	< 0.01	-

The signal parameters shown in **Table 2** are evaluated from left to right, i.e., the quality scale algorithm first checks whether an excellent gain was reached for a channel, then evaluates the signal strength in both wavelengths, and lastly estimates the noise level encountered.

The final classification of the signal quality for a given channel relies on the worst indicator obtained.

Figure 39 shows an example of *Signal Quality* map in which all the channels were judged as *Excellent*, i.e. the *masked* channels have received amplification Gains within the range [1 - 6] (NIRScout), the resulting Levels obtained for them lie within [0.09 – 1.40]V and the corresponding Noise values are under 2.5%.

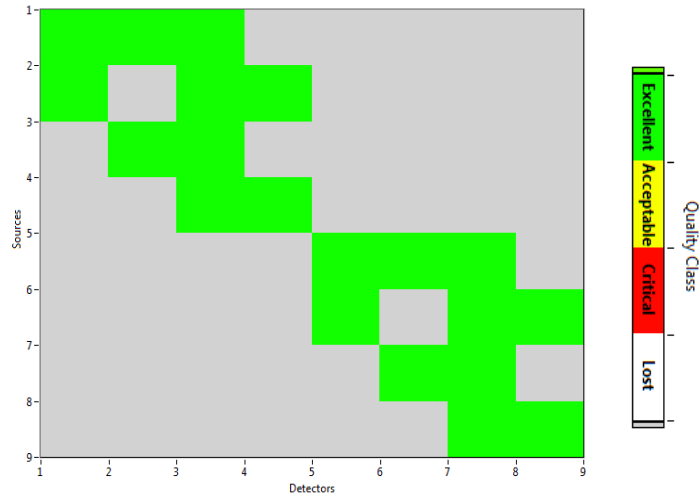
The values obtained for each parameter listed in the table above can be individually checked using the main function *Details* (Section 8.2).

### Refresh

The *Refresh* function serves to update the quality measures without having to perform a full calibration procedure. When the user clicks on the *Refresh* button, another brief measurement will be performed, consisting of the number of scans specified in the *Scans:* field. The data recorded during these scans are used to update the *Signal Quality* map according to the new Level and Noise indicators (but NOT the gain settings). Depending on the chosen number of scans, a refresh usually is much faster than the initial calibration. In this way the user can efficiently monitor incremental improvements in probe placements.

### Use Topo View

The channel indicators are shown in the 2D topographic representation defined by the *Topo Layout* (see Section 5.4) if the option *Use Topo View* (found in the *General Display Options* at the bottom of the NIRStar main screen) is selected. Otherwise, all source-detector combinations are displayed (Figure 41).

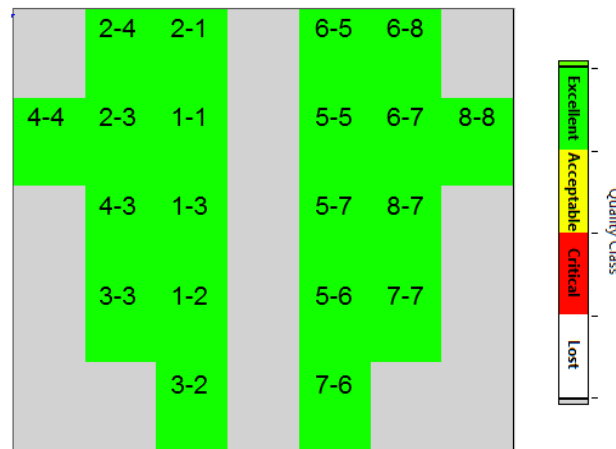


**Figure 41. Signal Quality map in full channel view (sources x detectors)**

The topographic display mode has the advantage of helping the user to quickly locate measurement channel of interest on the scalp. An example of signal quality result displayed in *Topo View* is shown in Figure 39. Empty cells in the *Topo Layout* matrix are grayed out. In the all-channels (*i.e.*, non-topographic) view, channels that are not included in the mask (see Section 5.5) are likewise grayed out.

**Show Topo Labels**

If the *Show Topo Labels* option is selected, in *General Display Options* at the bottom of the software GUI, a source-detector identifier will be overlaid onto all topographic displays, as illustrated in Figure 42. Please note that this option is only enabled when “Use Topo View” is selected.



**Figure 42. Signal Quality map according to the defined Topo Layout with corresponding Topo labels shown.**

In case short-distance channels are enabled and defined in the topo layout, the related detectors will be indicated with the labels ‘SD’ instead. For example, the label ‘1-SD’ indicates a short-distance channel with source #1. This is used for all visualizations in NIRStar to facilitate identification of short-channels.

## 8.2 Gain Map, Level, Noise, Dark Noise and Cross Talk Displays

Previous versions, up until NIRStar14-0, showed the calibration results in individual maps of Gain, Level and Noise. For convenience, and to make judgment of signal quality more reliable, these have been combined into a single metric, as outlined under Section 8.1 above.

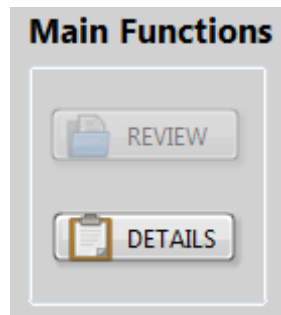


Figure 43. How to access the Quality Scale feature (*Details* button)

These original indicators are still available and may be accessed under the Quality Scale visualization tool, which can be accessed from the “Main Functions” list on the main screen window by clicking on *DETAILS* button (Figure 43).

### Gain Map

The gain-settings results are displayed, color-coded, as a *Gain Map*. Recall that each step represents a 10-fold increase in amplification. There is an inverse relationship between gain and the intensity of the received light: the weaker the light signal, the more it must be amplified. For typical source-detector separations (2.5 – 3.0 cm), gains of 4 and higher are expected. Gain stages lower than 4 occur when the level of light attenuation is relatively low. This can occur when with short source-detector separations, measures performed on the static phantom supplied with the NIRx imagers, or with measures performed on the forehead. Channels for which the maximum gain level of 7 does not provide sufficient signal strength to reach the recommended signal level are marked red. In such cases, it is advised that you check and possibly improve the optode-skin contact. The gain settings for a chosen source-detector layout generate a characteristic pattern, which should be qualitatively reproducible across different subjects.

### Signal Level

While the gain for a particular channel is the same at both wavelengths, signal levels and noise ratios can be inspected for each wavelength separately. The user can choose the respective quantity by selecting the appropriate radio buttons.

The *Signal Levels* are mapped, on a logarithmic scale, in units of voltage. For each channel, the displayed quantity is the average signal value obtained during the short scan that follows the gain setup.

## Noise

The quantity used as a measure of each channel's *Noise* is the Coefficient of Variation (CV = Standard Deviation / Mean \* 100) of the data values recorded used to evaluate the signal levels. Because the Quality Scale operates on unfiltered data, a SNR of around 1% (orange on the old-style scale) is typical for physiological setups, owing to light-signal fluctuations associated with the cardiac pulsation.

## Dark Noise

In addition to the metrics above, which are accounted for the Signal Quality calculation (section 8.1), the *Quality Scale* visualization allows the user to visualize complimentary calibration information regarding the setup's dark-noise results (see section 6.2). High dark-noise levels (labeled as 'Critical') may be due to ambient light interference and - in case of NIRSport – system connection to the power (110V or 220V). Please note that the results displayed are related to the system's highest amplification gain.

Please also note that NIRSport systems with dual-tip active detectors and NIRScout family systems with avalanche photodiode (APD) detector cards have different dark-noise thresholds than those currently set as default. The proper threshold settings can be done in the Hardware Specification (see 16.1.1 and 5.1).

## Cross Talk

An objective metric to assess the cross-talk between sources activated at the same time (i.e. in parallel) has been incorporated in NIRStar. The algorithm looks for sources that are expected to be enabled in parallel according to the illumination pattern set by the user. If there is only one source enabled for a given step of the pattern, the cross-talk metric for all channels concerning that source will be automatically set to 0, as it is impossible to have cross-talk in this scenario, given that the sources are indeed perfectly synchronized. If at least two sources are activated in the same step, then following equation calculates the cross-talk metric for a given channel  $S_i$ - $D_j$ :

$$CrossTalk(S_i, D_j) = \frac{\sum_k Level(S_k, D_j) - Level(S_i, D_j)}{\sum_k Level(S_k, D_j)}$$

In other words, the cross-talk is measured by the influence of other sources into the current signal measured for a given channel ( $S_i, D_j$ ).

## Color scheme

By default, the color scheme is displayed as '*Quality Scale*', which is graded into the 'traffic light' scheme (Excellent, Acceptable, Critical and Lost) outlined on Section 8.1 so the user can examine whether a channel reaches a specific quality threshold for that metric. By deactivating the '*Quality Scale*' selector, the old color scheme, as present on older versions of NIRStar, will be displayed as shown in Figure 44.



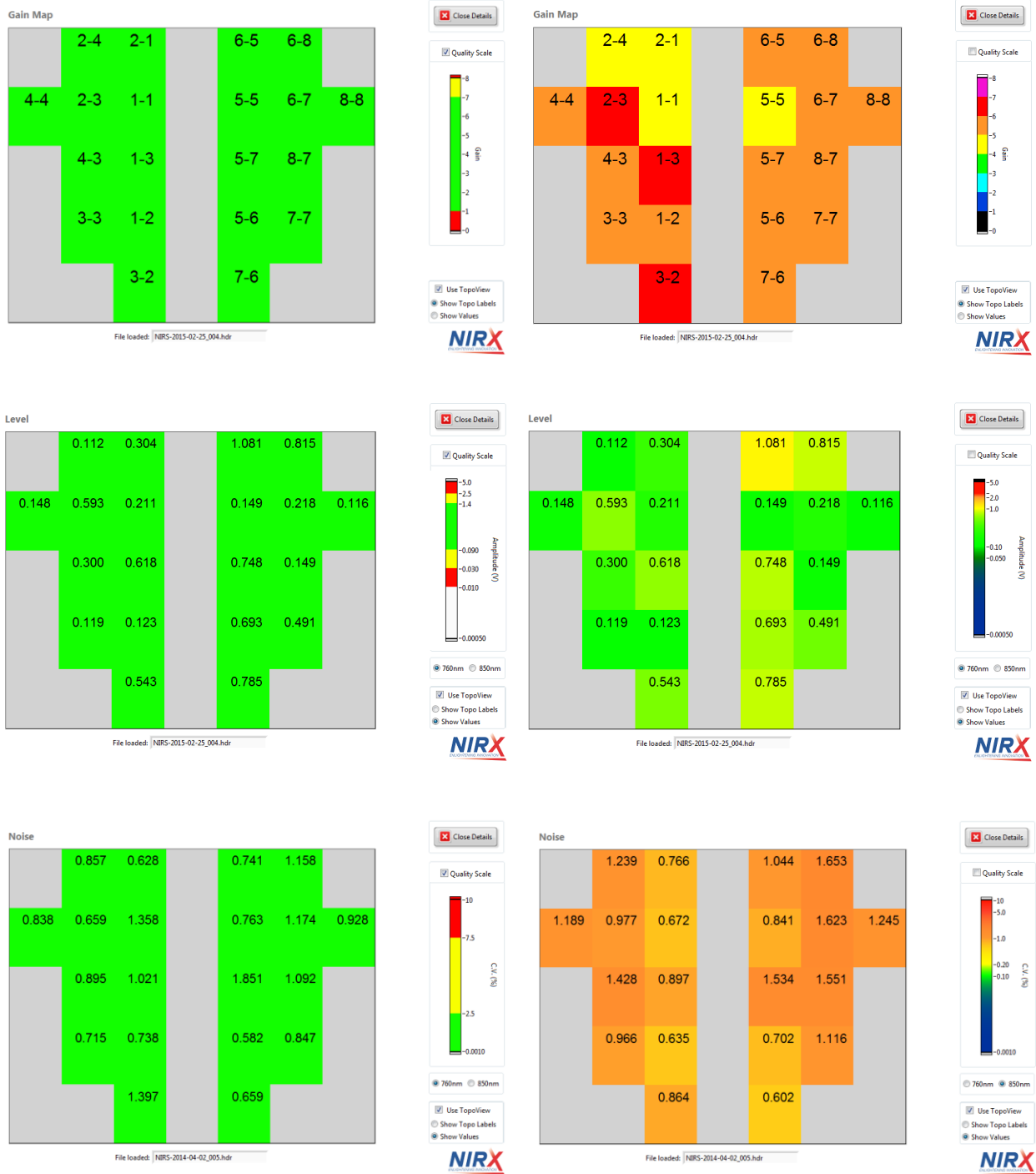
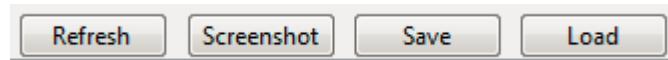


Figure 44. Gain (top), Level (mid) and Noise (bottom) maps are displayed on new (left) and old (right) style

### 8.2.1 Navigating the Quality Display

There are several buttons available on the *Quality Scale* window, as shown in Figure 45.



**Figure 45. Further buttons available on the *Quality Scale* window.**

**Refresh:** May be used to refresh the results depicted from the current calibration setup, similar to the Refresh button on the NIRStar main screen: the system will perform a brief measurement in order to update **only** the Level and Noise results. The user may also click on Refresh in order to restore the calibration results, e.g. after having loaded another dataset (see description below).

**Screenshot:** Saves the current screen as an image file to a user-specifiable location.

**Save:** Generates an ASCII (text) file (\*.stp) with a summary of the measured results (Signal Quality, Gain, Level, Noise).

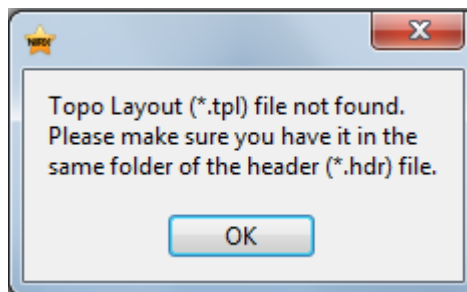
**Load:** Allows loading previously recorded datasets or saved signal quality results. A dialog allows browsing to the desired header (\*.hdr) or setup (\*.stp) file.

File loaded: NIRS-2014-04-02\_004.hdr

**Figure 46. Indicator of the file loaded that is currently being displayed on the *Quality Scale* window.**

After successfully loading the file, an indicator on the bottom of the screen will display its name (Figure 46).

Please note that for loading previously recorded raw data, the selected folder must contain the corresponding Topo Layout (\*.tpl file) used for that measurement so the channels can be displayed correctly.



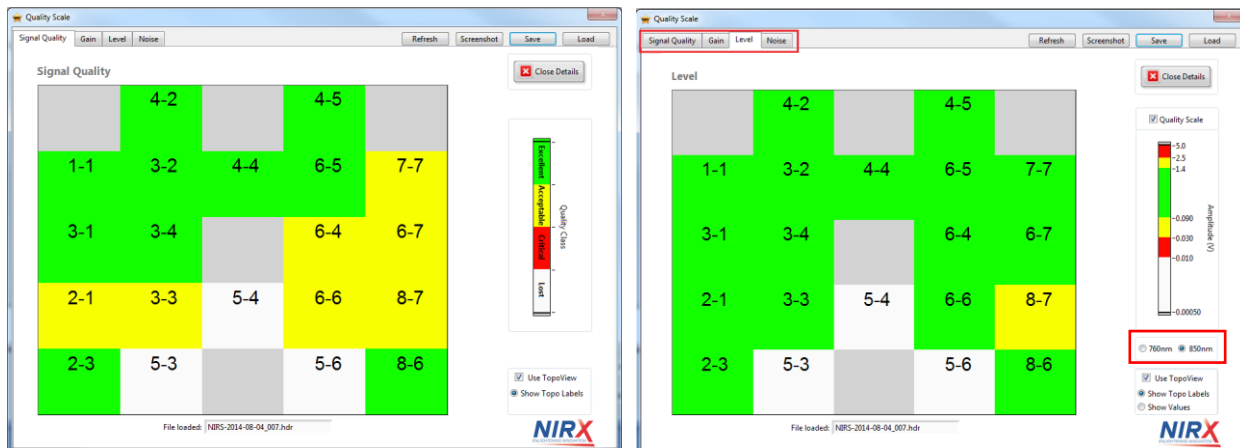
**Figure 47. Error message when Topo Layout (\*.tpl) file cannot be found in the dataset folder.**

## Quality Scale Example

Figure 48 (left) shows one example of the quality scale results where three channels are labeled 'lost'. Channels labeled red (critical) or white (lost) should be re-evaluated to see if a technical problem occurred, or whether the optode preparation should be improved.

Please note, that in this example, all *lost* channels share the same source (No. 5). This leaves several possible explanations for the problem:

- i) The source 5 is not placed in the correct position (i.e. too far from the detectors)
- ii) There may be bad optical contact, e.g. because of hair blockage
- iii) Hardware problems affect source no. 5



**Figure 48. Results of signal quality for a setup using an LED with one wavelength broken. Left: Signal Quality index; Right: evaluating the signal levels for wavelength 850nm.**

In this particular case, evaluating the source levels in detail revealed critically low signal level for one wavelength only, so case iii (a damaged emitter for the second wavelength) seemed most likely to be the cause.

Please note that NIRx recommends its customers running periodical static phantom tests in order to make sure that the hardware is working correctly. The *Quality Scale* itself is not enough to evaluate it and should be used only as a first indicator of some problem. A more in-depth evaluation of system performance is possible with the static phantom provided with NIRx instruments.

## 9 Experiment Notes and System Status History

Instrument in Use:

NIRScout 16x24

Source Type:

LED

Modulation Amplitude:

Human Subject

Instrument in Use: Instrument type detected by the software

Source Type: Indicates whether LED or Laser source is used (Laser is only available for NIRScoutX systems with optional equipment)

Modulation Amplitude: Indicates the LED power level, 'Human subject' or 'Phantom' (see Section 5.1)

Experiment Notes

[Type notes here]

The *Experiment Notes* editor allows the user to enter plain-text comments, which are recorded in the data .hdr file (see file formats, Section 13.3).

System Status History

24.04.2012  
 [16:03:00] Startup...  
 [16:03:00] Initialize...  
 [16:03:00] Ready  
 [16:03:09] Calibration finished

The *System Status History* window will maintain an account of all user actions, with time stamps, to help keep track of the experimental conditions. The start of measurement is recorded in a text file automatically (see file formats, Section 13.3).

## 10 Data Visualization and Recording

Following the proper System Setup steps, data may be previewed or recorded. The real-time data visualization capability of the NIRStar software in the *Data Visualization* tab is automatically opened. Two basic ways of data display are presented side-by-side: A traces display, and topographic maps.



Data in the *Trace Display* and in the *Topographic Display* are by default shown as the estimated changes in oxy- and deoxy-hemoglobin concentrations. Please note that the recorded data are the raw signals (voltages) at the individual measurement wavelengths. These can be visualized by unchecking the 'Show Hb States' check button.

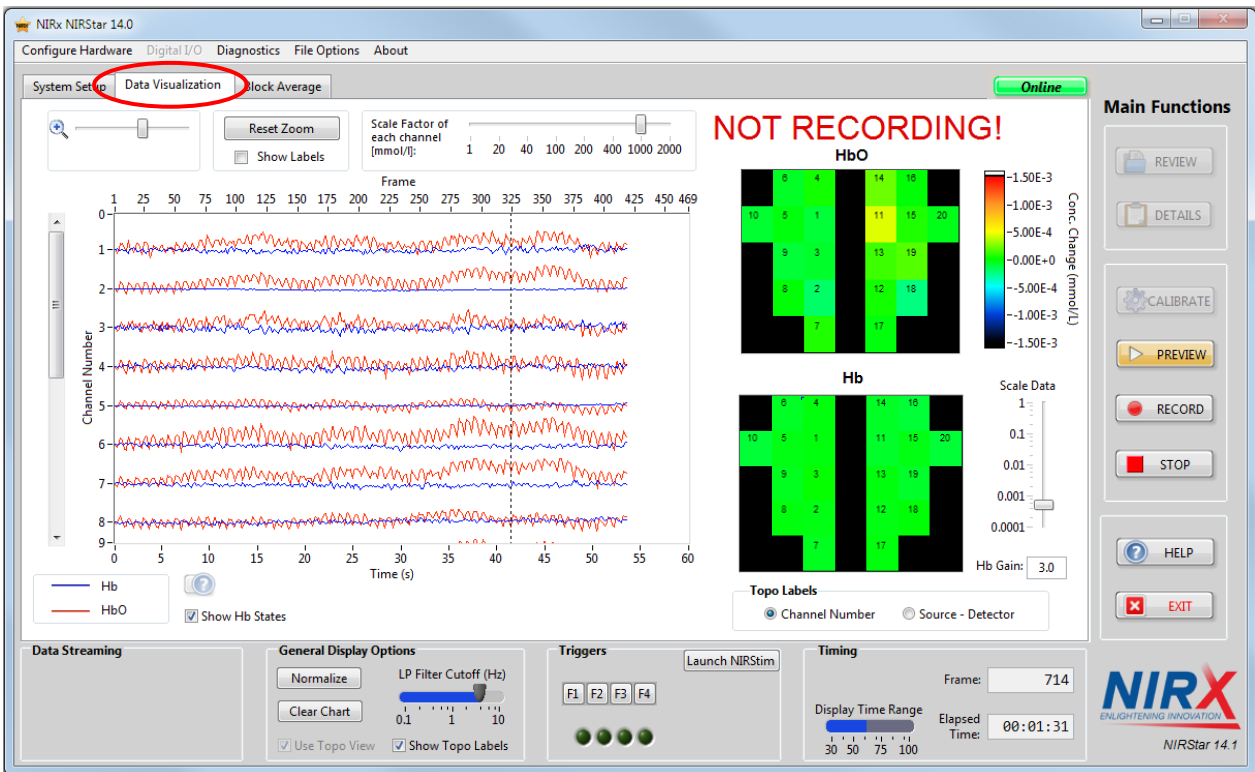


Figure 49. Data Visualization tab showing the trace display (left side) and the topographic displays for Hb and HbO changes (right side).

## 10.1 Trace Plot Display

The time series data of the estimated oxy- and deoxy-hemoglobin concentration changes for each channel selected in the Channel Mask (see Section 5.5) are represented in a trace plot on the left side of the Data Visualization tab (see Figure 49



Data in the *Trace Display* and in the *Topographic Display* are by default shown as the estimated changes in oxy- and deoxy-hemoglobin concentrations. Please note that the recorded data are the raw signals (voltages) at the individual measurement wavelengths. These can be visualized by unchecking the 'Show Hb States' check button.

Trace Plot Display).

A variety of display features are available for optimizing the appearance of the trace and topographic displays. Note that some of these tools are available only during the *Preview* or *Record* phase and are grayed out otherwise.



Please note that all visualization tools, including the scale factor and the low-pass filter, apply to the illustrated data and have no effect on the data that is saved for offline analysis.



With the *Zoom Tool*, the user can select specific channels for viewing. Note that zooming affects only the *Channel Number* axis (*i.e.*, vertical zoom) and not the time scale. Use the vertical scrollbar to the left of the time-series graph to select a specific set of channels.

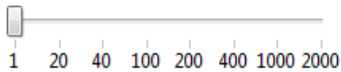
Reset Zoom

The *Reset Zoom* button returns the trace display to its default settings, in which the first 20 channels selected in the *Channel Mask* (see Section 5.5) are visible.

Show Labels

Checking the *show labels* box brings up a channel legend next to the trace plot. After a scan, the user is also able to select which channels are to be shown.

Scale Factor of each channel [mmol/l]:



All channels can be scaled up (*i.e.*, displayed amplitude of signal-level fluctuations is increased) to increase visibility of data details. If no scale factor (*i.e.*, '1') is applied, the unit of the Hb states is mmol/l. This can be scaled up to a factor of 2000 mmol/l. After the recording session is stopped, the chosen scale factor is applied to the entire data set.

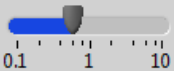
Normalize

Normalizes the data by recalculating the baseline for concentration changes.

Clear Chart

Clears the trace display for real-time visualization. After the user clicks on the *Stop* button, the last time frames are displayed, and a scrollbar for selecting the time interval of interest appears, below the trace display's time axis.

LP Filter Cutoff (Hz)



A moving-average low-pass filter is applied, whose cutoff frequency can be set by adjusting the slider labeled *LP Filter Cutoff (Hz)*. This feature may be used to remove high-frequency noise and/or the heartbeat component from the displayed signal. Figure 51 shows an example of a filtered data display; the prominent cardiac frequency at around 1Hz is filtered out, by selecting a cutoff frequency lower than the heart rate.

## 10.2 Topographic Display

In addition to the trace displays, the relative Hb concentration changes in the measurement channels are presented as 2-D color maps in a topographic view (see Figure 49 and Figure 51). Depending on whether

or not the *Use Topo View* box is checked, the map represents either the channel arrangement defined in the *Topo Layout* tab of the *Hardware Configuration* user interface (see Section 5.4), or all channels as a ‘Sources × Detectors’ matrix.

If the *Show Topo Labels* option is checked, channel labels are superimposed onto the topographic display. The *Topo Labels* selector specifies whether these reflect the source-detector combination, or the channel number (Figure 50).

The user can adjust the range of data values displayed on the color scale by using the slider control. Because the Hb response is generally weaker than the HbO response, the option *Hb Gain* allows setting a

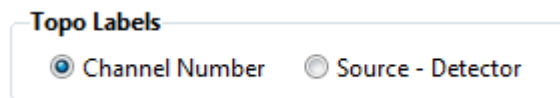


Figure 50. Label selector for the topographic display

multiplier factor to enhance the Hb dynamics for display clarity purposes.

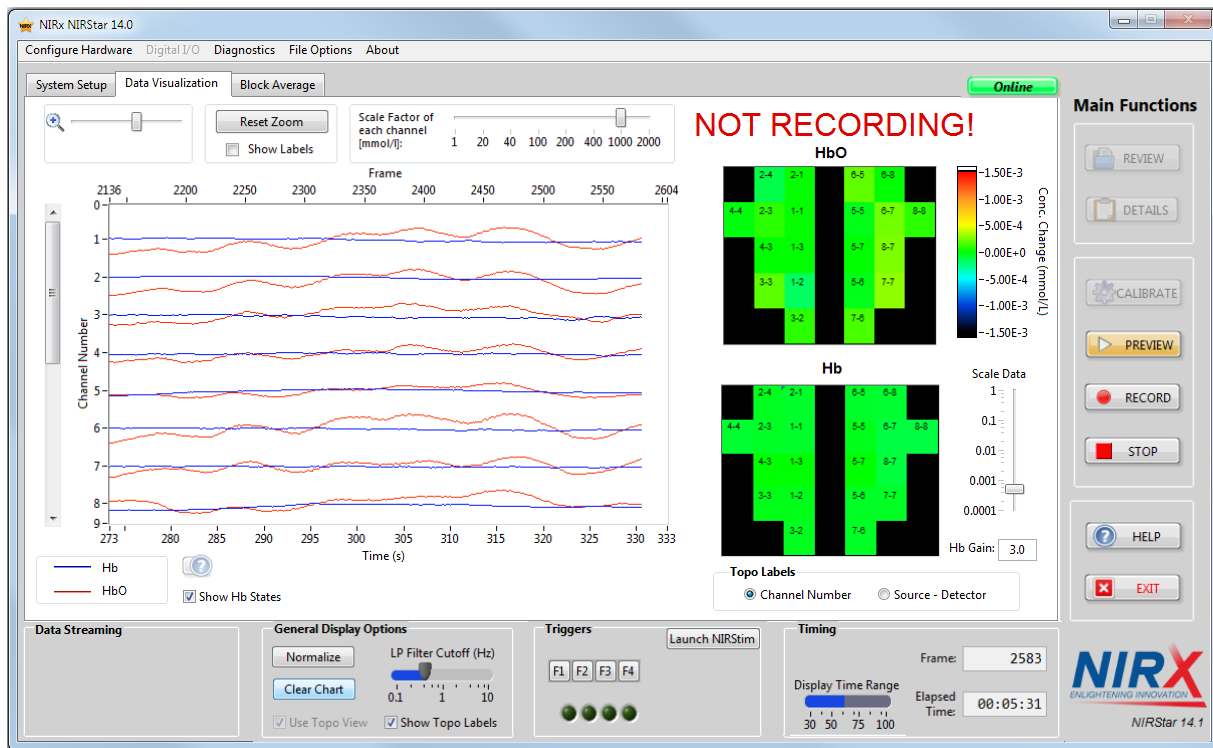


Figure 51. Filtered data in the curve display



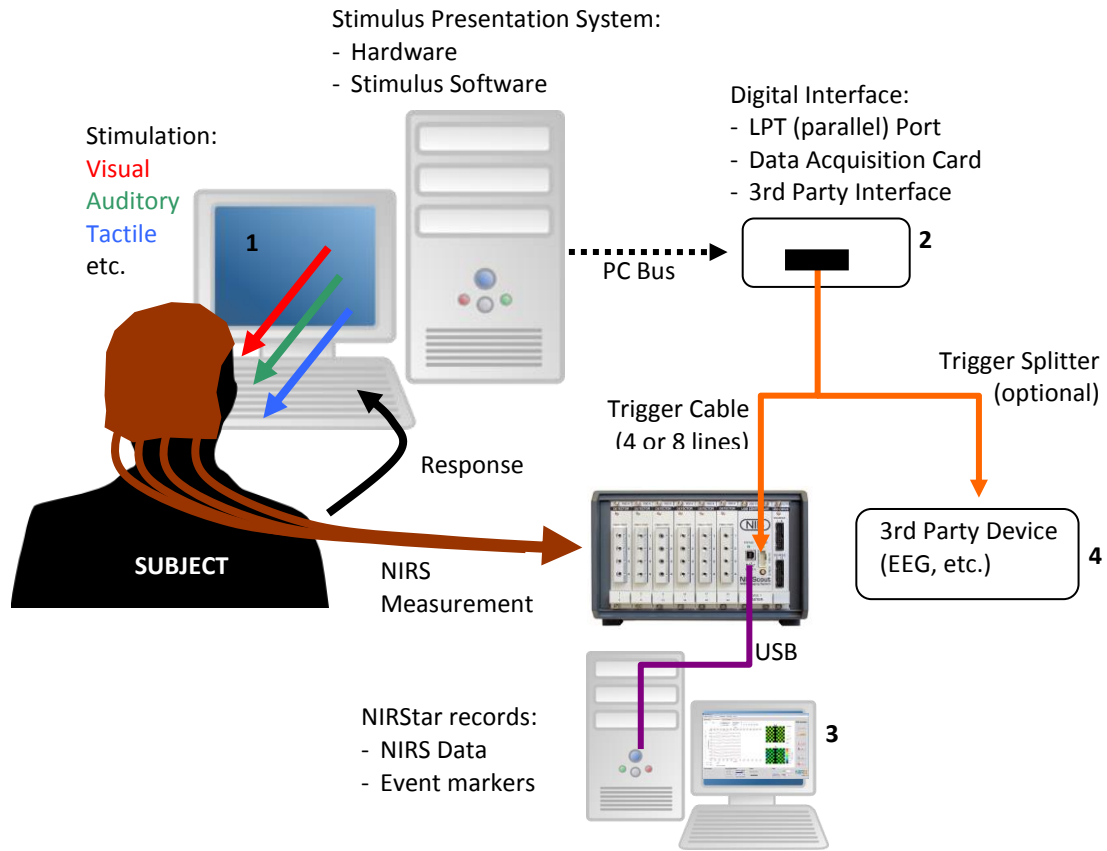
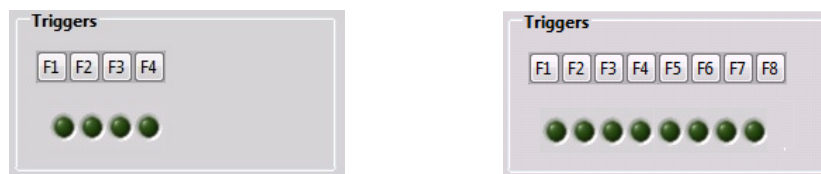


Figure 52. Experimental setup, device connections, and data flow for a typical multi-modal NIRS experiment. A computer with user-specific stimulation presentation software (1) provides stimuli to the subject and may record their response. Time markers of presentation and response events are made available to recording equipment in the form of digital pulses (usually, TTL level). These may be sent over the PCs bus and LPT port (built-in or plug-in PC extension card) or, alternatively, over third-party hardware interfaces communicating with the USB bus (2). These trigger signals are transmitted over a cable to the Trigger Input of the NIRScout(X) / NIRsport instrument where they are recorded, digitized, and transmitted to NIRStar for display and storage on the recording PC (3). Optional cabling and splitting adaptors are available to transmit the trigger signals to 3<sup>rd</sup> party devices simultaneously (4).

### 10.3 Triggers

In a typical NIRS experiment, the subject's reaction to certain psycho-physiological stimuli (audio, visual, tactile, *etc.*) are of interest. A typical experimental setup is shown in Figure 52. In order to time-correlate the NIRS signal to these events or the subject's response, a mechanism needs to exist for synchronizing the data with external time markers. Typically, event markers may signify the start or the cessation of a task, or a subject response. To this end, all NIRx imaging devices have digital signal inputs that accept trigger signals from other equipment such as stimulus presentation computers. These inputs are compatible with the widely used, standardized digital TTL format as produced by PCs and many 3<sup>rd</sup> party research devices. More information on trigger communication possibilities is available in a dedicated white paper that provides an overview on hardware fundamentals and basis on how to send triggers. The technical details of the requirements for trigger signals may be found in the appropriate NIRx imager hardware manuals. Please review section 2.3 for a list of related documents available.



**Figure 53. Different trigger displays: (left) For a NIRScout system, four trigger ports and four manual markers are available. (right) For the NIRScoutX, eight trigger ports and manual markers are available.**

Whenever a trigger signal is received at one of the imager's input lines, this event is recorded by saving the time point of its occurrence together with the number of the receiving input line. Each input line (four for NIRScout/NIRSport devices, and eight for NIRScoutX) is represented by an indicator light on the main screen for visual feedback. The indicators flashes briefly when a trigger is received on the respective line (see Figure 53).

In addition to generate trigger events through external signals, the NIRtar software also allows the user to set trigger markers manually during the course of the measurement. For NIRScout and NIRSport, a manual marker can be recorded either by clicking the respective button (see Figure 53) or by pushing the keys F1...F4 on the keyboard. Four marker numbers are provided so that the user may assign different ones to different types of event; each marker number can be used as many times as the user desires. For NIRScoutX systems, eight manual markers are available (F1...F8, also see Figure 53).

This function may be used in addition to electronic event triggering and is particularly useful for marking unexpected experimental events (such as motion artifacts, subject distraction, *etc.*), especially in conjunction with adding brief experimental notes in the setup screen.

NIRStar also presents a further triggering capability based on markers saved in a text file. If the user creates a file “Trigger.nrx” under “C:\NIRx\Commands\”, it will be periodically checked for new trigger markers. This allows for remote triggering that can be sent via a local network given that access to the acquisition computer is provided.

One extension of this capability is, for example, to send trigger markers from within Matlab without the requirement of additional parallel or serial cables. An example of Matlab function prototype along with its application to send trigger marker ‘1’ is illustrated as code snippets in Figure 54.

```

function Trigger_Control(marker)

    pathname = 'C:\NIRx\Commands\';
    filename = 'Trigger.nrx';

    if exist(pathname,'dir') ~= 7
        mkdir(pathname);
    end

    fid = fopen([pathname filename],'at');
    fprintf(fid,'%d\n',marker);
    fclose(fid);

end

%% Send Trigger Marker programatically
marker = 1; %select trigger marker
if isnumeric(marker)
    marker = max(min(marker,15),1);
    Trigger_Control(marker);
end

```

Figure 54. Example of Matlab code and function prototype to send trigger programatically to NIRStar.

## 10.4 Timestamps

The Frame counter (Figure 55) displays the number of completed scans, or frames, which is defined as the number of full illumination steps. The  $n^{\text{th}}$  illumination scan (frame) is completed when all illumination points (LEDs) have blinked  $n$  times during the measurement.

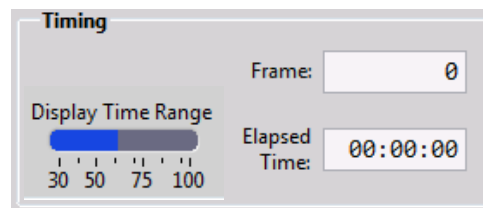


Figure 55. Timing Display

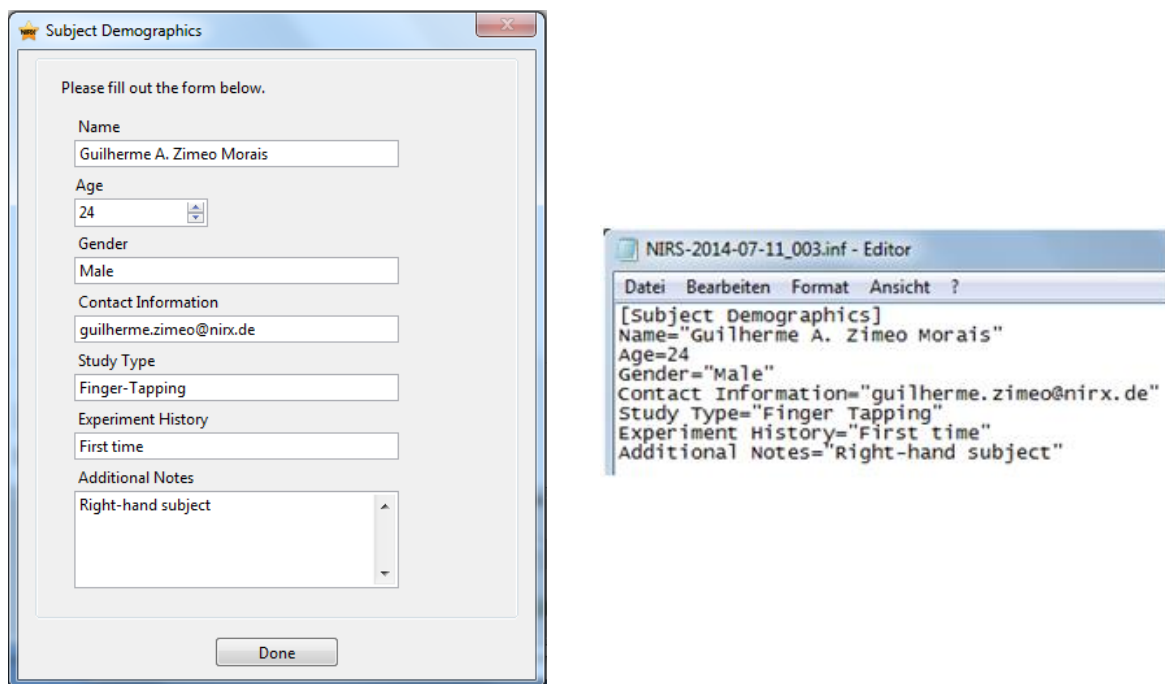
The timer shows the *Elapsed Time* since starting a scan. And *Sec Display* shows the size, in seconds, of the time interval currently being displayed in the Data Visualization tab. The user can change the display time interval by positioning the mouse cursor over the *Sec Display* bar and clicking. Note that doing this during a measurement will clear the chart. The most recent data history can be shown with the help of the x-axis scrollbar after the measurement has been stopped. The length of the data history is dependent on the number of channels and the scan rate and is roughly given as:

$$\text{No. of data frames in history} \approx 3 \times 10^5 \div (\text{No. of channels})$$

## 11 Subject Demographics

NIRStar offers a convenient way of recording the subject's demographic and other information relevant to the statistical analysis of the experiment. Whenever the 'Preview' or 'Record' button is clicked, a dialog form will appear that allows entering information about the subject (identity, gender, age, etc.), the experiment, and general notes. After clicking 'Done' the NIRS acquisition will commence.

To make use of this feature, be sure that the box labeled 'Subject Demographics?' under *Hardware Configuration > Channel Setup* (see0) is checked, which is the default. If this box is unchecked, clicking the 'Preview' or 'Record' button will immediately start the scan, without prompting the subject information input dialog.



**Figure 56. Left: Dialog for entering the subject information as it appears at the start of a recording. Right: Corresponding output saved in the .inf file.**

## 12 Integrated Stimulus Presentation

NIRx' stimulus presentation and experimental timing software, NIRStim™ can be started from within NIRStar by clicking the Launch button in the NIRStar Trigger section of the main screen (Figure 57).



Figure 57. Integrated Stimulus Presentation

### 12.1 NIRStim Features

NIRStim is an easy-to use graphically operated environment for generating and presenting basic psychophysiological stimuli, and for providing experimental timing and control (Figure 58). In summary, its main features are

- Graphical operation (no line coding)
- Presentation of various stimulation materials: Text, Pictorial, Auditory (Sound)
- Unrestricted programming of timing, order, duration and repetition of stimulation events, including randomizing and jittering.
- Generation of synchronization signals (i.e., 'triggers', 'event markers') through various hardware ports
- Direct event synchronization to NIRStar through software

NIRStim's primary purpose is to provide a simple, turn-key solution to the user for testing, demonstration, and training purposes. Nevertheless its capabilities are sufficient to allow the control and timing of many basic psychophysiological experimental paradigms.

NIRStim is particularly well suited to operate in wearable settings with NIRSport: Running NIRStim on the portable acquisition PC allows auditory stimulus or instruction presentation to the subject through headphones while trigger signals are transmitted to NIRStar through software without the requirement trigger generating hardware or trigger cabling.



## 13 Data File Formats

### 13.1 File Naming and Organization

By default, the NIRStar software organizes and names files automatically, using to the date and time of acquisition to define the target directory name and the common root of the file names. Alternatively, the user may specify a directory and/or a file-name prefix (see Section 6.3). Whichever method is used, the number of files saved and the type of information contained in each one is the same. Most of the files are saved in text (ASCII) format, apart \*.nirs and \*\_probeInfo.mat, which are saved in Matlab format.

### 13.2 Detector Readings: \*.wl1, \*.wl2

The recorded signals for both wavelengths are stored in two separate files:

prefix-yyyy-mm-dd\_xxx.wl1            ← contains data for wavelength 1 (760 nm)  
 prefix-yyyy-mm-dd\_xxx.wl2            ← contains data for wavelength 2 (850 nm)

These data files contain the raw voltage readings recorded by the source-detector channels.



The saved raw data are never processed in any way. That is, any preprocessing steps selected on the user interface, such as filtering or normalization, are for display purposes only and have no impact on the recorded data.

The file format is a space-separated ASCII table where columns represent data channels and rows represents time frames. The file contains no header, explicit row or column labels, or time stamps. The data structure is illustrated in the table below.

Table 1: Structure of the optical data files \*.wl1, \*.wl2.  $S_i$ :  $i^{\text{th}}$  source;  $D_j$ :  $j^{\text{th}}$  detector;  $t_k$ :  $k^{\text{th}}$  scan, or time frame of measurement.  $S_i-D_j(t_k)$ : reading at the  $j^{\text{th}}$  detector, of light emitted by the  $i^{\text{th}}$  source, during the  $k^{\text{th}}$  scan.

$S_1-D_1(t_1)$	$S_1-D_2(t_1)$	...	$S_1-D_{\max}(t_1)$	$S_2-D_1(t_1)$	...	$S_2-D_{\max}(t_1)$	$S_3-D_1(t_1)$	...	$S_{\max}-D_{\max}(t_1)$
$S_1-D_1(t_2)$	$S_1-D_2(t_2)$	...	$S_1-D_{\max}(t_2)$	$S_2-D_1(t_2)$	...	$S_2-D_{\max}(t_2)$	$S_3-D_1(t_2)$	...	$S_{\max}-D_{\max}(t_2)$
...	...	...	...	...	...	...	...	...	...
$S_1-D_1(t_{\max})$	$S_1-D_2(t_{\max})$	...	$S_1-D_{\max}(t_{\max})$	$S_2-D_1(t_{\max})$	...	$S_2-D_{\max}(t_{\max})$	$S_3-D_1(t_{\max})$	...	$S_{\max}-D_{\max}(t_{\max})$

The number of columns in the file equals (number of sources  $\times$  number of detectors):  $S_{\max} \times D_{\max}$ .

To extract a desired data channel  $S_i-D_j$  from the file, use the following formula to identify the appropriate column  $n$ :

$$n = (S_i - 1) \times D_{\max} + D_j$$

## Parallel source Illumination

It is important to note that even when more than one source is active per scan step (*e.g.*, 'bilateral' setup), or the sequence in which the sources are illuminated, NIRStar will still save the data channels in the format outlined above. The source numbers  $S_i$  in the outlined scheme will always refer to the physical source optode number, independent of its temporal placement in the scanning sequence. Likewise, the preceding formula still applies when parallel illumination is employed.



### LEGACY NOTE

EARLIER SOFTWARE VERSIONS (up to NIRStar 11.8) did NOT record all ( $S_{\max} \times D_{\max}$ ) source-detector channels, but only ONE set of detector readings for each scan step, irrespective of the no. of LEDs illuminated at each step. As a result, the number of columns was equal to  $Cyc \times D_{\max}$ , where *Cyc* is the number of source-switching steps in each scan. When parallel source illumination was employed, this resulted in a number of recorded channels less than  $S_{\max} \times D_{\max}$  (in bilateral setup, only half of it)

## 13.3 Header File: \*.hdr

The header file contains important information about the instrument's configuration and setup, the experiment timing, *etc.*, which is pertinent to the identification and analysis of data sets.

The file is structured into sections identified by a [section header] containing variables ('keywords'), to which parameter values are assigned according to a 'keyword=value' scheme.

The following explains the header file sections using exemplary values.

### General

Contains general information about the time and date of data recording, and the filename.

[GeneralInfo]	
FileName="NIRS-2012-02-16_004"	Filename as defined above in Section 6.3
Date="Do, 16. Feb 2012"	Date of recording
Time="15:54:22.442"	Start time of measurement (ms precision)
Device="NIRScout 16x24"	System type in use
Source="LED"	Type of source used (LED or Laser)
Mod="Human Subject"	Modulation amplitude according to study type
NIRStar="15.2"	NIRStar version used to record the dataset
Subject=1	Subject index

### Imaging Setup Parameters

Lists instrument setup parameters employed for the measurement, such as the number of sources, number of detectors, and trigger channels employed in the measurement.

[ImagingParameters]	
Sources=16	No. of source steps in measurement
Detectors=16	No. of detector channels
ShortBundles=0	No. of short detector bundles used
ShortDetIndex=""	Detectors connected to short-distance bundles
Steps = 16	No. of steps (illumination pattern)



Wavelengths="760 850"	Wavelengths used for the measurement
TrigIns=4	No. of trigger inputs
TrigOuts=0	No. of trigger outputs (only available for NIRScoutX)
AnIns=0	No. of auxiliary analog inputs (future option)
SamplingRate=3.906250	Sampling rate in Hz
Mod Amp="0.70 0.70"	Modulation amplitude used for illumination
Threshold="0.00 0.00"	Modulation threshold used (≠0 only for Laser)

### Paradigm Information

Records details about the experimental paradigm.

```
[Paradigm]
StimulusType=None           Specifies paradigm (future option)
```

### Experimental Notes

Notes entered into the notes editor of the user interface (see Section 9) are saved here.

```
[ExperimentNotes]
Notes="[Type notes here]"
```

### Gain Settings

The gain settings used in the measurement are recorded in a table. The gain for channel  $S_i-D_j$  is found in the  $i^{\text{th}}$  row and  $j^{\text{th}}$  column (counting from the upper left).

Valid gains for neighboring source-detector-pairs usually are in the range of 4...7 for adults, depending on head size, hair density/color, and measurement site. A gain value of '8' indicates that too little or no light was received for this particular pairing (see also, Section 8.2).

```
[GainSettings]
Gains=#
5 8 5 5 8 8 8 8 8 8 8 8 8 8 8
4 4 5 8 8 8 8 8 8 8 8 8 8 8 8
8 8 6 6 6 6 8 8 8 8 8 8 8 8 8
8 8 8 5 8 6 5 8 8 8 8 8 8 8 8
8 5 5 8 6 8 8 8 8 8 8 8 8 8 8
8 8 8 8 8 6 5 5 8 8 8 8 8 8 8
8 8 8 8 6 6 8 6 8 8 8 8 8 8 8
8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
8 8 8 8 8 8 8 8 8 5 6 8 5 8 8
8 8 8 8 8 8 8 8 4 4 5 8 8 8 8
8 8 8 8 8 8 8 8 8 8 6 6 6 6 8
8 8 8 8 8 8 8 8 8 8 8 6 6 8 6
8 8 8 8 8 8 8 8 5 8 5 6 8 8 8
8 8 8 8 8 8 8 8 8 8 8 8 6 5 5
8 8 8 8 8 8 8 8 8 8 5 8 6 6 8
8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
#
```

The gain values range from 0 (gain factor  $10^0 = 1$ ) through 8 (gain factor  $10^8$ ). The hash symbols '#' are used to identify the beginning and end of the table.

### Event Trigger Markers

Records the event markers received by the digital trigger inputs, with time stamp and frame number.

**Column 1:** Time (in seconds) of trigger event after the scan started.

**Column 2:** Trigger channel identifier, or condition marker. Triggers received on each digital input DI<sub>x</sub> (where x denotes the trigger channel) on the front panel are encoded as numbers  $2^{DI(x-1)}$ , e.g. DI1, DI2, and DI3 are encoded as 1, 2, and 8, respectively. The file stores the sum of simultaneously triggered inputs in decimal representation. By using combinations of trigger inputs, as many as 15 conditions can be encoded by NIRScout and NIRSport systems, while NIRScoutX receives up to 255 conditions (8 inputs).

**Column 3:** The number of the scan frame during which the trigger event was received.

```
[Markers]
Events=#
86.40    1    300    Trigger of input 1 recorded after 1.80 s, during frame no. 12
116.40   2    404
146.40   1    508
...      ...    ...
476.39   2    1654
#
```

### Data Structure

This section records the arrangement of detector channels in the .wl1 and .wl2 files, and the channel masking pattern.

```
[DataStructure]
S-D-Key="1-1:1,1-2:2,1-3:3,1-4:4,1-5:5,1-6:6,1-7:7,1-8:8,1-9:9,1-10:10,
...

S-D-Mask=#
1  0  1  1  0  0  0  0  0  0  0  0  0  0  0  0
1  1  1  0  0  0  0  0  0  0  0  0  0  0  0  0
0  0  1  1  1  1  0  0  0  0  0  0  0  0  0  0
0  0  0  1  0  1  1  0  0  0  0  0  0  0  0  0
...
0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
#"
```

'S-D-Key' (source-detector key) denotes the order in which the columns of the data files (\*.wl1, \*.wl2) are assigned to source-detector combinations. Each channel is denoted by the source number, a minus sign ('-') and the detector number. The channel pair is followed by a colon (:) and the corresponding

column index in the optical data files. The column index is followed by a comma (',') and the next channel. This variable may be read to generate a table header for the data files.

'S-D-Mask' stores the masking pattern in a table (for channel masking, see Section 5.5). Channels that are set not to be displayed are identified by '0's, while channels set to be displayed are labeled with '1's. Counting from the upper left, the column number corresponds to the detector channel, and the row number corresponds to the source position. Shown above is an example of a 4-source/4-detector measurement, in which all channels are displayed except for source 2 / detector 3.

### Dark Noise

The dark noise results obtained for each wavelength during the last calibration prior to the measurement are stored in the header file for future references. However, only the values obtained for the highest gain available (e.g. 7 for NIRScout or 2 for NIRSport) will be saved. Therefore, each wavelength will present its results as a vector, whose size equals the number of detectors used for the corresponding experiment.

```
[DarkNoise]
Wavelength1="#"
1.271    1.427    0.967    1.081    1.145    1.237    1.098    1.138
#"
Wavelength2="#"
1.406    1.407    1.161    1.177    1.263    1.248    1.166    1.267
#"
```

### Cross Talk

The results of the cross-talk metric (see section 8.2) for each wavelength during the last calibration prior the current experiment are also stored in the header file. The results for all possible source-detector combinations are saved. Thus, for an experiment with 8 sources and 8 detectors and two wavelengths, it will result on two matrices (one per wavelength) of 8 rows and 8 columns each. If standard illumination pattern (i.e. one source enabled per step) has been employed, all values will be 0, as represented below.

```
[CrossTalk]
Wavelength1="#"
0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
...
0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
#"
Wavelength2="#"
0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
...
0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
#"
```

## Channels Distance

The channel distance values entered in the Hardware Configuration and used for the Beer-Lambert Law calculations during a scan are recorded here. The order corresponds to the order of the channel list in the dialog (Figure 53).

[ChannelsDistance]

```
ChanDis="30.0    30.0    30.0    30.0    30.0    30.0    30.0    30.0
         30.0    30.0    30.0    30.0    30.0    30.0    30.0    30.0
         30.0    30.0    30.0    30.0"
```

### 13.4 Other Files: \*.set, \*.evt, \*\_config.txt, \*.inf, \*.nirs, digpts.txt, \*.tpl, \*\_probeInfo.mat

The files filename.set, filename.evt, filename\_config.txt generated for each measurement contain mostly information that is redundant with entries in the .hdr file. These files are generated to maintain compatibility with other NIRx products.

#### 13.4.1 filename.set

This file stores the gain-settings table in a format identical to the table Gains of the [GainSettings] section in the \*.hdr file.

#### 13.4.2 filename.evt

This file records the event marker channel code and frame number in a format compatible with the NIRx NIRS imaging systems. Each row of the tab-separated table corresponds to a recorded trigger event. The first column contains the frame number at which the trigger was received. Columns 2–9 record the trigger markers for up to 8 trigger input channels. '1' marks those inputs where a trigger signal was received. Because NIRScout and NIRSport systems have a maximum of 4 digital input lines, columns 7-10 are always all 0.

In the example .evt file below, digital input 1 (DI1) was triggered during frame 20, DI4 was triggered during frame 29, etc.

```
20  1  0  0  0  0  0  0  0
29  0  0  0  1  0  0  0  0
31  0  1  0  0  0  0  0  0
35  0  0  0  1  0  0  0  0
50  1  1  1  1  0  0  0  0
```

#### 13.4.3 filename\_config.txt

This file is required by the NIRx NAVI analysis software and provides general information about the measurement parameters.

```
raw_data_name='NIRS-2010-08-27_001';      Filename
SamplingRate=6.25;                       Sampling rate in Hz
waveLength_N=2;                           No. of wavelenghts
```

```

Wavelengths=[760 850];           Wavelengths used
source_N=8;                       No. of sources
detector_N=16;                   No. of detectors
time_point_N=100;               No. of recorded scans
source_detector_key=[1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 0 0 0 0 0 0 0;...
                        0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 2 3 4 5 6 7 8];
probeInfo_file='C:\NIRx\Montages\Motor_16x16\Standard_probeInfo.mat';

```

source\_detector\_key lists the optode numbers acting as detectors (first row) and as sources (second row). Since every optode is *either* a source *or* a detector for NIRScout devices, a non-0 value in one row will always line up with a 0 in the other (the number of blank spaces between numbers in a row is arbitrary).

probeInfo\_file lists the path for the ProbeSetup file used for the measurement, if a Predefined Montage (section 5.2) previously entered with a valid ProbeSetup has been chosen. Otherwise, probeInfo\_file = ''.

#### 13.4.4 Subject Information file: filename.inf

This file records the information entered in the subject Demographics dialog. The following is an example of this file as it would appear for the entries shown in Figure 56.

```

[Subject Demographics]
Name="John Doe"
Age=35
Gender="Male"
Contact Information="email@server.domain"
Study Type="Go/No-Go"
Experiment History="First time"
Additional Notes="Right-hand subject"

```

#### 13.4.5 Homer format file: filename.nirs, digpts.txt

If the feature “Export data to Homer2 format” has been enabled under File Options (see section 6.3) and a Probe Setup file corresponding to the measurement has been correctly loaded, then a \*.nirs file will also be created in the dataset folder. This Matlab file contains information about the acquired data and cap layout used for the measurement and may be directly imported into Homer2 for further analysis.

Also, to enable AtlasViewer compatibility, NIRStar now exports a “digpts.txt” file with 3D coordinates and reference points obtained from the probeInfo file. With this information, one is able to firstly process the data in Homer2 using the \*.nirs file and then import the results into AtlasViewer.

For example, to accomplish an overlay of the concentration changes on Colin27 in AtlasViewer, follow these steps after launching AtlasViewer: (i) Tools -> Register Atlas to Dig Points; (ii) Register Probe to Surface; (iii) Tools -> Hb Conc Overlay.

Please note that only probeInfo files created from within NIRSite can be used to create a “digpts.txt” file.

### 13.4.6 Topo Layout file: *filename.tpl*

This file records the topographic layout information as it is entered in the topo layout editor of the Configure Hardware dialog (see section 5.4). The information is recorded in a tabular layout identical to the row and column structure in the Topo Layout editor. Instead of separating source and detector numbers by a hyphen ('-') a purely numerical format was chosen to make computer reading easier. Each channel is recorded by a positive integer number (although in floating point notation) whose 'hundreds' represent the source position, and whose 'ones' represent the detector.

Therefore: Channel 'xx-yy' would be noted 'xxyy', e.g., channel 5-7 → 507; channel 16-14 → 1614.

The example below corresponds to the topo layout shown in Figure 18.

507.000	503.000	103.000	0.000	0.000	0.000	1513.000	1113.000	1109.000
707.000	505.000	303.000	101.000	0.000	1515.000	1313.000	1111.000	909.000
705.000	305.000	301.000	0.000	0.000	0.000	1315.000	1311.000	911.000
708.000	605.000	304.000	201.000	0.000	1615.000	1314.000	1211.000	910.000
608.000	604.000	204.000	0.000	0.000	0.000	1614.000	1214.000	1210.000
808.000	606.000	404.000	202.000	0.000	1616.000	1414.000	1212.000	1010.000
806.000	406.000	402.000	0.000	0.000	0.000	1416.000	1412.000	1012.000

### 13.4.7 Probe Setup file: *filename\_probeInfo.mat*

NIRStar automatically saves the Probe Setup file that is used for Topographic Rendering (see sections 18 and 19) and data analysis. This file will be saved if the user has either made use of the Topographic Rendering capability by plotting the data online or selected one of the available Predefined Montages (section 5.2) having a *\_probeInfo.mat* file.

Please refer to the NIRSite User Manual for more information on how to create a Probe Setup file.

### 13.5 Backup files: *\*.nosatflags\_wl1, \*.nosatflags\_wl2*

In NIRStar14-2, a saturation flagging had been implemented to automatically replace saturated data points with NaN values in the *\*.wl1* and *\*.wl2* files (section 16.1.3). As we recognize the importance to still provide the users with the original, non-corrupted data, NIRStar stores additional data files (e.g. *\*.nosatflags\_wl1*) if any saturation has been occurred during the measurement. Therefore, these files will only be saved for NIRSport systems in measurements where at least one data point saturated.

### 13.6 Hidden files: *\*.dat, \*.avg*

NIRStar presents two files that are saved into the dataset folder as hidden, because these are intended to be used by the acquisition software only. Both *\*.dat* and *\*.avg* files are required to employ the Data Review feature (section 15). The *\*.dat* file is a matrix containing the hemodynamic states *displayed* in NIRStar Data Visualization screen during the measurement, while *\*.avg* is a data structure with diverse information about measurement settings that should only be opened and used by NIRStar.

## 14 Quick Start Guide

### 14.1 Turning on the System

1. Make sure all system components are plugged in and that the host PC is turned on.
2. If using a NIRScout system, make sure that a valid USB link is established between the devices, by noting that the green Status LED on the USB controller front panel is blinking continuously.
3. Turn on the imager: For a NIRScout system, use the power switch on the rear panel next to the power inlet. The red Power LED on the USB controller must light up. For a NIRScoutX system, use the power switch on the lower left of the front of the unit. The switch will light up.
4. If using a NIRScoutX system, the connection with the USB port is established only after turning on the imager (preceding step). Make sure the USB device has been recognized by the computer.
5. Launch NIRStar, either by double-clicking on a link on the Windows™ Desktop or by calling the software from the Windows™ Start menu.

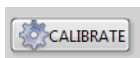
### 14.2 System Configuration

Make sure the system's configuration (especially the numbers of sources and detectors, and the trigger channels used) matches the requirements of the planned measurement. If necessary, adjust the hardware configuration as explained in Section 5. You may also select one of the *Predefined Montages* for a quick setup of the system configuration.

### 14.3 Cap setup

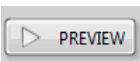
The optodes to be used for the measurement should be placed on the target, as described in the optode user manual.

### 14.4 Initializing a Measurement



Use the *CALIBRATE* function to determine the gain setup for the measurement. This process will take several seconds. You will see the signal quality display change as the calibration procedure progresses. This indicates that the system is testing different gain values. Use the *REFRESH* function to optimize and check your setup, if necessary. After the setup is complete, the map will provide several measures of the signal quality achieved, as discussed in detail in Sections 7.3 and 8.1.

### 14.5 Preview



A test scan for visual inspection, for which the acquired data are not saved, may be initiated through the *PREVIEW* button. The real-time display may be used, as described in Chapter 10. The preview operation does not affect the measured data and is for visualization purposes only. A second push of the button will stop the acquisition.

### 14.6 Perform Scan (Measurement)



The measurement is initiated by pressing the *RECORD* button. Adjust viewing options as desired.

### 14.7 Stop Scan (Measurement)



Use the *STOP* button to terminate the data recording.

### 14.8 Shut Down System



1. Close the software by clicking on the *EXIT* button
2. Turn off the imager using the main switch on the rear panel.
3. Disconnect the USB link if desired.
4. Shut down the PC if desired.



## 15 Data Review

### 15.1 Online/Offline Mode

NIRStar can be run on two different operating modes: online (acquisition) or offline (review).

The online mode is used to acquire data and to which almost all the functions described on the previous chapters refer. The offline mode is used to load and review previously recorded datasets, including their signal quality, hemodynamic time series, trigger markers and corresponding block average. This function will be thoroughly explained on Section 15.2.

The first important consequence of having an offline mode is that NIRStar can now be launched without having an instrument (real or simulated) detected by the computer in which it is installed. If you launch NIRStar without any device available in NI MAX (Appendix A), an alert message will be displayed with the information that only Offline mode will be available (Figure 59).

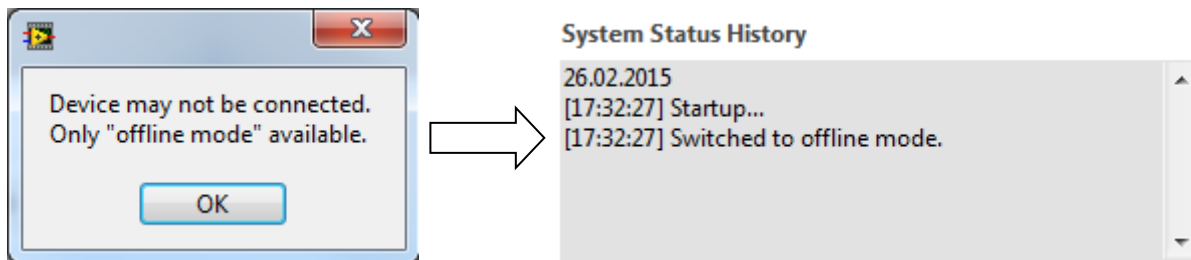


Figure 59. Alert message (left) and corresponding system status history (right) for offline mode only.

In the NIRStar main screen, under the System Setup tab, the "Instrument in Use" field will be defined as "None (Offline)"; and the indicator on the top right corner of the screen will appear disabled as Offline with red background (Figure 60).

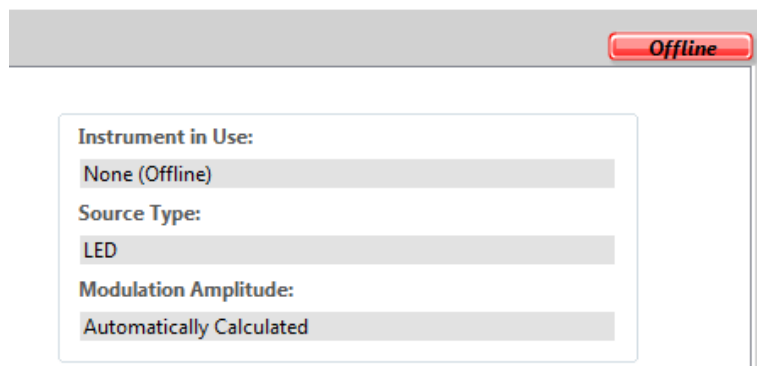


Figure 60. Instrument in Use: None (Offline)

On Offline mode, all the buttons on NIRStar main screen concerning hardware configuration, diagnostics and online measurement will be disabled and grayed out (Figure 61), because this mode is only expected to be used for data reviewing purposes.

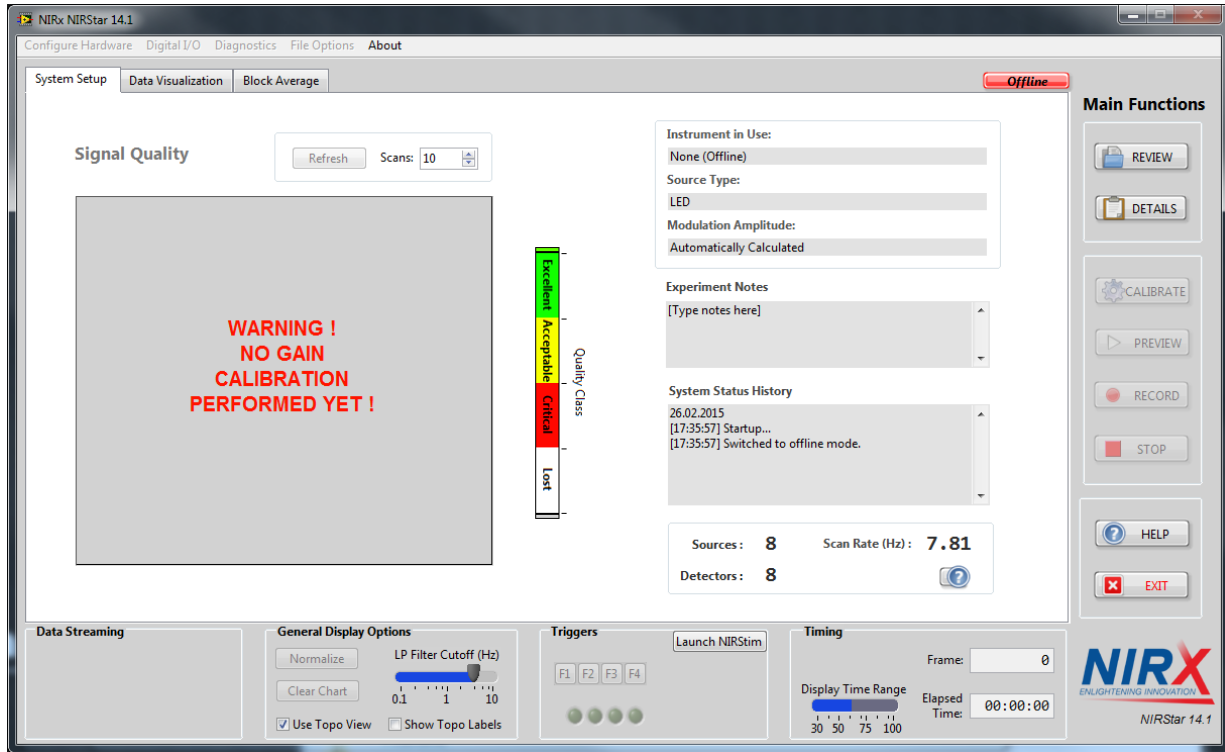


Figure 61. Offline mode with hardware-related buttons on NIRStar main screen disabled and grayed out.

Now, if the user launches NIRStar with a device (real or simulated) connected, it will automatically start on Online mode, which will have all the hardware-related buttons enabled to be used. The only button from the Main Functions block (right side of the screen) that will now be disabled is “Review”, because this function is only intended to be used on Offline mode.

The capability of reviewing datasets when an instrument is plugged in has also been appreciated by NIRStar: the user is able to switch from Online to Offline mode by clicking on the button indicating the current operating mode, located on the top-right corner of the screen, as shown in Figure 62.

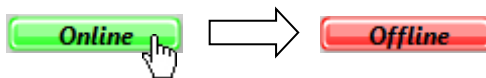


Figure 62. Switching from Online to Offline mode.

Anytime, one may switch *back* from offline to online mode and the hardware settings will be restored.



Please note that it is only possible to switch between operating modes **if** NIRStar has been originally launched under Online mode, i.e. **if** there is a device (real or simulate) available.

## 15.2 Reviewer Function

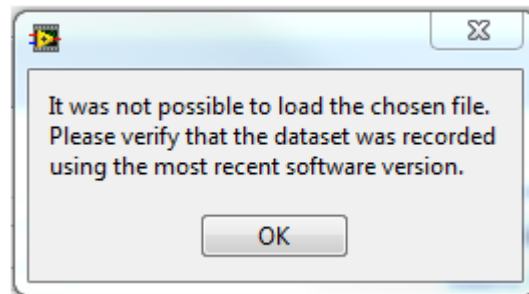
NIRStar provides its users with the feature of reviewing previously recorded datasets. This can be done by clicking on the “Review” button of the Main Functions list (buttons located on the right side of the NIRStar main screen).



Please note that the Review button will be disabled and grayed out for Online mode, since the function is only available Offline. Please review section 15.1 for more information.

By clicking on “Review”, the user will be prompted to select the header (\*.hdr) file of the dataset that is intended to be loaded and visualized.

As explained on Section 13.6, there are two new files being saved on NIRStar14-1 that are exclusively used for the Data Reviewer capability. With that said, if the user tries to load the header file of a dataset recorded with earlier versions of NIRStar, an error message will be shown as in Figure 63.



**Figure 63. Error message by loading dataset recorded from a NIRStar version earlier than 14-1.**

If the dataset is successfully loaded, the “System Status History” will be accordingly updated informing the loaded dataset and all fields in the NIRStar main screen (tabs System Setup, Data Visualization and Block Average – see section 17.3) will now represent the chosen dataset (Figure 64).

For example, if you had a NIRSport originally in use and you load a dataset recorded using NIRScoutX, the Instrument in Use will now display the information concerning the loaded file, because it is on Offline mode. Nevertheless, anytime the user is able to switch back to Online mode (see section 15.1) and the corresponding settings will be restored.

### File loaded:

Next to the operating mode indicator (here: “Offline”), a field called “File loaded:” will be visible while a dataset is being visualized by the user. It indicates the latest header file that has been successfully loaded by NIRStar. If one loads a new dataset, this field will be overwritten, as well as the others on the software main screen, to now represent the new settings. By switching to “Online” operating mode, the “File loaded” field becomes invisible, because the information now shown represents the actual device.

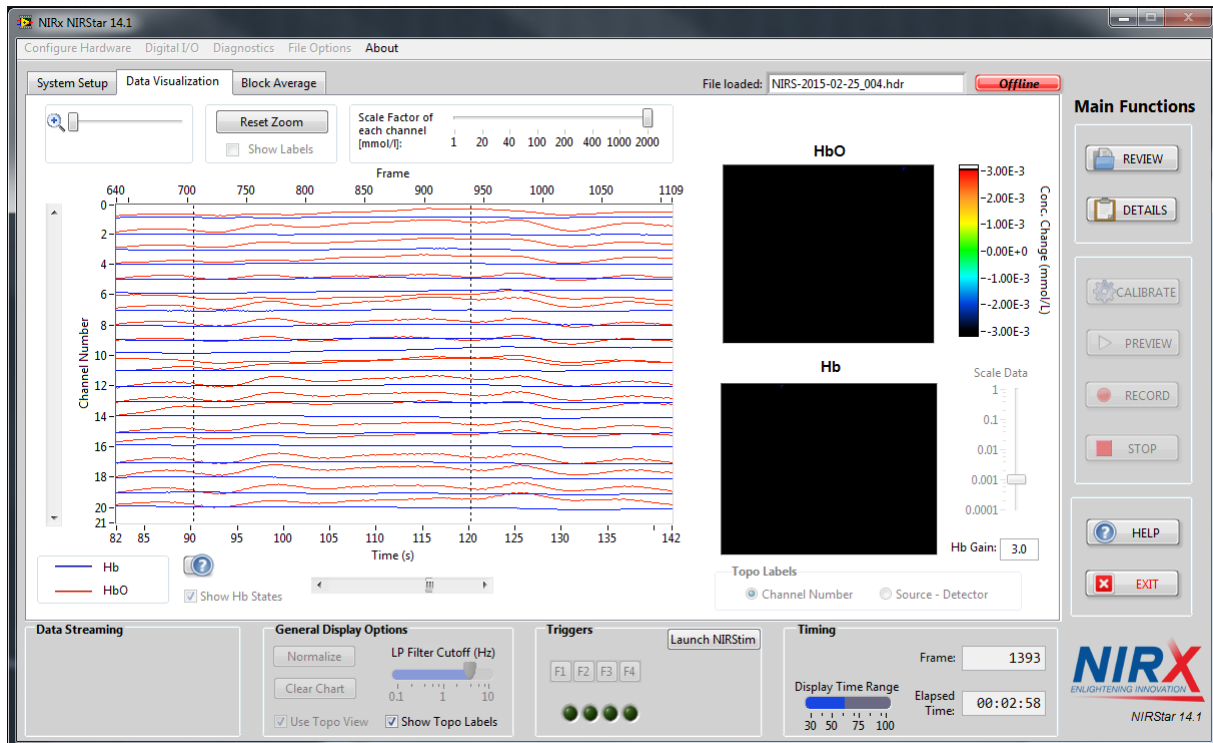
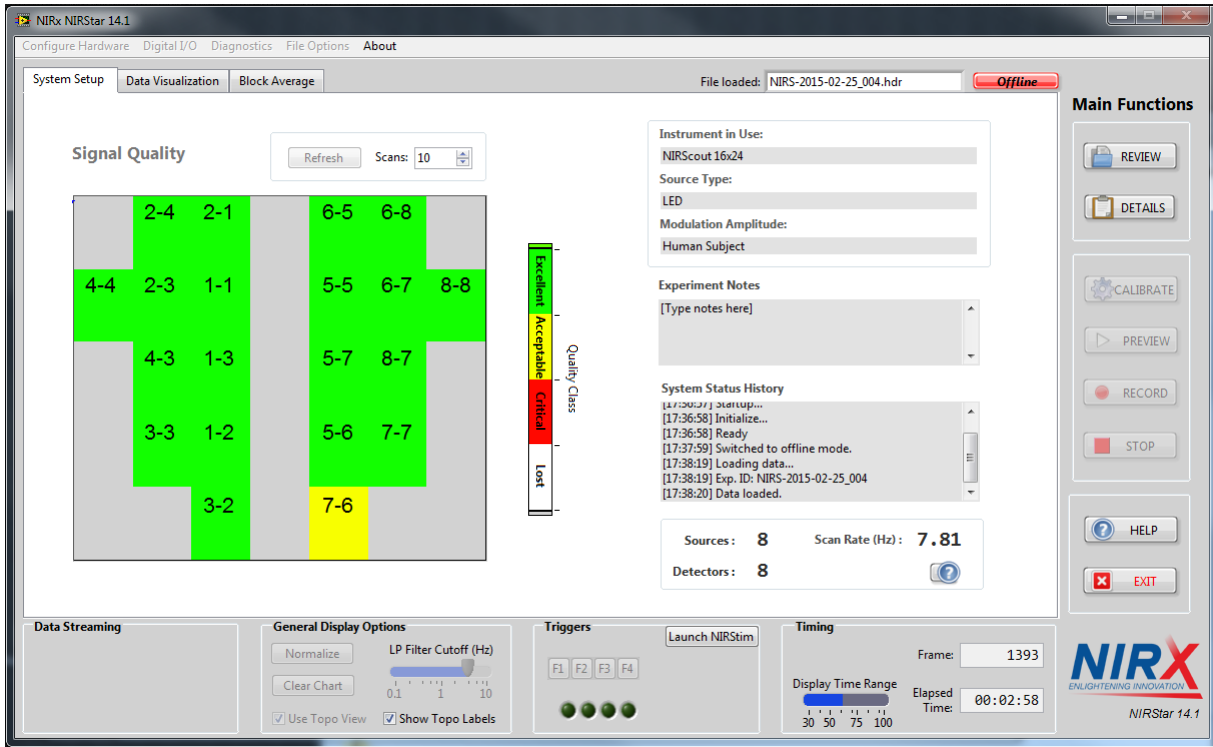


Figure 64. NIRStar screens after dataset is correctly loaded. Top: System Setup; Bottom: Data Visualization.

## 16 Device-Specific Information

NIRStar is an integrated solution, which supports the following NIRx NIRS imaging devices and configurations:

- NIRScout
- NIRScout eXtended (NIRScoutX)
- NIRSport

All of these instruments can be operated as single devices or in a parallel ‘Tandem’ mode, doubling the available channel capacity.

### 16.1 NIRSport

#### 16.1.1 Hardware Configuration

When connecting a NIRSport unit, the *Configure Hardware* dialog (see Chapter 5) shows a different *Hardware Specification* view (Figure 65) as compared to NIRScout devices. It is not possible (or necessary) to set up the hardware-specific number of installed detector or source channels because these parameters are fixed. Also, instead of having the option to enable avalanche photodiode detectors, the user should rather check whether dual-tip active detectors are available (Figure 65) to allow for proper adjustment of the thresholds to be used for the dark-noise metric (section 8.2).

#### LEGACY NOTE



For some older NIRSport and NIRScout devices, an *Instrument Type* drop-down menu may be displayed. In this case, the Instrument Type must be manually set by the user. Please verify if this corresponds to the system currently connected for acquisition.

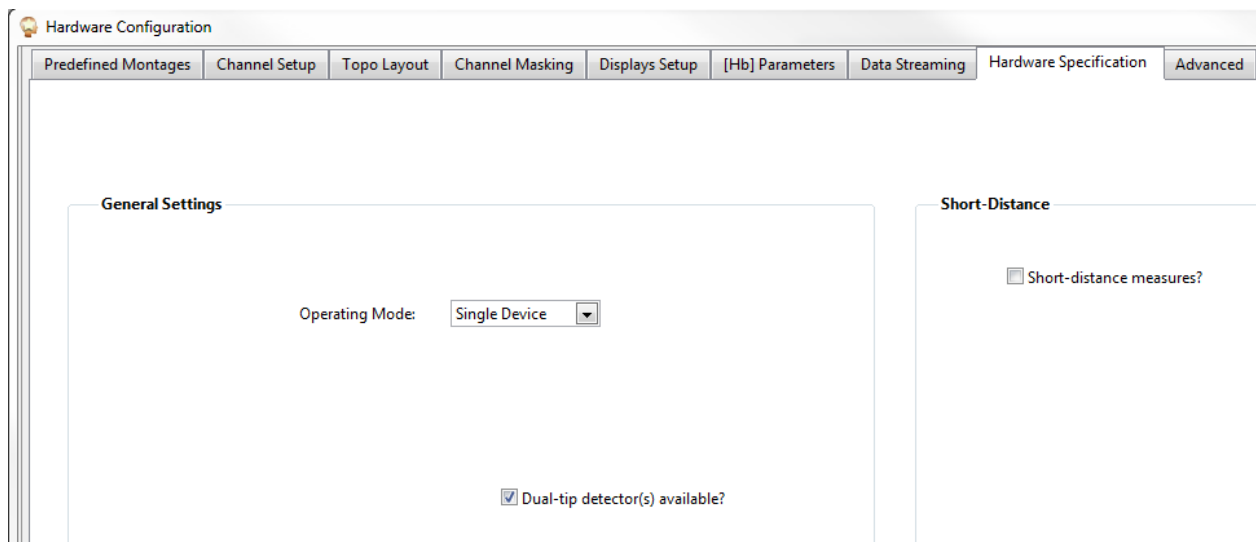


Figure 65. Hardware Specification dialog for NIRSport devices

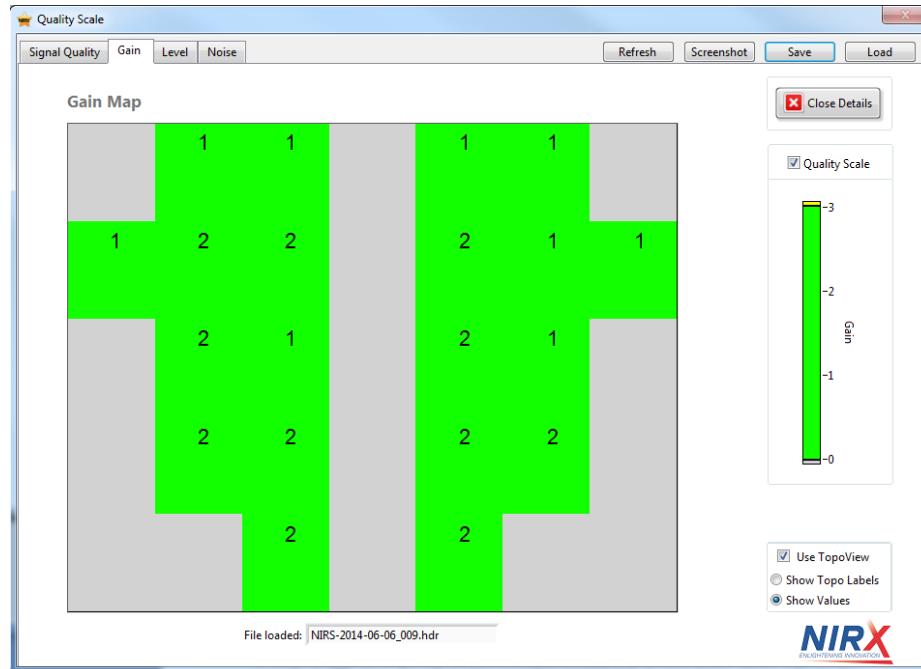


Figure 66. Quality Scale: Gain Map for NIRSport devices.

## 16.1.2 Setup Screen

### Gain Display

The main technical difference between NIRSport devices as compared to the NIRScout product family is the replacement of optical sensor fibers with active detection circuitry. As a result, the number of available gain-setting levels is reduced from eight to three. Accordingly, when connecting to a NIRSport device, NIRStar will change the range of the gain display in the Quality Scale screen (Figure 66) to show the permissible Gain levels of 0, 1 and 2. The old-style color scheme is modified to match that for Gain steps 4-6 of a NIRScout device, to which these roughly correspond.

### Battery Charge Indicator

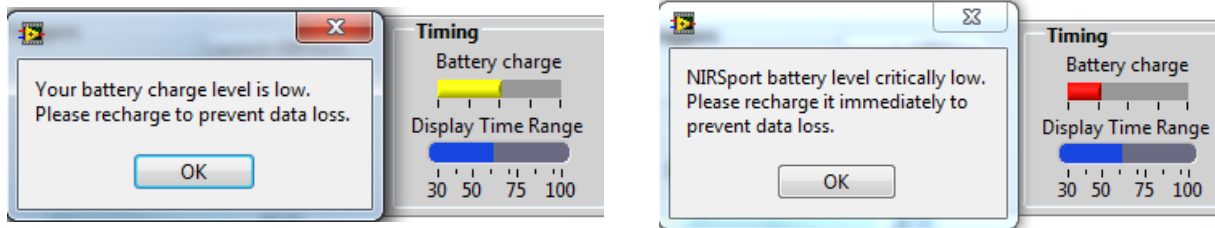
When connecting to a NIRSport device, a 'Battery Charge' indicator will appear in the Timing area of the user interface. The indicator will probe and update the battery's charge level every 10 seconds, in 25%-steps. If the battery charge reaches any level  $\leq 50\%$ , an alert message pops up for the user (Figure 67).

This alert is only intended to warn the user that the battery level is low and therefore it may not suffice to run a complete measurement. Nevertheless, all functionalities of NIRStar will remain enabled.



The battery charge indicator will show accurate readings only while the power / charging supply is NOT connected to the NIRSport.

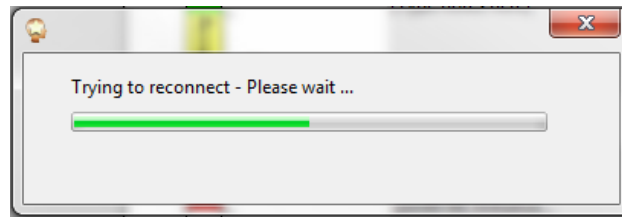
The indicator will not update during the acquisition of data.



**Figure 67. Low levels of battery charge and alert messages. Left: Level  $\leq$  50%; Right: Level  $\leq$  25%.**

In previous versions of NIRStar (up to 15-0), there were cases of error that will mislead to an indicator of low battery level. This has been fixed in NIRStar15-1, and the battery indicator is more robust to these.

Also, in case NIRStar is launched just after connecting the NIRSport to the acquisition computer, NIRStar will attempt to reconnect to the device (instead of issuing an low battery level alert), as shown below:

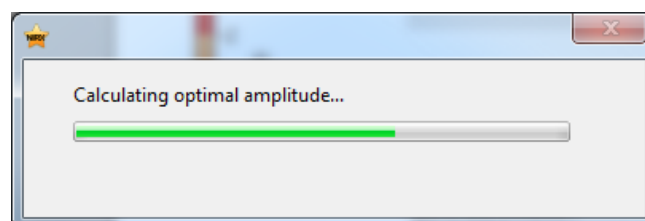


### 16.1.3 Dynamic Range Consideration: Detector Gain and Source Amplitude

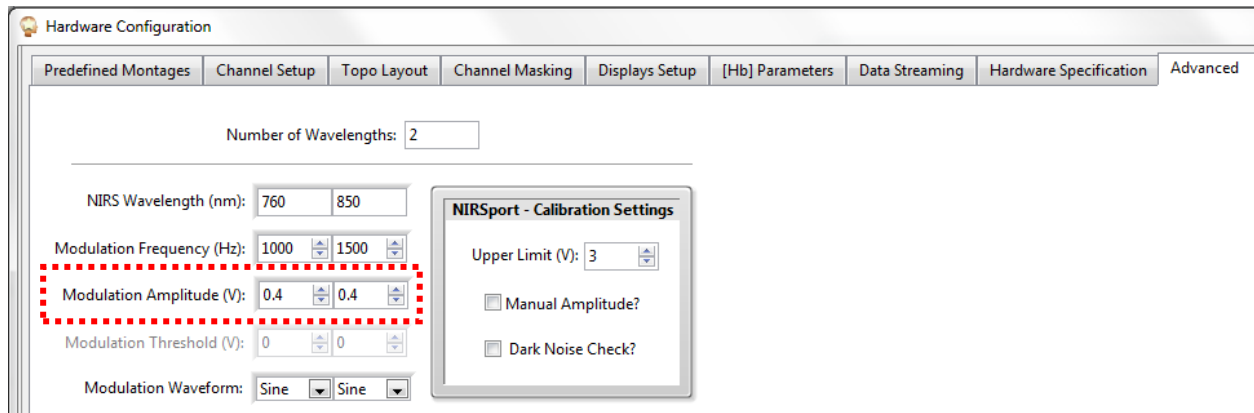
In addition to the detector gain switching mechanism, by which NIRSport achieves a dynamic measuring range of approximately  $1:10^5$ , a new LED intensity adjustment was implemented to prevent situations of detector saturation.

Depending on the chosen target site, probe configurations, or subject populations one may encounter situations in which a rather strong light transmission could cause detector saturation, which, if not accounted for, can lead to signal distortion or loss. Examples are prefrontal measurements, layouts utilizing short source-detector distances ( $< 2.5$  cm), or measurements on children. To avoid potential detector saturation, prior to the gain setting procedure, NIRStar will automatically perform an LED intensity optimization. The procedure consists of illuminating the target at the lowest LED intensity and evaluating the signals received at the lowest gain settings. The LED intensity is then incrementally increased until a satisfactory signal level is obtained, or the highest permissible LED current is reached. The LED adjustment covers an illumination intensity range of 1:100.

During this procedure, a waiting bar informs the user of the progress.



After the calibration is finished the LED adjustment result may be viewed in the 'Hardware Configuration → Advanced' display. The LED intensity level is specified in the field 'Modulation Amplitude' in units of the control voltage, with 0.4V (or 0.7V, depending the limit of your NIRSport unit) being the maximum.



**Figure 68. Display of the modulation amplitude of the LED sources.**



Please note that the 'Advanced' view is password-protected. You will be able to view the values but will not be able to make any adjustments.



The LED intensity adjustment is ONLY available for NIRSport devices. NIRScout(X) systems have an extended gain range ( $< 1:10^8$ ), which allows the detection of very high light intensity levels and therefore does not require any LED adjustment. Administrators with password access can use the option 'Manual Amplitude' to override the automatically established value with a custom setting.

### Example

Figure 69 shows the case where very bright and very dim light intensities are to be anticipated. Shown is the example of a NIRSport Tandem setup for simultaneous measurements on strongly (prefrontal) and weakly (motor) transmitting areas of the head. In this particular case, one device (Primary) was imaging the prefrontal area, and the second (Secondary) device was imaging the motor region. We illustrate the general case of a Tandem measurement; the illustration translates accordingly to the special case of a single NIRSport device. Further details about Tandem Operation mode may be found in section 16.2.

Figure 70 shows the resulting gain setup. For both the prefrontal and the motor cortex, valid gain values are reached, and no signal saturation is observed. In this example, the LED amplitude of the NIRSport imaging the prefrontal area was set to 0.018 V for optimal, non-saturated readings while the more absorbing motor region required the full intensity setting.



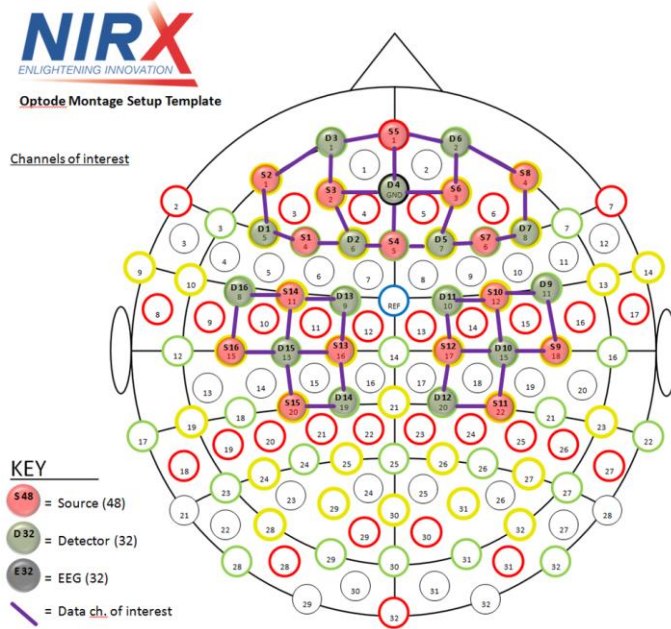


Figure 69. Example of simultaneous prefrontal and motor measurement for NIRSport Tandem

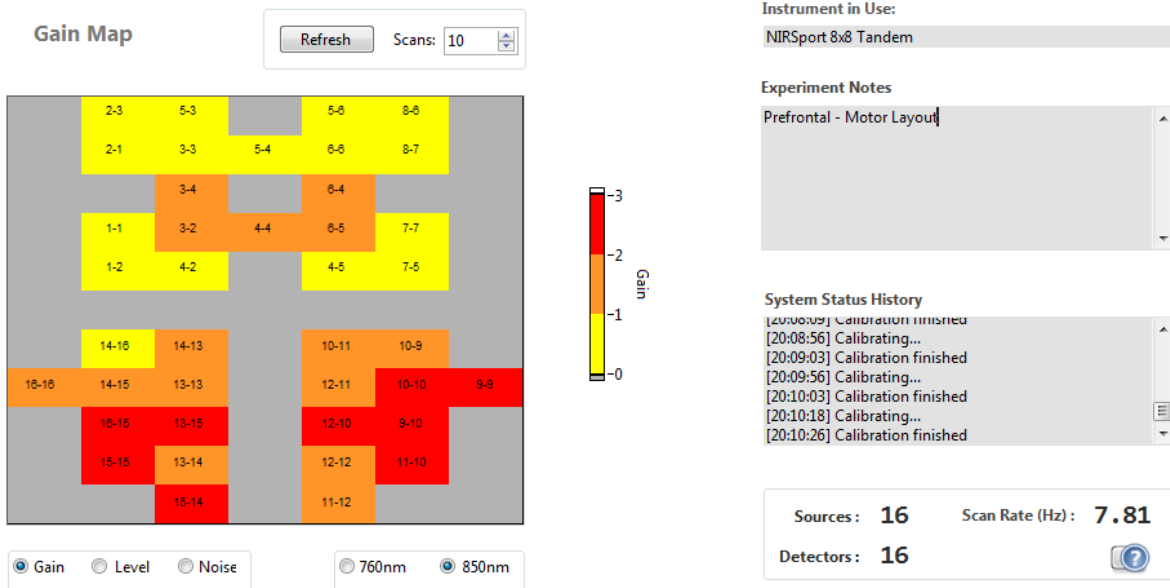


Figure 70. Gain setup for the layout example above (screenshot from an earlier version of NIRStar).

In Tandem mode, each NIRSport is set to the optimal illumination strength individually.

### Saturation Flagging

NIRStar presents conservative algorithms to avoid saturation by calculating the optimal LED amplitude as well as the amplification gains during the calibration process. This also takes into account the power spectrum, as saturated data yield other components than those of modulation frequencies.

Additionally, we have also incorporated a real-time data flagging to saturated data points during an experiment. The flagging is based on marking the clipped data with 'NaN' values. In Data Visualization screen, a color-coded LED will advise on whether the detector saturation is currently occurring (red), was detected in the past (yellow) or has not been detected (green). As depicted in Figure 71, this is presented along with further details on the saturation occurrences, i.e. a counter of number of frames and another for number of channels affected during the measurement. These indicators should assist the user on the subjective assessment of eventually stopping the experiment to improve the setup.

For the offline analysis, saturated channel(s) can be excluded from the analysis on both nirsLABv201704 and Homer2. For the latter, the exported data into Homer2 format (section 6.3) will automatically have any channels containing 'NaN' values in its data pruned as 'bad'. Nevertheless, if the user would like to retrieve the original data (i.e. without 'NaN' values), it is now also possible, as described in section 13.5.

Figure 71 illustrates saturation frames that have been artificially created by pressing the optodes against the scalp, thus resulting on spontaneous increased light detected (peaks on data), leading to saturation.

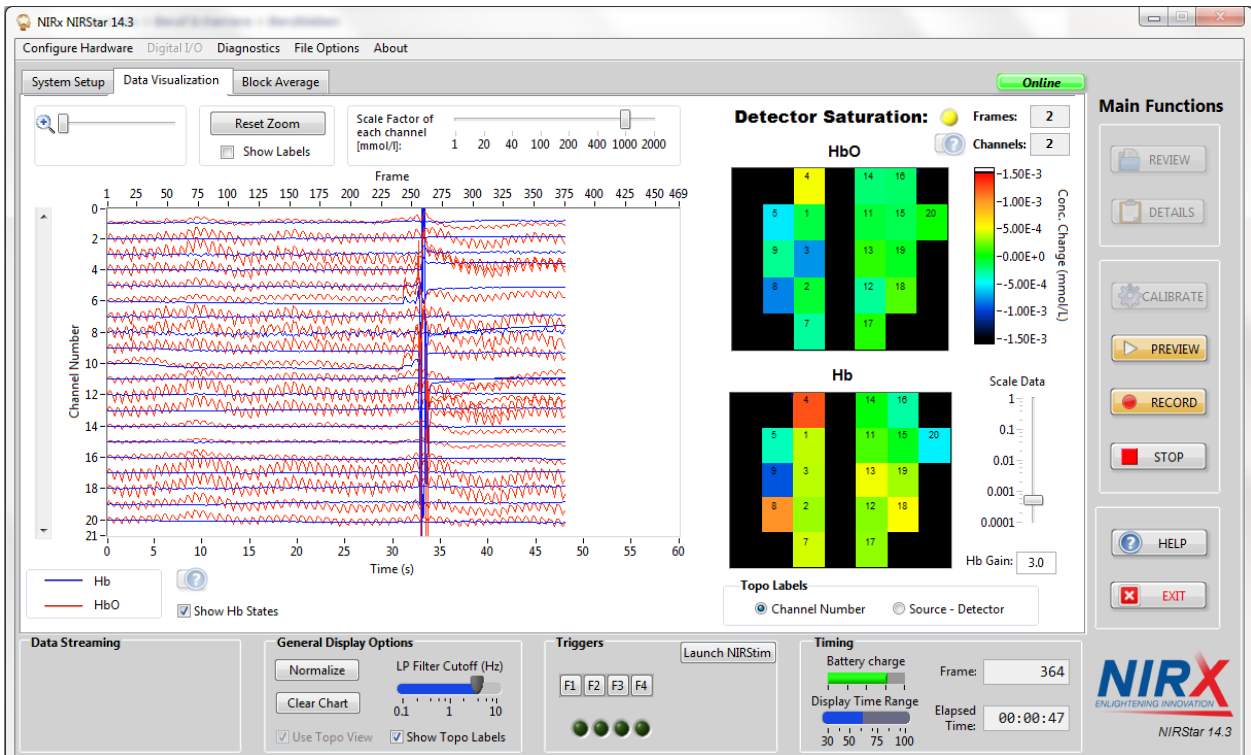


Figure 71. Example of saturation alert display along with number of frames and masked channels affected.

### 16.1.4 Diagnostics/Dark Noise Test

For NIRSport devices, the dark-noise test window shows a scale with Gains 0-2, according to the specifics of the detection hardware (Figure 72). For expected noise levels, please refer to the hardware manual.

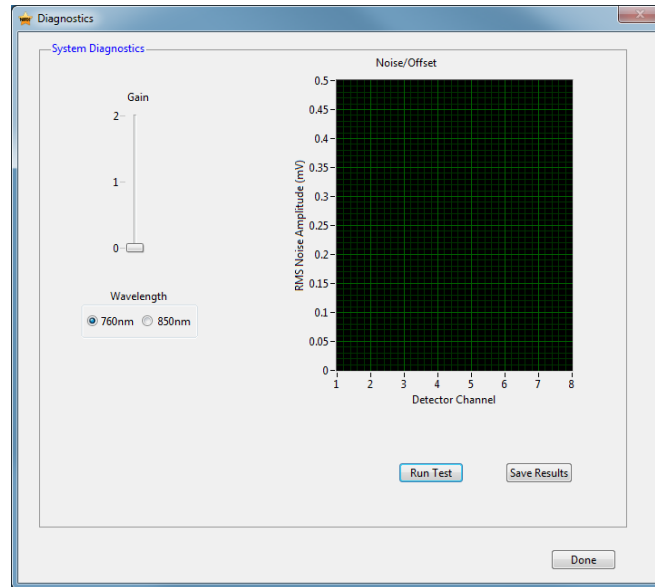


Figure 72. Diagnostics/dark noise test dialog for NIRSport device.

### 16.1.5 Channel Setup

Due to NIRSport hardware restrictions, the illumination pattern is disabled and grayed out (Figure 73). The user can change the number of sources and detectors to be used, but not the illumination order. The number-of-steps control is also disabled and grayed out, because it will automatically follow the chosen number of sources.

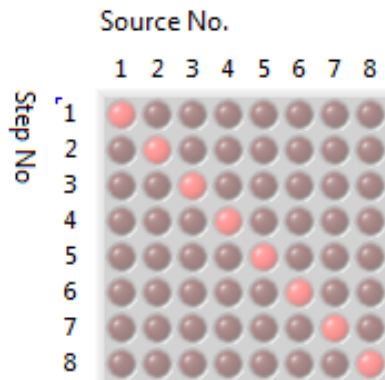


Figure 73. Illumination Pattern is disabled and grayed out for NIRSport device.

## 16.2 Tandem Operation

When two identical NIRx NIRS imager models are connected to the control PC, NIRStar offers the option of operating both instruments in Tandem Mode, *i.e.*, as one imaging system with twice the channel capacity of either unit by itself.

The screenshot shows a software dialog box for hardware configuration. At the top, there are two dropdown menus: 'Study Type' set to 'Human Subject' and 'Operating Mode' set to 'Tandem Mode'. Below these is a red-bordered box containing the text: 'The following settings should be adjusted if the device is new or the hardware configuration changed:'. Underneath this box are two spinners: 'Available sources' set to 32 and 'Available detector cards' set to 12. Below the spinners are two checkboxes, both of which are unchecked: 'APD detector card(s) available?' and 'Short-distance measures?'. A help icon (a question mark inside a blue circle) is located in the bottom right corner of the dialog box.

**Figure 74. Specification of Tandem Mode in the Hardware Configuration dialog**

To activate tandem operation, specify 'Tandem Mode' in the *Operating Mode* drop-down menu of the *Hardware Specification* tab of the *Hardware Configuration* interface (Figure 74).

For NIRScout family imagers, make sure to select, in the *Hardware Specification* tab, the combined number of *Available detector cards* and *Available sources* of both instruments. For example, when using two NIRScout16×24 devices in Tandem mode, this should be 12 detector cards and 32 source channels.



Tandem operation is possible only for two IDENTICAL instrument models, *i.e.*, both imagers must be of the same type (NIRScout, NIRScoutX, or NIRSport) AND have the same numbers of available sources and detectors.

### 16.2.1 Primary and Secondary Concept

The software will automatically designate one instrument 'Primary' and the other 'Secondary'. The assignment of Primary and Secondary is relevant for the channel numbering and the connection of event-trigger cables. Whenever a new NIRS instrument is connected to the control computer, the NIRStar instrument drivers will automatically assign it an internal device number that will be permanently retained for this particular instrument. This number will be preserved even after dis- and reconnecting the instrument, and is independent of on/off powering cycles of the instrument or the computer. The device numbers will also be preserved when upgrading to a newer version of NIRStar. Device number assignments will be lost only when the NIRStar software, with all components including device drivers, is completely uninstalled.



#### LEGACY NOTE

NIRStar14-2 and earlier versions presented a different terminology to refer to the devices connected in Tandem Mode, namely “Master” and “Slave”. This has been updated, in NIRStar15-0, for “Primary” and “Secondary” to be in agreement with commonly accepted industry terminology.

The instrument that is connected to the control computer first during the initial setup of the tandem mode will be designated the ‘Primary’ instrument. After the initial connection of the imagers to the PC this assignment will be permanent, and any future order in which the USB connection is established will be irrelevant.

If a single device has been used and is upgraded to a tandem configuration by adding a second instrument, the original instrument will always assume the role of the Primary.

Both instruments are controlled by NIRStar, so no direct connection between the devices is required.



Cross-talk between devices must be avoided by all means because sources from one device can cause signal distortion in the other device’s detector channels.

Measurements are possible only between sources and detectors of the same (*i.e.*, Primary or Secondary) device.

Trigger inputs are active only on the Primary device.

To enforce a specific Primary/Secondary assignment, make sure to connect the ‘Primary’ device first and wait until USB connection is established (green status LED blinking). Then connect the ‘Secondary’ instrument. *This will only work the first time on the two devices are connected to a particular computer or after a previous Primary/Secondary assignment is deleted.*

### 16.2.2 Channel Numbering Scheme

Sources and detectors are numbered consecutively, starting with the Primary device. For example, if two NIRScout16×24 devices are operated as one Tandem system, sources are numbered 1...32 (Primary: 1...16, Secondary: 17...32), and detectors are numbered 1...48 (Primary: 1...24, Secondary: 25...48). In Tandem Mode, the number of detectors used will always be equal to the number of detectors available; consequently, in the *Channel Setup* tabs the “number of detectors” setting is grayed out.

### 16.2.3 Channel Setup

In tandem mode, the *Hardware Configuration* GUI contains a pair of radio buttons, labeled *Primary* and *Secondary*, near the lower right corner of the interface (Figure 75).

In tandem operation, the illumination patterns need to be defined for both devices separately. Use the Primary/Secondary selector button to toggle between them.

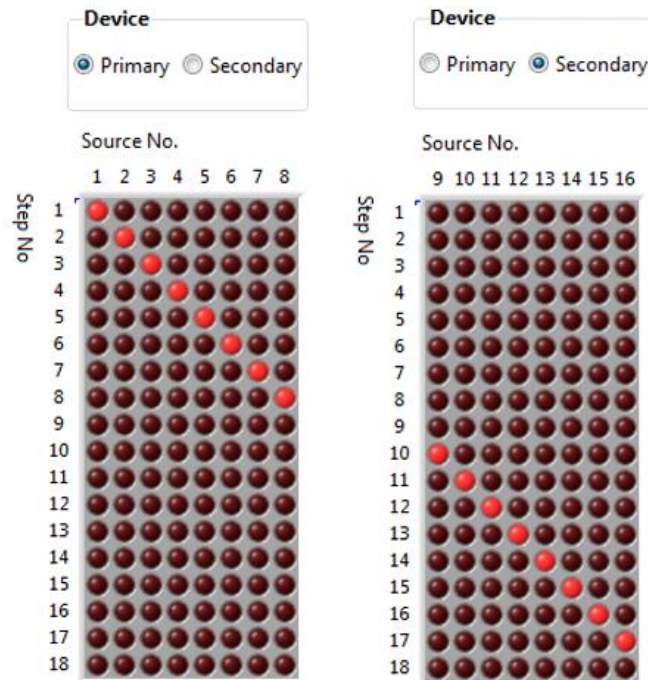


Figure 75. Example of Primary device (left) and Secondary device (right).

Within each device’s illumination pattern, further parallel source illumination may be implemented, *i.e.* single-device parallel illumination (see Section 5.3) within tandem illumination. Please note that the number of illumination steps is always identical for the Primary and Secondary. Please also note that, for NIRSport tandem, the illumination pattern will be disabled and greyed out.



**LEGACY NOTE**

NIRStar14-2 and earlier versions had a parallel illumination pattern for Tandem mode. This has been changed starting on NIRStar15-0 to avoid cross-talk between devices. Now, once Tandem Mode is selected, the standard illumination pattern is selected by default. Also, there are two dead steps (between devices) included.

**16.2.4 Channel Masking**

Two separate channel masks are defined, one per device. Similar to the *Channel Setup*, use the Primary/Secondary selector radio button to toggle between the *Channel Masking* corresponding to each device.

## 17 Advanced Displays Capabilities

NIRStar provides advanced real-time display features including topographic rendering (built-in and NIRSPay) and event-related block averaging. These features are available under the *Displays Setup* tab in *Hardware Configuration* (Figure 76).



### LEGACY NOTE

NIRStar 13 versions required the installation of a MATLAB licenses on the acquisition PC in order to use the built-in rendering capabilities. Starting with version 14 this is no longer necessary; the required MATLAB functions are now incorporated in a standalone-distribution.

### 17.1 Built-in Topographic Display

This function provides rendering of the topographic hemoglobin data onto realistic coordinate spaces in 2D or 3D (Figure 77). This functionality is implemented in a separate module distributed with NIRStar, and requires separate installation (see section 3).

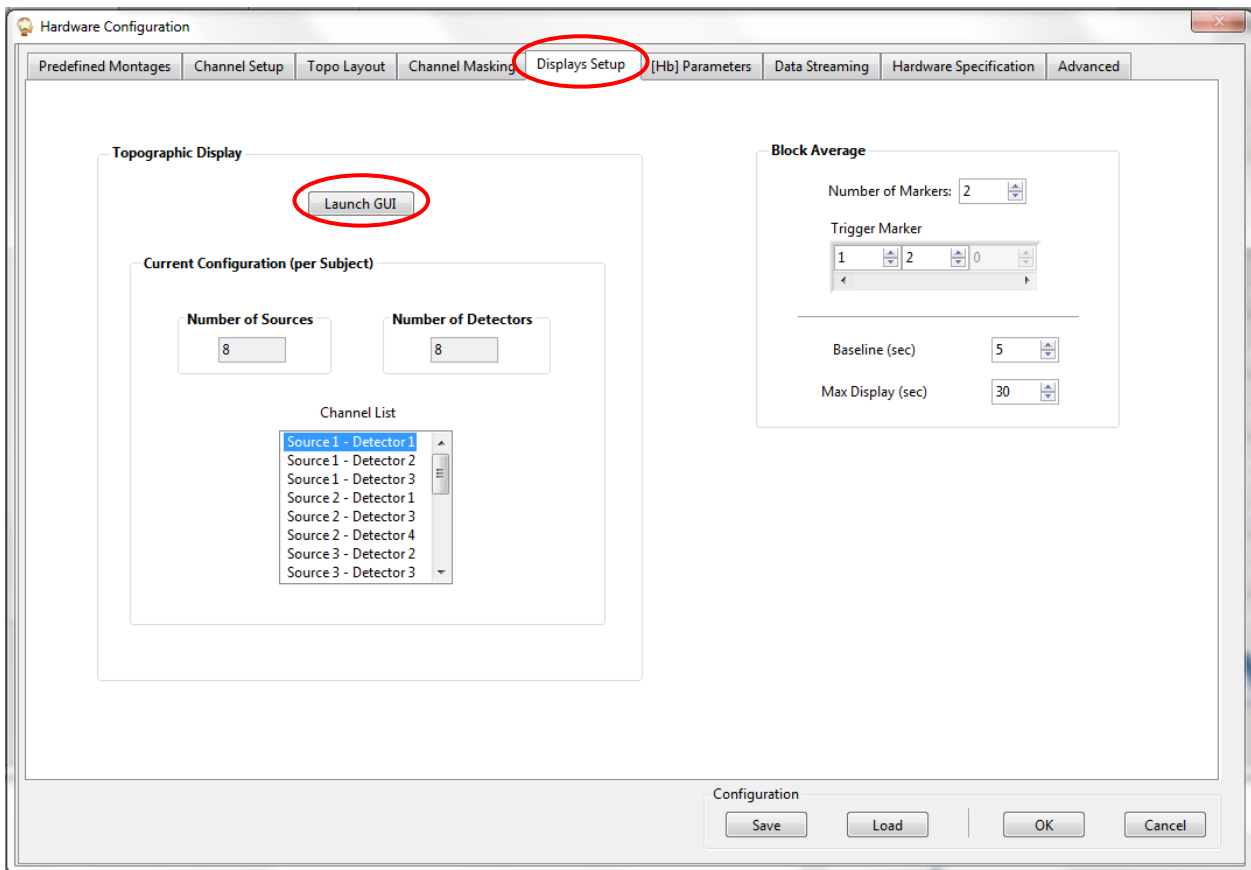
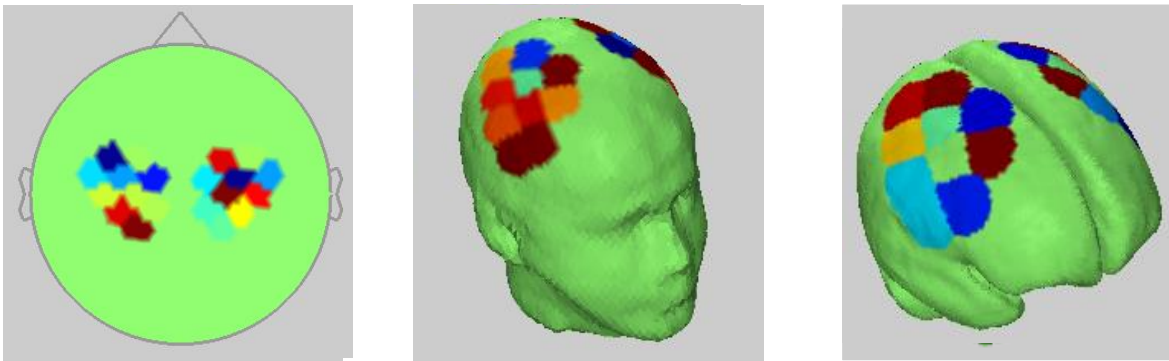


Figure 76. Hardware Configuration → Displays Setup





**Figure 77. Examples of rendered topographic displays, left to right: 2D, 3D, Cortex**

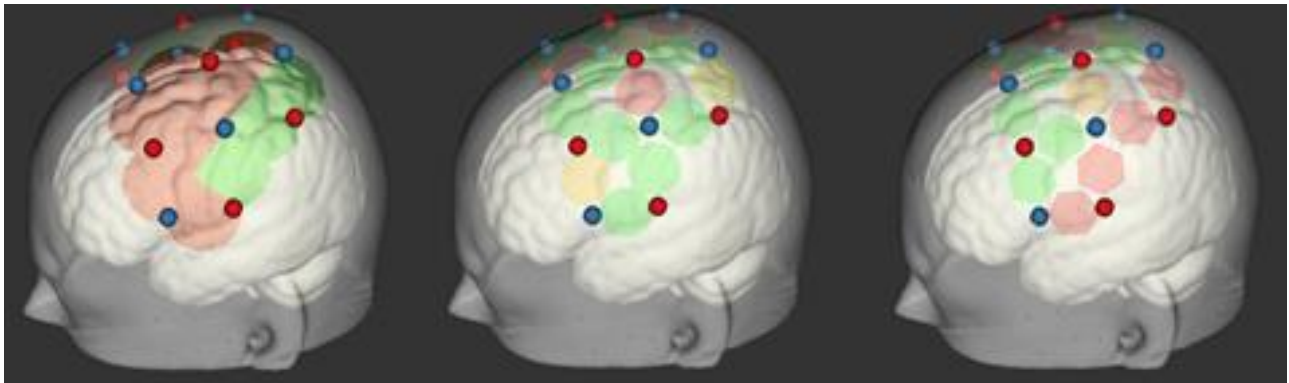
In order to use topographic rendering, click on 'Launch GUI' in the 'Displays Setup' tab of the hardware configuration and follow the steps further outlined below (section 18.2).

Please note that the built-in topographic display is only compatible with probeInfo files from nirsLAB.

### 17.2 NIRSPay Topographic Display

The NIRSPay topographic display is distributed as a separate standalone package and was completely integrated with NIRStar starting in version 15-1.

It can be automatically launched during NIRStar initialization. Please refer to sections 5.7.2 and 19 for further details on the setup and the underlying functionalities.



**Figure 78. Visualization options for NIRSPay rendering: patches (left), discs (middle) and hexagons (right).**

Please note that NIRSPay is only compatible with probeInfo files created from within NIRSite.

### 17.3 Block Average

The Block Average feature allows users to generate topographic displays, in real time, of event-related data averaged across event epochs, for multiple conditions (Figure 79).



**Block Average**

Number of Markers: 5

Trigger Marker

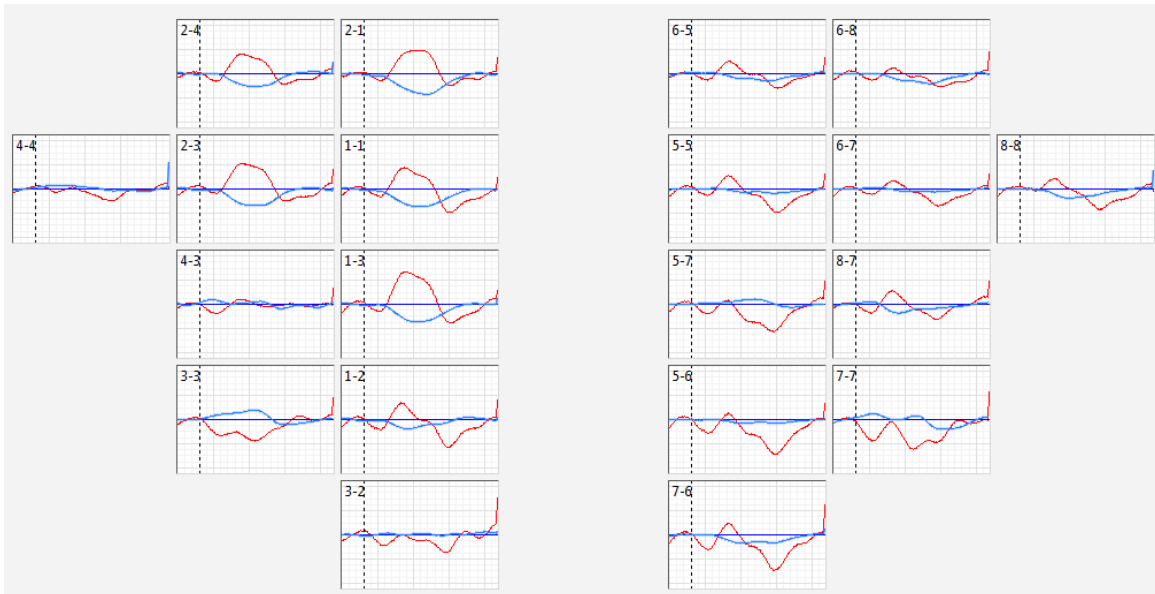
2 3 4

---

Baseline (sec) 5

Max Display (sec) 30

**Figure 80. Hardware Configuration → Displays Setup → Block Average**



**Figure 79. Example of a Block Average display .**

### 17.3.1 Preparing the Block Average Display

In order to generate a real-time Block average, the user needs to specify some parameters *prior* to starting the recording in the *Block Average* module of the *Displays Setup* user interface of the *Configure Hardware* menu (see Figure 80).

**Number of Markers:** Specify the number of conditions which you would like to differentiate in the plots. For each condition, a unique event trigger marker is expected to be received by NIRStar.

**Trigger Marker:** Specify the event marker code associated with each condition (1-15 for NIRScout or NIRsport, 1-255 for NIRScoutX). Block averaging is performed only if at least one of the fields is assigned a non-zero value.

**Baseline (sec):** Event-related averages are computed relative to a pre-stimulus baseline period, which may have a user-specified duration between 3 and 10 seconds. These data are entered as positive integer values. Data are averaged over the specified baseline period, and the resulting average value is subtracted from every frame of the corresponding block to mitigate effects of drift.

**Max Display (sec):** This parameter determines the maximum time (right-hand boundary on the time axis) of the event-related average plots. The “0 seconds” point in these plots is the time when the trigger was received or manually set.

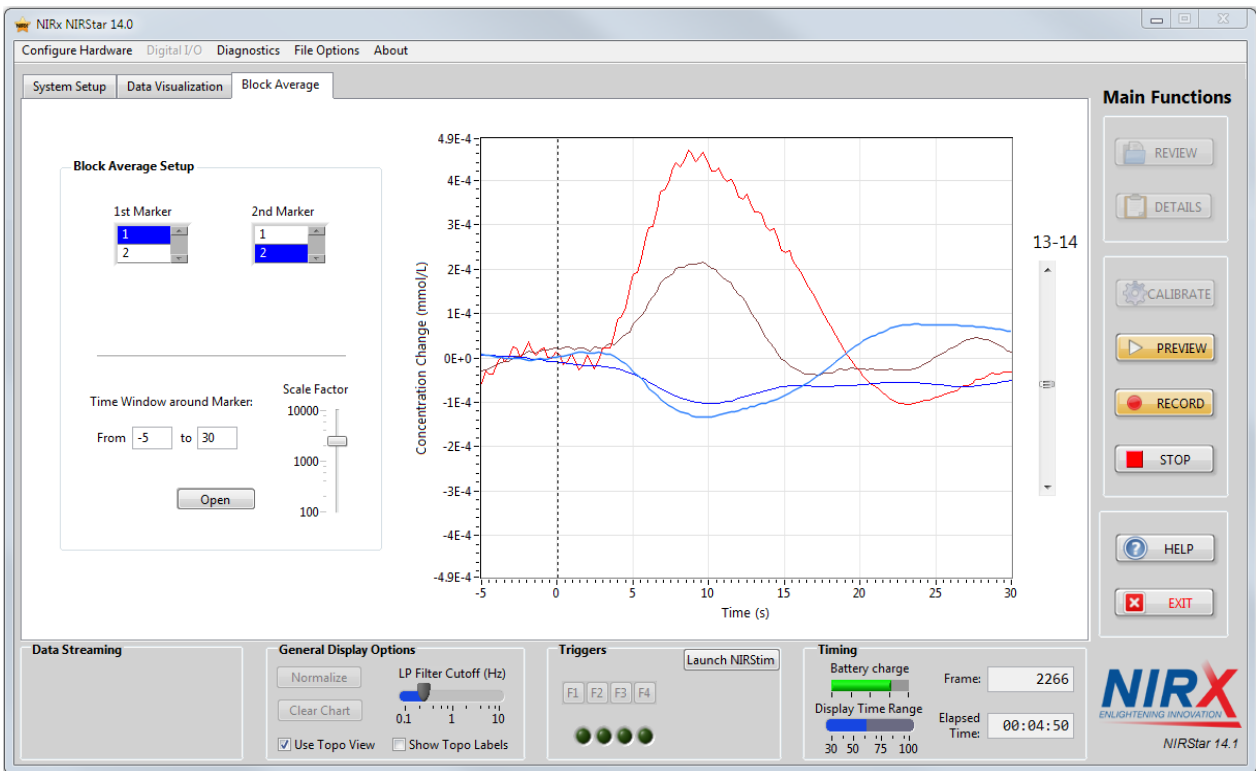


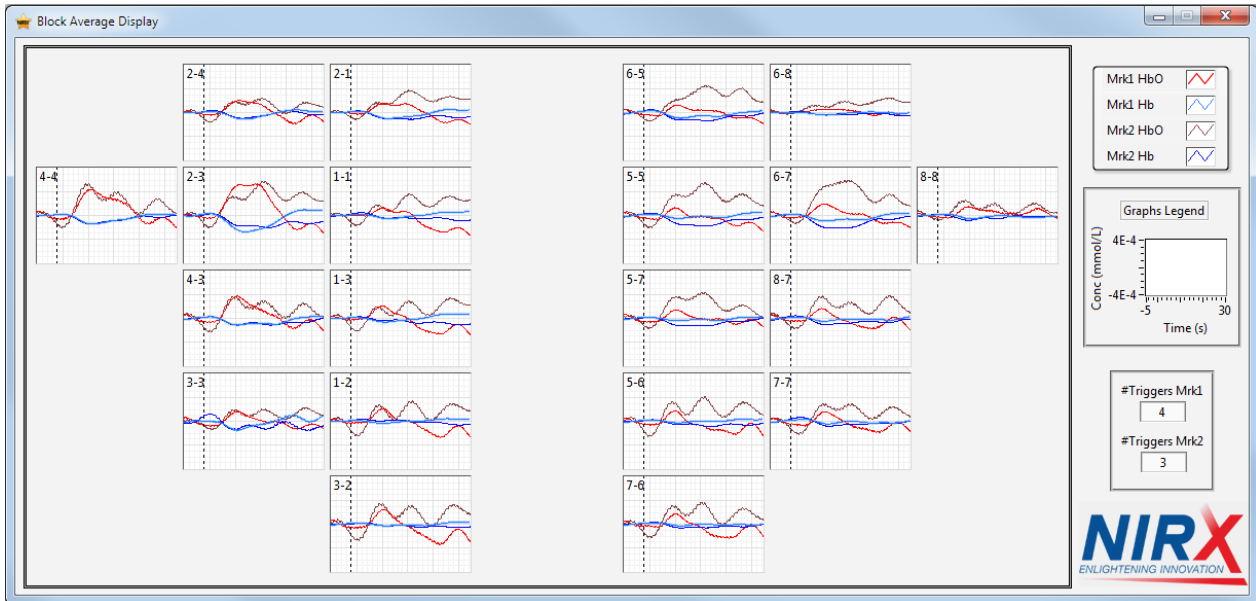
Figure 81. Block Average control.

### 17.3.2 Displaying Real-Time Block Average Plots

The Block Average plot is activated and controlled in the ‘Block Average’ tab of the NIRStar main screen (Figure 81), under ‘Block Average Setup’. The ‘Block Average’ tab also contains an enlarged plot of one channel, which may be selected with the vertical scroll bar to the right of the plot.

All display control functions in this tab are applied to the block average displays ‘on the fly’.

**1<sup>st</sup> Marker, 2<sup>nd</sup> Marker:** Up to two conditions of any two marker values may be plotted at the same time. Condition one (‘1<sup>st</sup> Marker’) is identified by light red and blue; condition 2 (‘2<sup>nd</sup> Marker’) by deep red and blue (for HbO and Hb changes, respectively).



**Figure 82. Block Average Display in action**

**Time Window around Marker:** Specifies the time axis range for the event-related plots in units of seconds. The occurrence of the trigger marks time  $t = 0$ . By default, the time scale displayed covers the entire available range set up in the Hardware Configuration (Figure 80). A smaller range may be specified, with a minimum duration of 0-5 seconds.

**Scale Factor:** Allows vertical scaling of the Block Average plots. All channels in the Block Average are scaled to the same y-axis.

**Open:** If at least one marker has been set to a non-zero value, the *Open* button is enabled as soon as the user clicks on *Preview* or *Scan*. Clicking this button will launch a separate *Block Average Display* window (Figure 82). The display is updated in real time when:



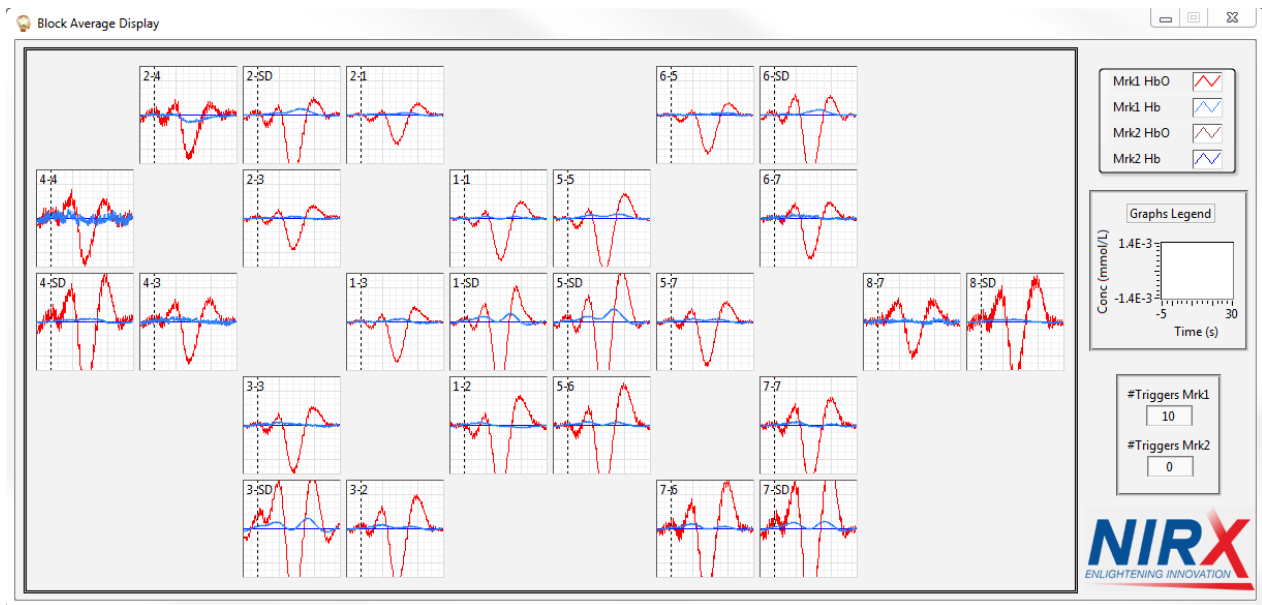
Please note that block-averaged data for a given marker will be displayed only after the period of time entered on the "Max Display" field (Configure Hardware) following the trigger has been reached. Until then, the window shows blank plots.

- i) The scale factor is changed;
- ii) The time window around the trigger is changed;
- iii) A new trigger corresponding to a selected marker is received.
- iv) One of the Marker values is changed in the Block Average Setup.

### 17.3.3 Block Average Display

Figure 82 depicts the *Block Average Display* window during a typical motor-task experiment configuration with 8 sources and 8 detectors, using two conditions. The display resembles the channels defined in the *Topo Layout* tab of the *Hardware Configuration* user interface as shown in the previous example in Figure 19. The block-average graph for each channel is in the same position as the cell for the corresponding channel in the *Topo Layout* matrix.

Please note that the numbers of rows and columns in *Topo Layout* determine the size of each graph in the Block Average Display. Therefore, we advise you not to insert any blank rows/columns.

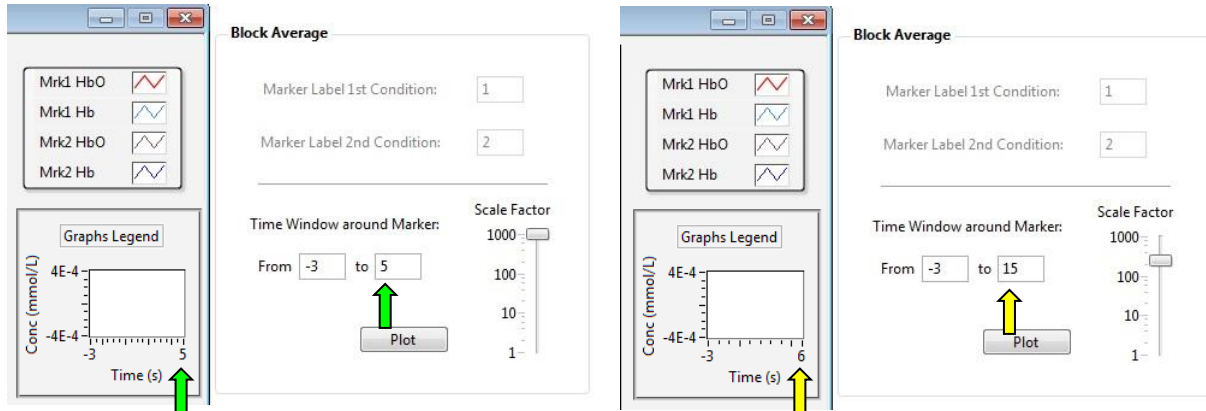


**Figure 83. Block Average Display with short-distance channels**

The label in each graph gives the source- and detector-optode numbers for the corresponding channel. For example, 5-7 displays block-averaged data for the channel defined by Source 5 and Detector 7.

If short-distance channels are enabled (section 5.1) and available in the *Topo Layout*, the corresponding detectors will be displayed with the label 'SD' to facilitate its identification on the block average display. Figure 83 shows an example of block average with 8 short-distance channels illustrating the activation following a respiration maneuver.

After block-averaged data are plotted in the display window (*i.e.*, at least two triggers for the same marker have been received), the trigger position with respect to the data is marked in every graph with a vertical dashed line at  $t = 0$ .



**Figure 84. Plot Legends and user-defined values**

### Traces colors

Consistent with other NIRStar displays available, the HbO traces are displayed in red and Hb in blue. If two markers are being displayed, the traces corresponding to the second marker will be distinguished from those for the first by being displayed in deep red (maroon) and deep blue.

### Graphs Legend

In 'Graphs Legend', the time scale and the resulting concentration change (mmol/L), after applying the scale factor selected in the *Advanced Displays* window, are shown. The scales correspond to the initial and final values depicted in each graph. For instance, in Figure 82, the displayed data are limited from -5s to 30 s. Figure 84 depicts the correspondence between the period actually displayed (Graphs Legend) and the period entered by the user ('Time Window around Marker'). On the left, the green arrows indicates the agreement between the user-specified and displayed period. The right side shows the case where the actual time between consecutive triggers (6s) is less than the specified width of the time scale (5 s); in this case, the scale will be adjusted to the smaller value.



Please note that the number of triggers for each marker displayed in the bottom-right corner of the window may be one less than the number of triggers received if the "Max Display" period following the last trigger has not been reached yet.



If the time interval between two consecutive triggers for the same marker is less than the user-defined upper limit for the display time period, then the upper limit will automatically be adjusted downward to the lower value (see Figure 84).

### Low-Pass Filter

The 'General Display Options' module in the primary user interface (see Figure 85) will affect the real-time average display. For example, the block averages will be affected by the setting of the low-pass filter; in the example above (Figure 82) the filter was set to 0.2 Hz cut-off, and the display show very minimal cardiac signatures.



Figure 85. General Display Options (present at bottom of NIRStar primary user interface)



Please note that if the cutoff frequency for the low-pass filter is changed during the course of a scan, it will be applied only to subsequently recorded data and not to the data already recorded. In order to restart the block averaging process, click on the *Normalize* button.

### Masking of Noisy Channels

Channel masking affects the block-average display and may be used to deactivate noisy channels.

After a calibration is performed, one may infer from the Gain, Level and SNR values that some channels are noisy and may, therefore, want to exclude them from real-time visualization. In order to do so, please de-select the undesired channels in *Channel Masking*, as indicated in the example shown in Figure 86. Afterward, flat lines will be plotted in the corresponding graphs of the Block Average Display window (Figure 87).

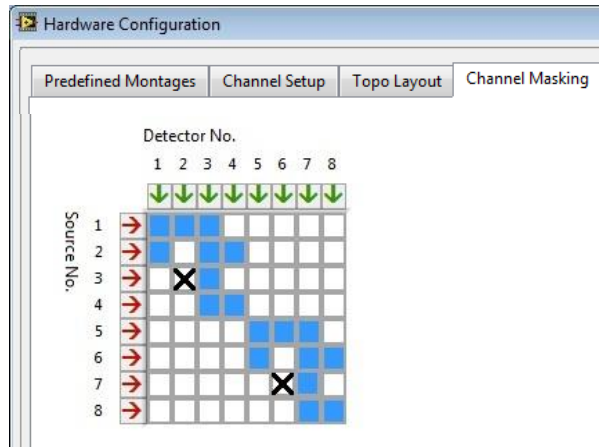


Figure 86. Deselecting two channels (3-2 and 7-6) in *Hardware Configuration*

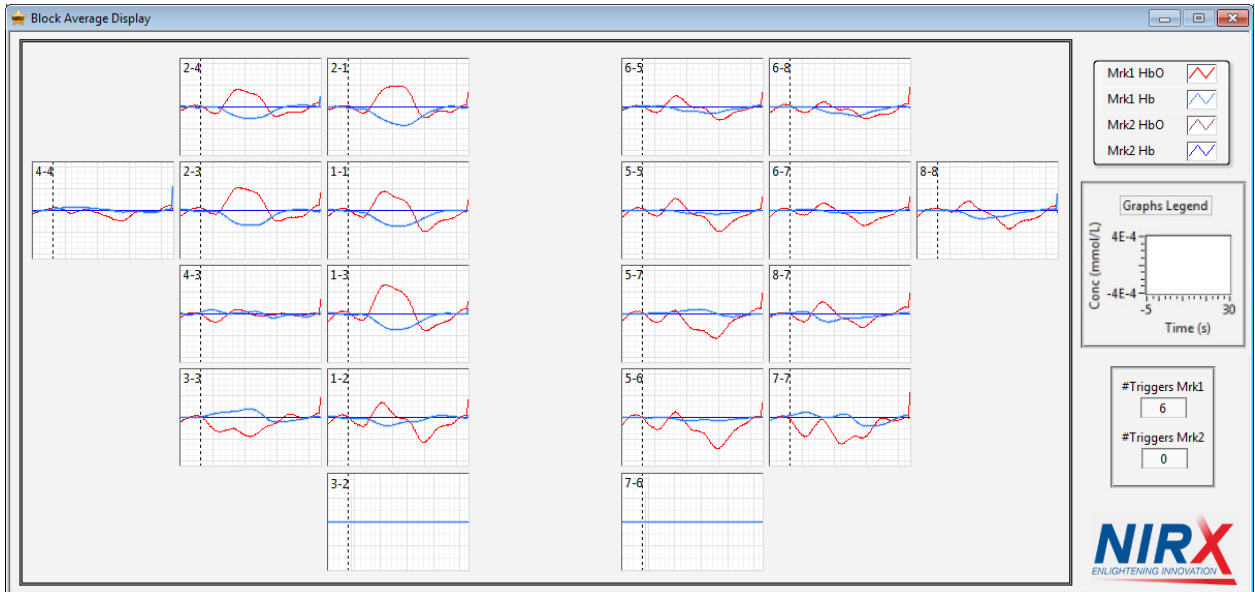


Figure 87. Corresponding Block Average Display: the disabled channels are displayed as zero

## 18 Built-In Topographic Rendering

Starting with NIRStar 14.0 the built-in topographic rendering functions no longer require the presence of a MATLAB license on the same computer. Topographic rendering is now a stand-alone module which is freely distributed with the NIRStar installer.

### 18.1 Installation

The installation package of NIRStar already contains the Matlab Compiler Runtime that is needed to run the Topographic Rendering. With that said, separate packages are no longer required to be installed.

Nevertheless, it is important to install NIRStar on its default directory (suggested during the installation process). Otherwise, the following error message will be displayed to the user.

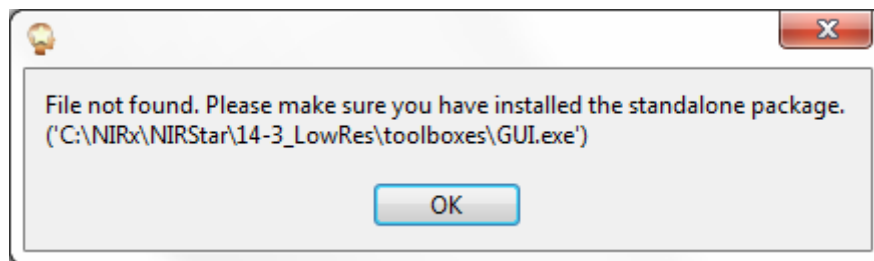


Figure 88. Error message example if Topographic Rendering capability is not installed



Please make sure to install NIRStar in its default location. In case of the need for specific, non-default file locations please consult with NIRx Support.

### 18.2 Use of Topographic Rendering Displays

To use Topographic Rendering please go to the *Display Setup* tab in the *Hardware Configuration* dialog. Clicking the 'Launch GUI' button will bring up a new dialog box 'GUI' (Figure 89).



Please note that it is also possible to use the Topographic Rendering and quickly generate its displays directly from the *Predefined Montages* tab (see section 5.2). In this chapter, we intend to demonstrate how it can be done for montages that have not been defined yet.

#### Run Probe Setup

The rendered displays require information about the physical arrangement of the measuring array relative to the head anatomy. This information is provided by the 'Probe Setup' utility which is launched by clicking on the 'Run Probe Setup' button. Probe Setup allows to create, edit, save and load maps of sources, detectors, and channels relative to anatomical landmarks in a head model. Most commonly,



these positions are defined relative to a standardized EEG coordinate system but other localization methods may be used. The positions are defined through simple point-and-click operations in a 2D or 3D virtual head model. Some examples are shown in Figure 90. A newly generated layout may be saved for later use in NIRx standard 'probeInfo' format (\*\_probeInfo.mat). If a pre-defined layout is available it only needs to be loaded for use. A library of standard cap configurations (source- detector arrangements) for a host of applications together with the appropriate probeInfo files are available from NIRx.

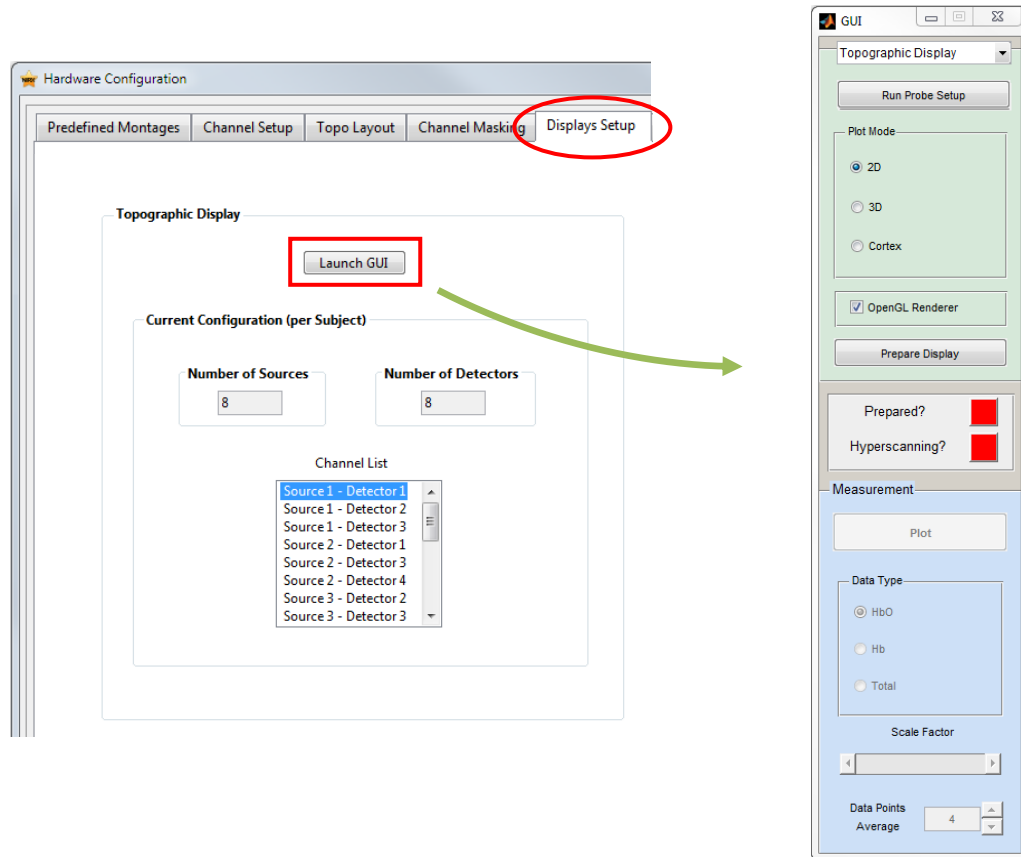


Figure 89. Launching the 'GUI' control box.

The Probe Setup utility is also part of the NIRS analysis software nirsLAB which requires the ProbeInfo files for topographic rendering of the fNIRS analysis results. ProbeInfo files generated by NIRStar may be used within nirsLAB, and *vice versa*.



For detailed information about the use of the '3D Probe Setup' tool, please refer to the separate nirsLAB User Manual.



Please note that the Probe Setup should be coherent to the configuration from NIRStar, i.e. the number of sources, the number of detectors and channels chosen should be the same. ("Current Configuration (per Subject)" under Displays Setup)

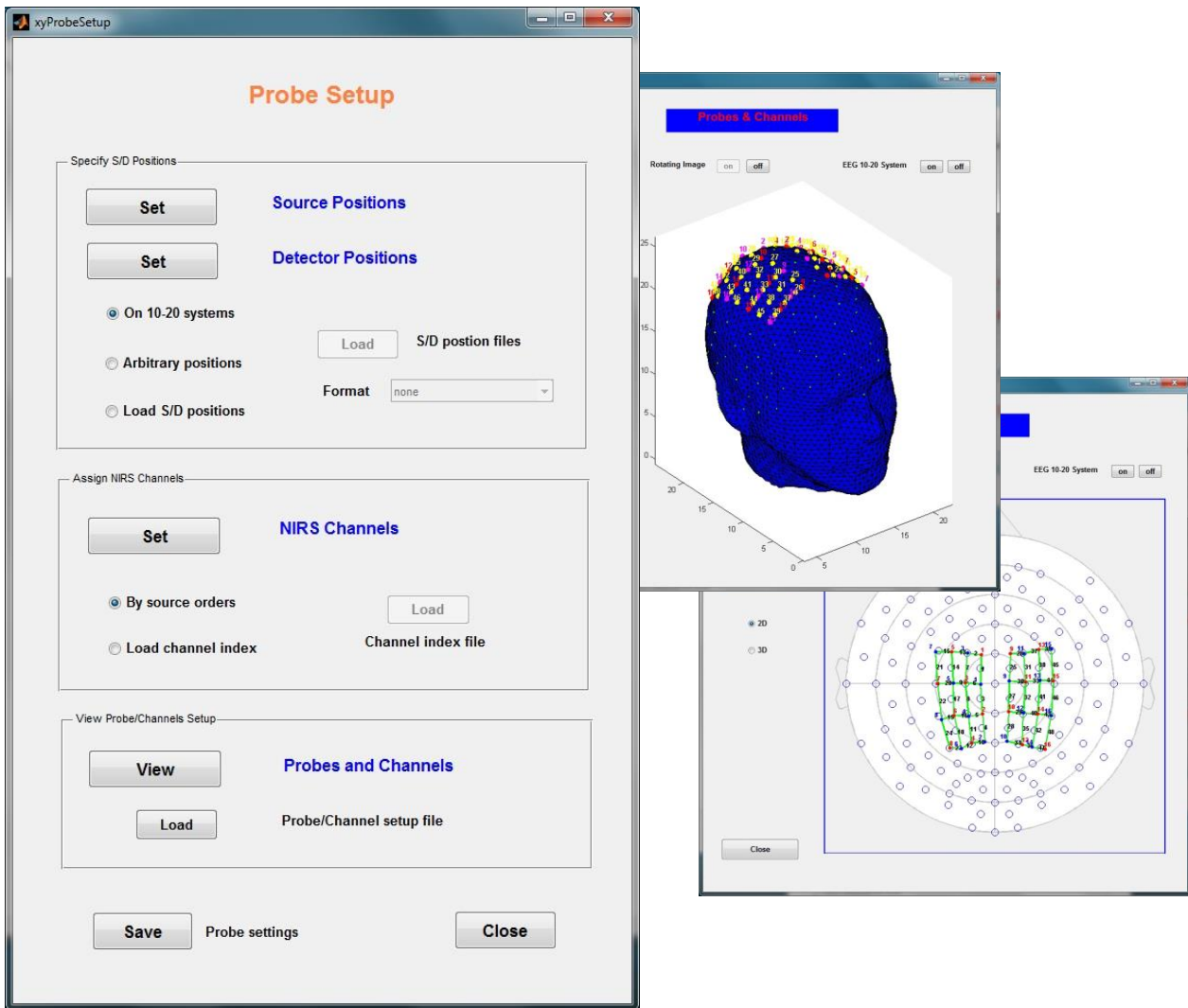


Figure 90. Probe Setup and sub-dialogs

## Plot Mode

After a ProbeInfo file has been loaded, use the Plot Mode area to select one of three available rendering views (for examples, please see Figure 77).

## Prepare Display

Clicking this button will bring up a topographic display window with a blank head plot of the selected mode (Figure 91). The 'Prepared' indicator will change from red to green. The Prepare Display function needs to be used every time after the Plot Mode is changed.

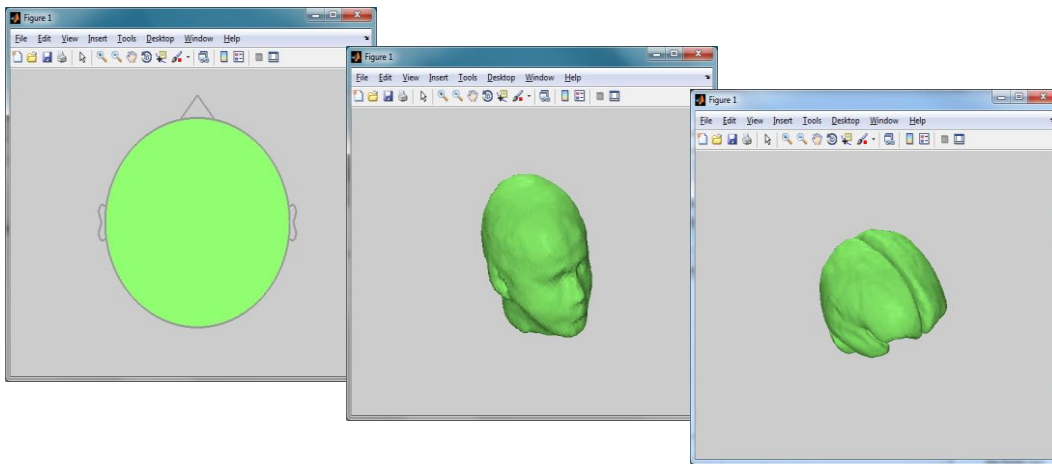


Figure 91. Possible Plot Modes: 2D, 3D and Cortex

### 18.2.1 Real-Time Display

Once all preparations have been made, the measurement can be started. During a scan (either *Preview* or *Record* mode), data are rendered in the selected mode.

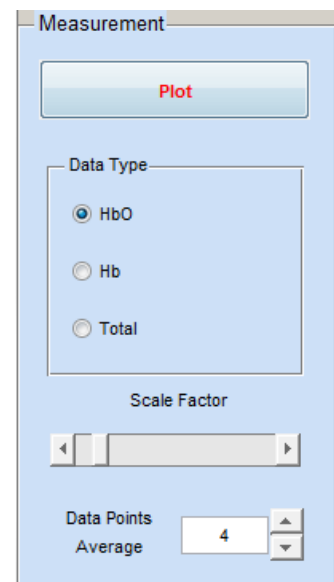
Several properties of the rendered display may be adjusted in real time in the GUI dialog:

#### Data Type:

Select the Hb-state to be shown in the display (HbO: Oxy-Hemoglobin; Hb: Deoxy-Hemoglobin; Total: Total Hemoglobin, i.e. the sum of Hb and HbO).

#### Scale Factor:

This slider may be used to adjust the amplitude scale of the topographic plot.



**Data Points Average:**

The time average (specified in data points) determines the number of scans that the software averages between successive display updates. The display rate for the advanced display will be reduced accordingly. You may use this feature to slow down the display rate to conserve computational power, or as means of reducing high-frequency signal components (heartbeat, noise).

**18.2.2 Quick Guide**

## Setting up a 2D/3D/Cortex-Plot

1. Make sure the standalone topographic rendering functionality is installed; run NIRStar
2. Call *Hardware Configuration* → *Displays Setup*; click on 'Launch GUI'; close Hardware Configuration.
3. In the 'GUI' dialog select *Run Probe Setup* → either define a new ProbeInfo file (and proceed to step 4), or load an existing ProbeInfo file (go to step 5).
4. After the channel positions have been defined, click on 'Save & Close' at the bottom of the 'Probe Setup' GUI and enter an appropriate file name (\*\_probeInfo.mat).
5. Close the 'Probe Setup' GUI and choose the desired plotting mode (2D, 3D or Cortex) in the *Plot Mode* module of the 'GUI' interface.
6. Click on the *Prepare Display* button. The 'Prepared?' indicator should change from red to green, and a plot window should open.
7. Keeping the plot window open, proceed with standard NIRStar gain setup to prepare for the measurement.
8. Start the scan (*Preview* or *Record*). The recorded data will be automatically displayed.
9. In the 'GUI' interface, click on 'Plot' to start the rendering display. You may adjust the display properties (type, scaling, averaging) as desired.
10. The plot display will stop at the end of the measurement.

### 18.2.3 FAQ

#### **The plots won't work as described!**

Please make sure that:

1. you have the standalone rendering program installed
2. the 'Prepared' indicator light is on (initially red color changes to green)
3. your measurement configuration (no. of sources, no. of detectors and channel masking) is correct and does not conflict with the advanced display settings
4. you have the most up-to-date driver for the graphics card in the computer running NIRStar

#### **I cannot see a plot, even after a successful preparation!**

Please check for background windows – NIRStar always runs in the foreground, while the rendering works in the background. Therefore, the plot window may have been there all along, but obstructed from your view by the NIRStar window.

#### **A black rectangle is shown on the plot!**

Please unselect the checkbox "OpenGL Renderer" available in the topographic rendering GUI and click on "Prepare Display" to create a new figure. This should be able to solve the issue.

#### **The Probe Setup does not pop up!**

Please check the background windows – NIRStar always runs in the foreground, while the rendering works in the background. Therefore, the probe setup window may have been there all along, but obstructed from your view by the NIRStar window.

#### **The 'Prepared?' indicator will not turn green!**

Please re-check your 'Probe Setup' preparations. Load a setup that was generated during an earlier session, or adjust the preferences.

When loading a file, make sure there is NO blank-space character in the file name or file path.

#### **There is no data in the plot during a scan!**

Please make sure you have clicked on "Plot" and try setting the *Scale Factor* to a higher level.

## 19 NIRSPplay Topographic Rendering

### NEW FEATURE

NIRStar15-1 provides a new topographic rendering (NIRSPplay), which is optimized to work with probeInfo files created from within NIRSite. As the latter is based on the ICBM152 atlas, we recommend the users to employ montages with these probeInfo to achieve greater precision of optodes and channels location.

Please refer to the related user manuals for comprehensive information on how to create probeInfo files using NIRSite and for a detailed overview of the features available in NIRSPplay as rendering tool. Herein we will rather focus on the integration of NIRSPplay with NIRStar, and the required settings for the latter.

### 19.1 Installation

The NIRSPplay build is provided as a standalone package and is obtainable as a compressed (zip) file. The default path NIRStar expects the uncompressed files to be located is: C:\NIRx\NIRSPplay\nirsplay\_v1.0

However, as explained in section 5.7.2, the user can set the path to NIRSPplay in the Data Streaming tab of the Hardware Configuration menu.

If the executable file under the defined path cannot be found, NIRStar will issue an alert message during the next software initialization, i.e. upon confirming the changes in the hardware configuration menu.

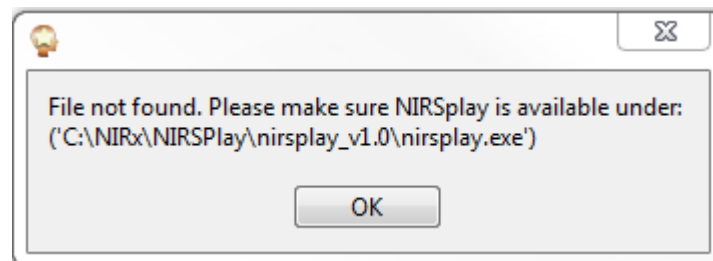


Figure 92. Example of alert message in case the NIRSPplay executable cannot be found by NIRStar.

### 19.2 Setup

The setup of NIRSPplay can be automated by selecting the option “automatically launch NIRSPplay” that is available under the Data Streaming tab of the Hardware Configuration menu (section 5.7.2). By doing so, the user will be automatically prompted to adjust the LSL settings to enable the LSL streaming and to stream Hb States only.

The first requirement is related to the communication protocol used between NIRStar and NIRSPplay, which is the Lab Streaming Layer. The second is related to the fact that NIRSPplay can currently only handle hemodynamic states as input streams.

Once the user accepts to adapt the LSL settings, the checkbox will be enabled and the NIRSPplay will be automatically initialized once the hardware configuration settings is confirmed (by clicking on “OK”).

For a smooth experience with NIRSPay, please make sure to set a predefined montage with a probeInfo file created in NIRSite. If no probeInfo file is available for the chosen montage, the user will be prompted to select the corresponding probeInfo file manually. Otherwise, if only a probeInfo file from nirsLAB is available for the montage, NIRStar rather issues an alert message for the user.

Figure 93 shows the starting screen that appears during NIRStar initialization after a successful launch of NIRSPay. The communication with NIRStar can be confirmed by the name of the stream, which should point to the name of the computer where NIRStar (and NIRSPay) are running, e.g. NIRxBR.

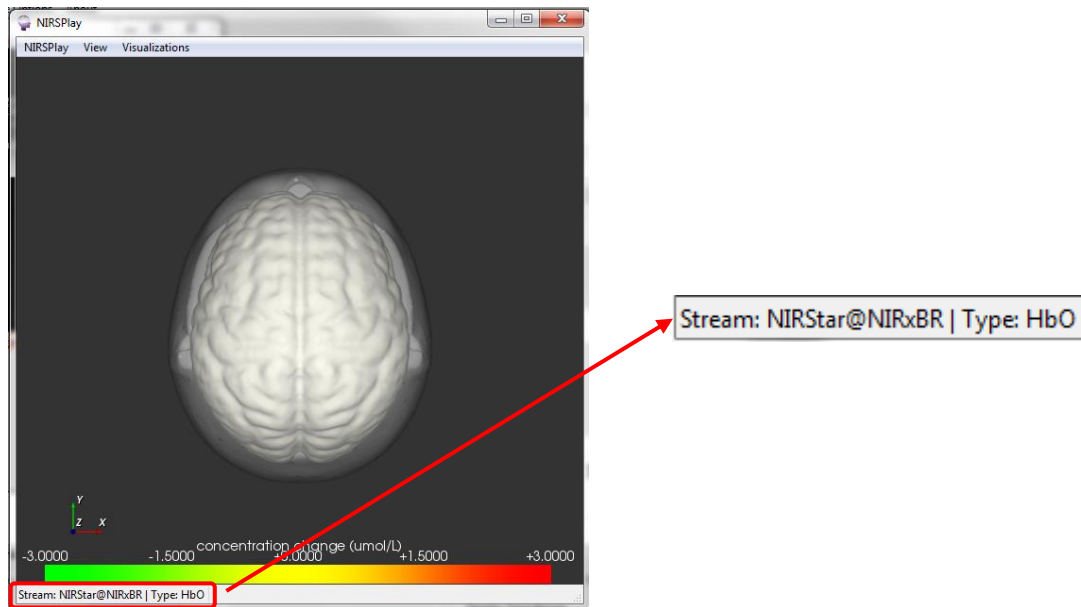


Figure 93. NIRSPay starting screen (left) and stream name (right) after successful connection with NIRStar.

### 19.3 Rendering

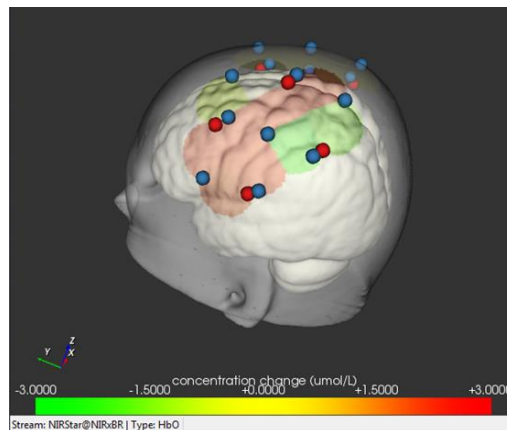


Figure 94. Illustration of real-time topographic rendering with NIRSPay.

Once the NIRSPay window is available and the NIRStar stream was found, the topographic rendering is ready to be used.

In fact, this should start automatically once a measurement in NIRStar starts, i.e. the data will be rendered in NIRSPay, as shown in Figure 94. Also, the user has the option to control the update rate of the rendering (i.e. number of samples to be averaged prior display) and also the color scale used. The “Display Options” can be accessed by pressing the key ‘F1’. Please refer to the NIRSPay Manual for further information on these options.

Once the measurement in NIRStar stops, no data frames will be streamed to NIRSPay anymore, and thus the last received data point will be displayed. By starting a new measurement, the rendering is automatically updated once again.

Finally, if a new montage is selected, NIRSPay will be restarted during the next NIRStar initialization to account for the new 3D coordinates of the optodes. NIRSPay shuts down when the user exits NIRStar.

## 19.4 Hyperscanning

As with the built-in topographic rendering, NIRSPay also allows for hyperscanning rendering. By enabling the hyperscanning option in NIRStar (see section 20), NIRSPay will be launched twice during the next initialization, one per subject of interest.

As shown in Figure 95, the identification of each subject can be achieved either from the window title (e.g. NIRSPay – Subject 1), or by the complimentary information available on the bottom of the window.

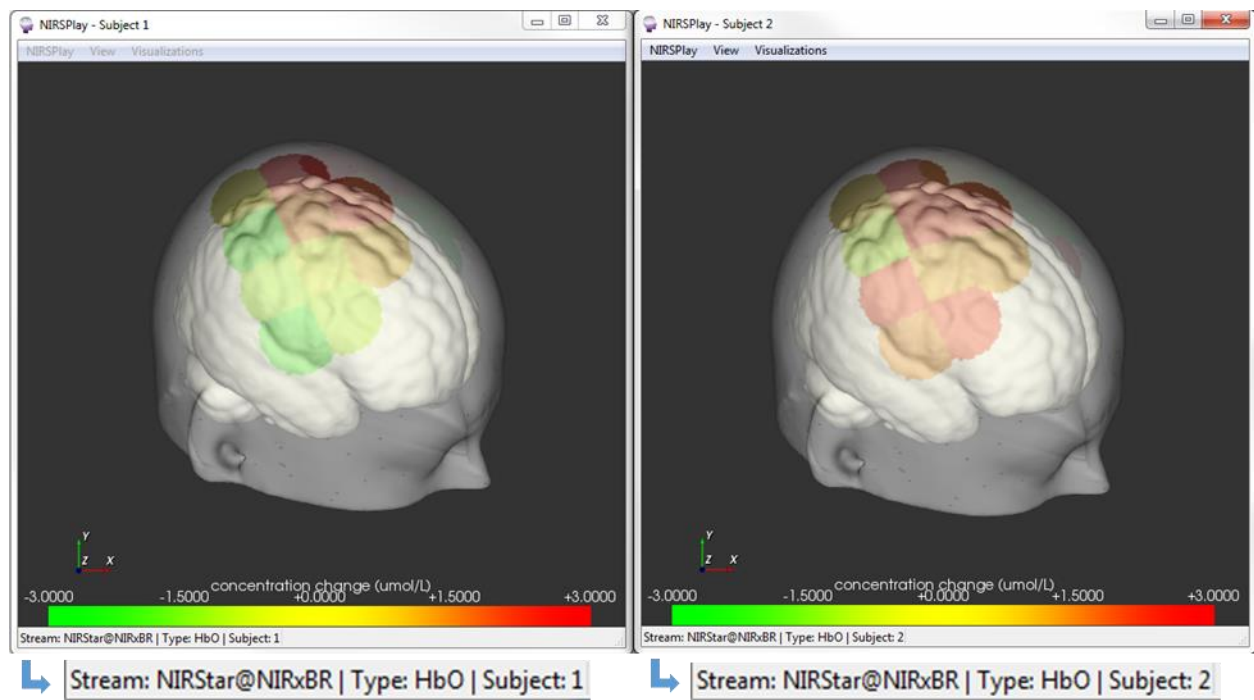


Figure 95. Illustration of real-time topographic rendering with hyperscanning: subject 1 (left) and subject 2 (right).





Figure 96. Hyperscanning example

## 20 Hyperscanning

### 20.1 Setting up Hyperscanning

NIRStar offers a Hyperscanning mode to study functional neurovascular activation on two people simultaneously (see Figure 96).

The Hyperscanning mode is accessible in *Channel Setup* tab of the *Hardware Configuration* GUI, provided that valid numbers of sources and detectors are available. Hyperscanning mode requires that no detector bundle (four channels) or Source bundle (eight sources) be split between subjects. Therefore,

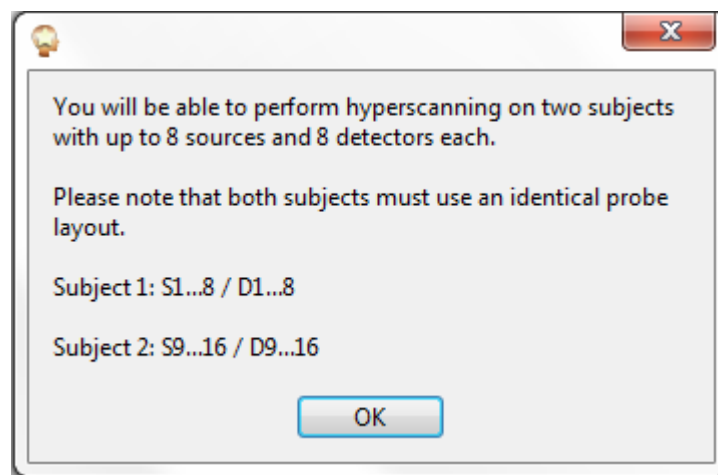
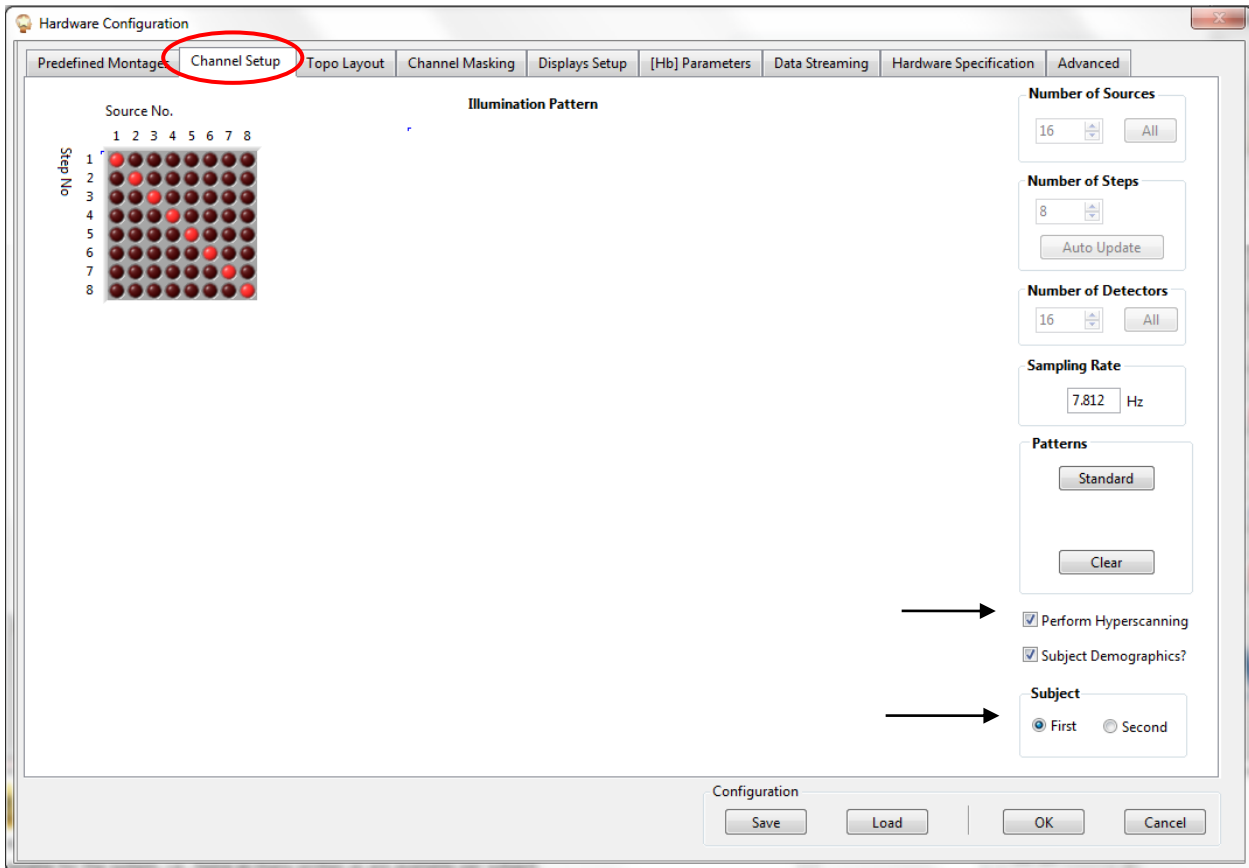


Figure 97. Confirmation dialog box: *Perform Hyperscanning* activated



**Figure 98. Hardware Configuration → Channels Setup: Perform Hyperscanning**

Hyperscanning is available only if an even multiple of four detector optodes and an even multiple of eight source optodes are available in the system. In *Channel Setup*, make sure to set the numbers of sources and detectors accordingly. Thus the smallest instrument configuration allowing Hyperscanning is a 16-sources / 8-detectors instrument.



Hyperscanning is available only if an even multiple of four detectors and an even multiple of eight sources are available in the system (e.g., 16 Sources and 16 Detectors).

Please note that the numbers of sources and detectors specified in *Channel Setup* corresponds to the total available for the system, *i.e.*, twice as many probes as are available per subject.

After placing a checkmark in the *Perform Hyperscanning* box (indicated by an arrow in Figure 98), a pop-up message similar to the one depicted in Figure 97 informs the user which ranges of source and detector numbers to use for each subject.

In order to achieve a high measurement sampling rate, a parallel illumination pattern is automatically set, *i.e.*, the scanning-step numbers are the same for both subjects. The illumination patterns do not have to be the same for both subjects. Use the *First* and *Second* radio buttons to toggle between

subjects. In *Channel Masking*, any change made for one subject will automatically be applied to the other, *i.e.*, both subjects will always have the same *Channel Masking*.

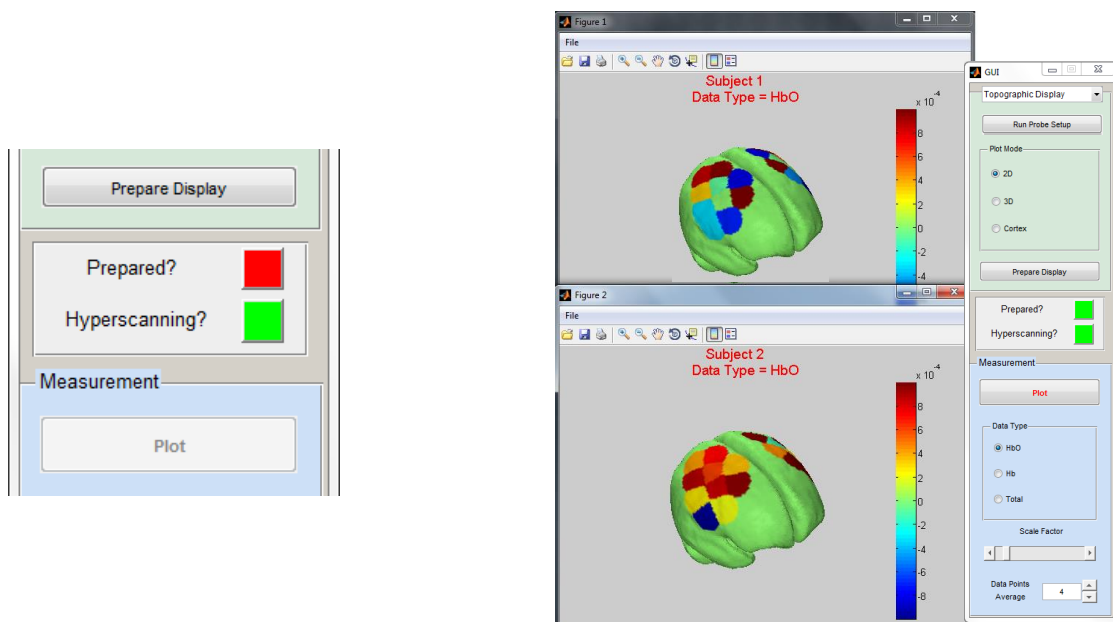
The recorded data are saved in two different folders, 'Subject1' and 'Subject2', that are located in the experiment-specific main directory (see Section 6.3). The files are saved as if two identical instruments (same number of sources and detectors) had been used to run the experiment. Gains (extension .set and .hdr), Channel Masking (.hdr), Subject Demographics (.inf) and Raw Data (.wl1, .wl2) are separately saved for each subject; while the Triggers (.evt) and the Topo Layout (.tpl) are the same and present in both folders.

## 20.2 Hyperscanning 3D Display

The advanced display options as outlined under section 17 are also available for hyperscanning experiments. If the 'Perform Hyperscanning' option is selected in the *Channel Setup* tab, the 'Hyperscanning active?' indicator in the Standalone control GUI will appear green (Figure 99).

Click the *Setup Probe* button to set up a topographic display as described under section 18.2. Scalp positions should be specified for half of the total numbers of detectors and sources. The configuration needs to be entered only once and will be replicated for the second subject.

After clicking on 'Prepare Display', two identical Figures will appear (Figure 99). Please note that the "close" option (X) of each figure is disabled. If one wants to change the Plot Mode, please switch the button under the standalone control GUI and click on *Prepare Display*.



**Figure 99. Hyperscanning topographic rendering. Left: Hyperscanning 'active' indicator in topographic control GUI; Right: Rendered display example.**

## 21 Laser Operation

NIRScout Extended and NIRScout Extended*Plus* devices allow the fiber-based target illumination with laser-diode light sources as an alternative to the standard LED-based light sources (Figure 100).

NIRStar allows the configuration and operation of laser-based NIRx devices.

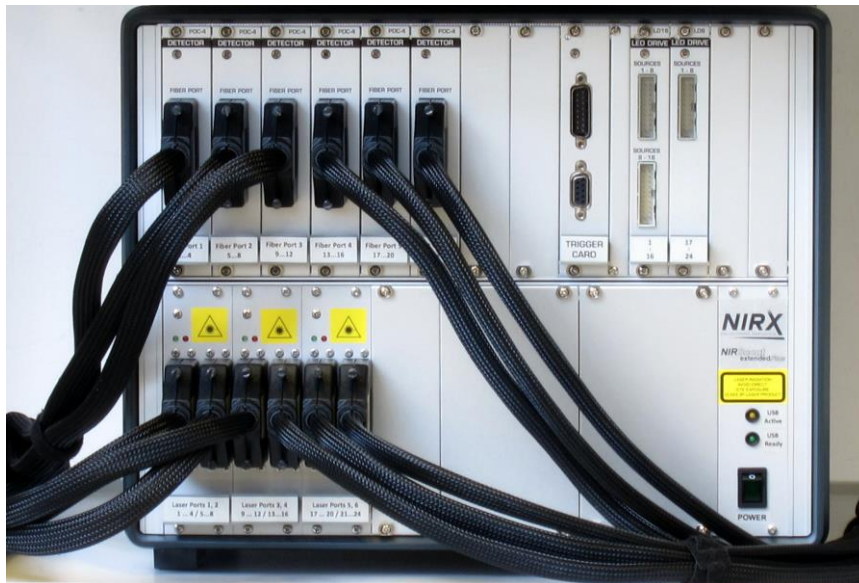
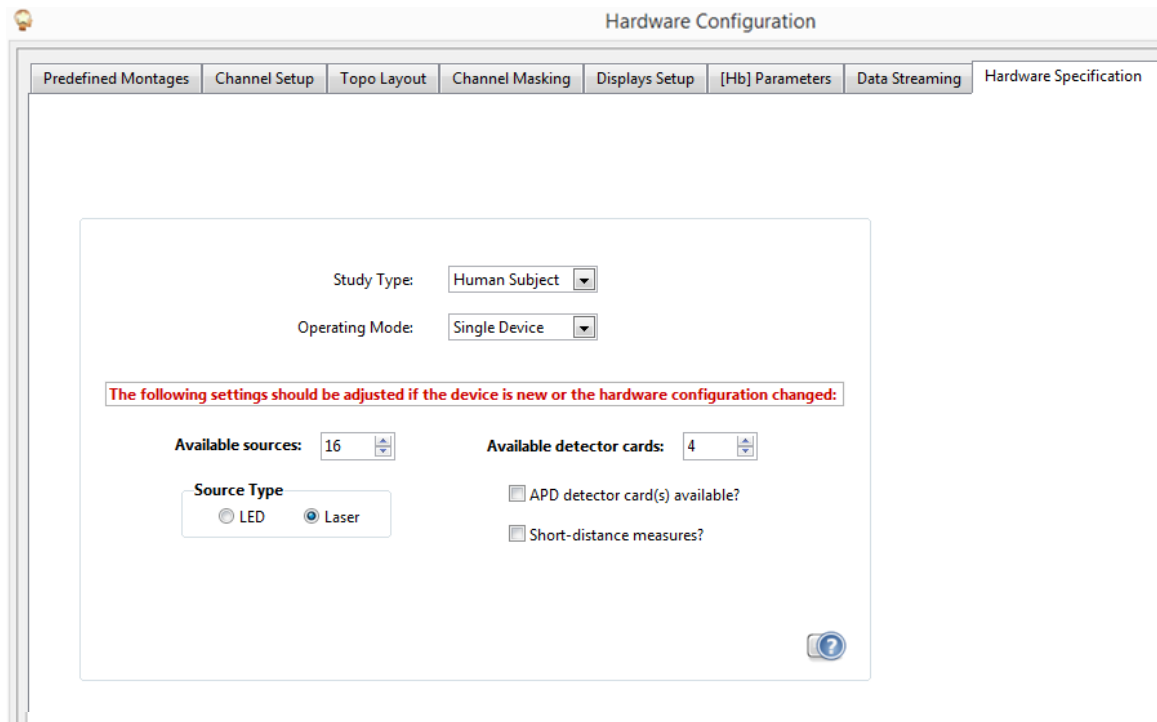


Figure 100. NIRScout devices offering laser illumination. Top: NIRScout extended*Plus* with integrated 2- or 4-wavelength laser illumination. Bottom: NIRScoutX with optional external 4-wavelength illumination module.



**Figure 101. Hardware Specification – Setup options for laser operation.**

## 21.1 Preparation of Laser Operation: Hardware Specification

The NIRStar software detects whether the instrument connected has the capability to operate lasers. Specifically, if at least one hybrid LED/Laser card is present, the setup options for laser operation will become visible in the software. For details about the hardware components, please refer to the NIRScoutX/NIRScoutXP User Manual.

To configure the instrument for laser operation, the ‘Source Type’ selector under *Hardware Specification* needs to be set to ‘Laser’. The number of wavelengths available in the Laser system will be automatically retrieved from the “LsrCfg.nrx” file that is provided by NIRx.

Set up the number of ‘Available sources’ to the number of source channels offered by the source driving cards in your system.



The number of ‘Available sources’ selected in the ‘Hardware Specification’ tab MUST match the actual number of source channels offered by the system. This number is easily confirmed by the number of LED-bundle connectors present on the LED-Driver cards installed; each connector corresponds to eight source channels. The number of ‘Available sources’ is derived as (number of source connectors \* 8).

After setting the NIRstar software to ‚Laser‘ mode, the following information will be displayed in the main window:

<b>Instrument in Use:</b>	NIRScoutX 64x32
<b>Source Type:</b>	Laser (2 wavelengths)
<b>Modulation Amplitude:</b>	Human Subject

### ***21.1.1 Considerations for switching between Laser and LED operation***

Switching between Laser and LED mode is easily achieved by checking the desired mode in the Hardware Setup ‚source Type‘ selection. All other software configuration settings (no. of sources, detectors, topo layout, masking, etc.) will be retained.

### Considerations for Laser operation

When using a Laser-enabled NIRScoutX+ system in Laser mode, please be sure to connect the laser source fibers to the Laser Ports of the laser source card (see figure on the right) before operating the instrument.

**LASER CLASS 3R DEVICE! AVOID DIRECT EYE EXPOSURE!**

The Device emits visible and invisible Laser radiation. Avoid direct eye exposure:



- Do not stare into the expose illumination fiber end
- Do not leave the laser output disconnected from the illumination fibers during operation; do not stare into the open laser ports.
- Only operate instrument after all source fibers are connected, and the source fibers are placed and secured on the target or are otherwise covered by suitable means (e.g., inserted in test medium).



It is not possible to work with mixed Laser and LEDs illumination in one instrument. For systems with both Laser and LED modules, please be aware that only one *Source Type* will be used during the scan.



For safety reasons, laser operation presents a minimum limit of two steps of illumination pattern (Channel Setup tab, see section 5.3).



**Figure 102. NIRScoutX system with external Laser module.**



## 21.2 Considerations for Use of the NIRScoutX with external Laser Module

NIRScoutX is capable of Laser illumination if an optional external Laser Module is used (Figure 102).

Please note that one laser driver card (8 laser sources/4 wavelengths) replaces one physical LED driver module for 16 sources at 2 wavelengths. Therefore, when toggling between *LED* and *Laser*, the *Available Sources* value for LED operation will be double the amount of that for Laser operation.



It is not possible to work with mixed Laser and LEDs illumination in one instrument. For systems with both Laser and LED modules, please be aware that only one *Source Type* will be used during the scan.



Please set the *Available Sources* field to EITHER the total number of **Laser** sources available OR the number of **LED** sources, according to the *Source Type* specified.

Since the light intensity used for LEDs is higher than the maximum amplitude for laser, one must only set the *Source Type* to LED if one is absolutely certain that no Laser is connected to the driver. The user is strongly encouraged to carefully read the section 5 (*LED Operation*) on the **NIRScoutX Laser Module Manual**.



Lasers must NOT be operated with LED modulation amplitudes. Mishandling this operation may permanently damage the system!

When the Laser option is selected as *Study Type*, the checkbox “Laser Splitter Box?” will appear (Figure 103).

Source Type

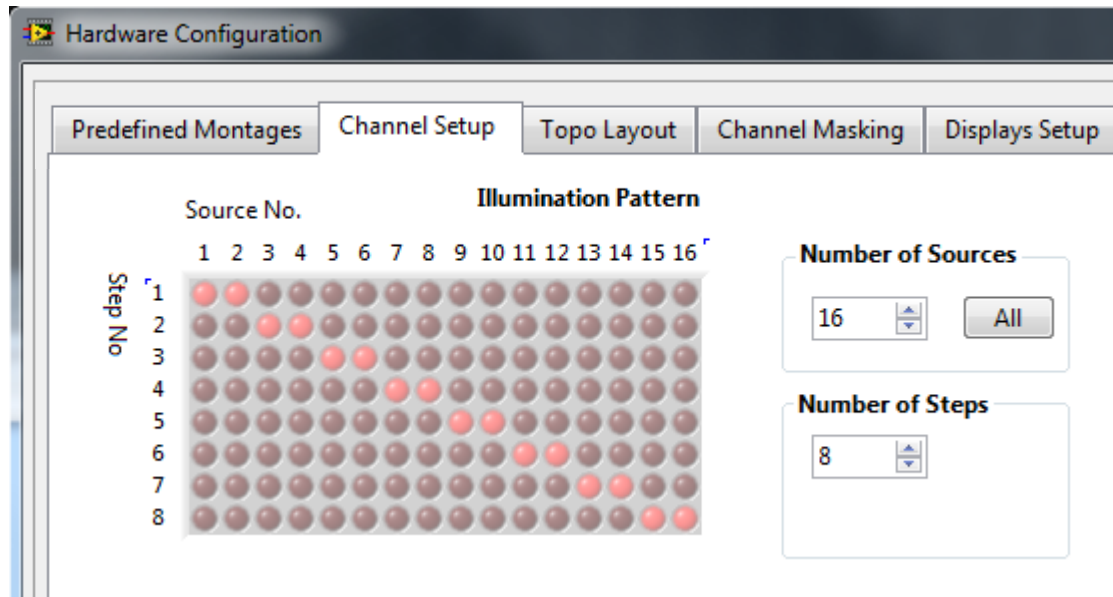
LED  Laser

Laser Splitter Box?

Figure 103. “Laser Splitter Box?” becomes visible once Laser is selected as *Source*



The “Laser Splitter Box?” option allows the use of bifurcated illumination bundles with the laser module, thereby allowing the optical splitting of each source for simultaneous bilateral illumination. This doubles the number of usable illumination sites from 8 to 16. Checking this option will make sure that the doubled amount of illumination points is accounted for in the software (e.g., by doubling the entry in the “Available Sources” field). When the splitter box option is checked, the illumination pattern will be automatically adjusted to a pattern as shown in Figure 104.



**Figure 104. Resulting Illumination Pattern for bifurcated laser fibers**

Manual modification of the illumination pattern will be disabled as long as the field “Laser Splitter Box?” under the *Hardware Specification* tab is checked.

When ‘Laser Splitter Box’ is checked, the *Number of Sources* field under the *Channel Setup* tab will be kept an even number i.e. each time the user increases or decreases the number of sources by clicking on the corresponding arrow up or down, a pair of sources will be respectively added or removed from the illumination pattern.



Because the *Hyperscanning* feature forbids splitting fiber bundles between subjects, in the case of using the ‘splitter box’ option, the *Hyperscanning* feature is only available for even multiples of sixteen sources.












When operating with bifurcated laser fibers, hyperscanning is available only if an even multiple of four detectors and an even multiple of sixteen sources are available in the system.

### 21.3 Saved files

For measurements performed with a 4-wavelength laser configuration, the signals are stored in four separate files:

prefix-yyyy-mm-dd_xxx.wl1	← contains data for wavelength 1 (685 nm)
prefix-yyyy-mm-dd_xxx.wl2	← contains data for wavelength 2 (780 nm)
prefix-yyyy-mm-dd_xxx.wl3	← contains data for wavelength 3 (808 nm)
prefix-yyyy-mm-dd_xxx.wl4	← contains data for wavelength 4 (830 nm)

 NIRS-2014-03-12_009.evt	12.03.2014 18:59	Klassische Ereignis...	1 KB
 NIRS-2014-03-12_009.hdr	12.03.2014 18:59	HDR-Datei	5 KB
 NIRS-2014-03-12_009.set	12.03.2014 18:59	SET-Datei	1 KB
 NIRS-2014-03-12_009.tpl	12.03.2014 18:59	TPL-Datei	1 KB
 NIRS-2014-03-12_009.wl1	12.03.2014 18:59	WL1-Datei	12.283 KB
 NIRS-2014-03-12_009.wl2	12.03.2014 18:59	WL2-Datei	12.283 KB
 NIRS-2014-03-12_009.wl3	12.03.2014 18:59	WL3-Datei	12.283 KB
 NIRS-2014-03-12_009.wl4	12.03.2014 18:59	WL4-Datei	12.283 KB
 NIRS-2014-03-12_009_config.txt	12.03.2014 18:59	Textdokument	1 KB

**Figure 105. Example of saved data files after a measurement operated with**

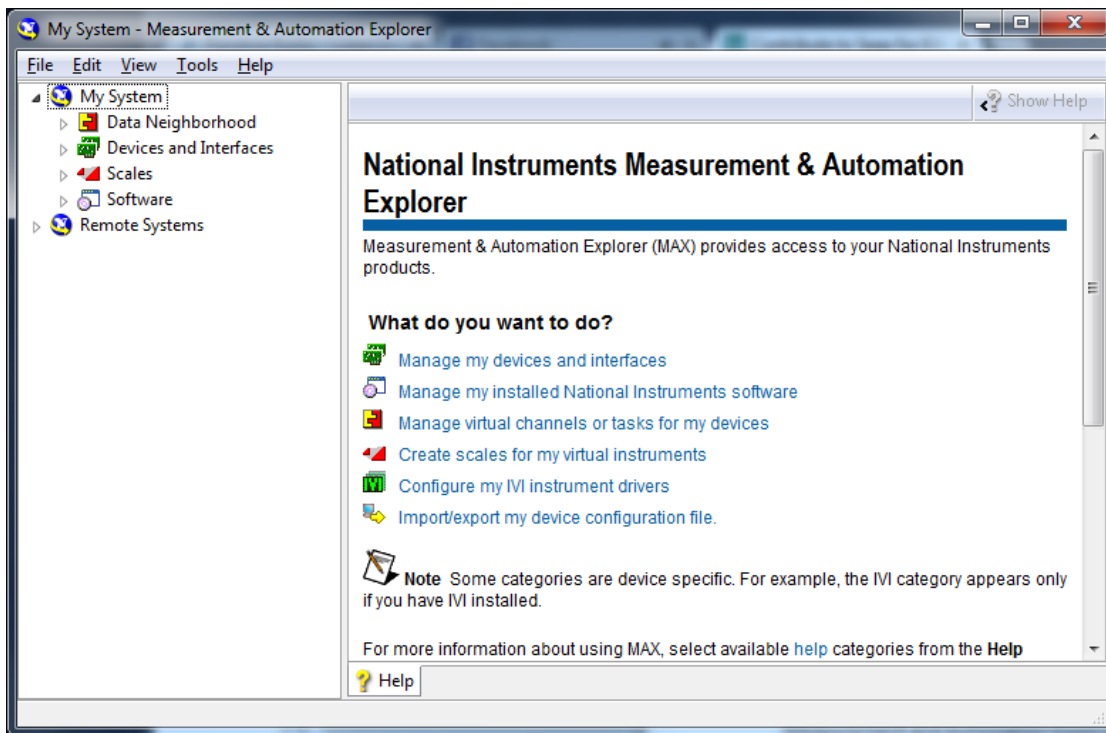
These data files contain the raw voltage readings recorded by the source-detector channels.

The file format is a space-separated ASCII table where columns represent data channels and rows represents time frames. The file contains no header, explicit row or column labels, or time stamps. The data structure for each file is identical to that outlined for regular (LED) illumination (see section Data File Formats).

## Appendix A. How to use a ‘Simulated Device’ for testing and training

NIRStar requires a system to be connected in order to run through much of the functionality. This appendix describes how to setup a simulation device on your PC by using National Instrument’s Measurement and Automation Explorer.

Please first open the Measurement and Automation Explorer (NI MAX) from your desktop or using the windows search engine to find it. This is automatically installed during the NIRStar installation.



**Figure 106. Measurement & Automation Explorer window.**

On the left-side list, under “My System”, please click on “Devices and Interfaces” to expand the list of devices that have been installed to your computer so far, i.e. that have created a successful connection with the computer acquiring the data. The devices have the following codes:

- i) NIRScout systems: NI USB-6218
- ii) NIRScoutX systems: NI USB-6259
- iii) NIRSport systems: NI USB-6216

Using the same codes listed above, with NIRStar one is also able to simulate these devices. In order to create a new device, right-click “Devices and Interfaces” and select “New”. A new window will pop up, as depicted below.

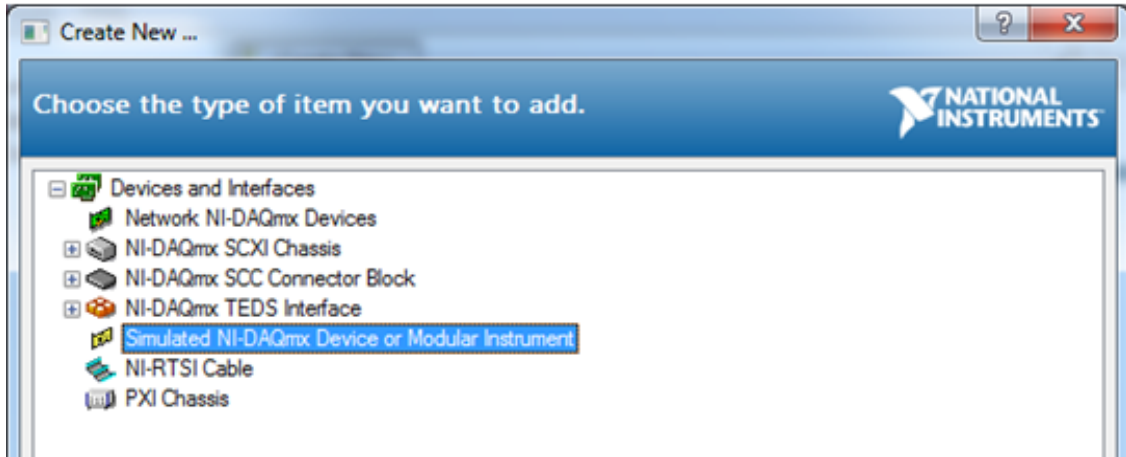


Figure 107. Create new NI

Select the option “Simulated NI-DAQmx Device or Modular Instrument”, as chosen on Figure 107.

On the new window, you may use the search field to look for the desired instrument. Following the example below, one may find the simulated device corresponding for NIRScout systems:

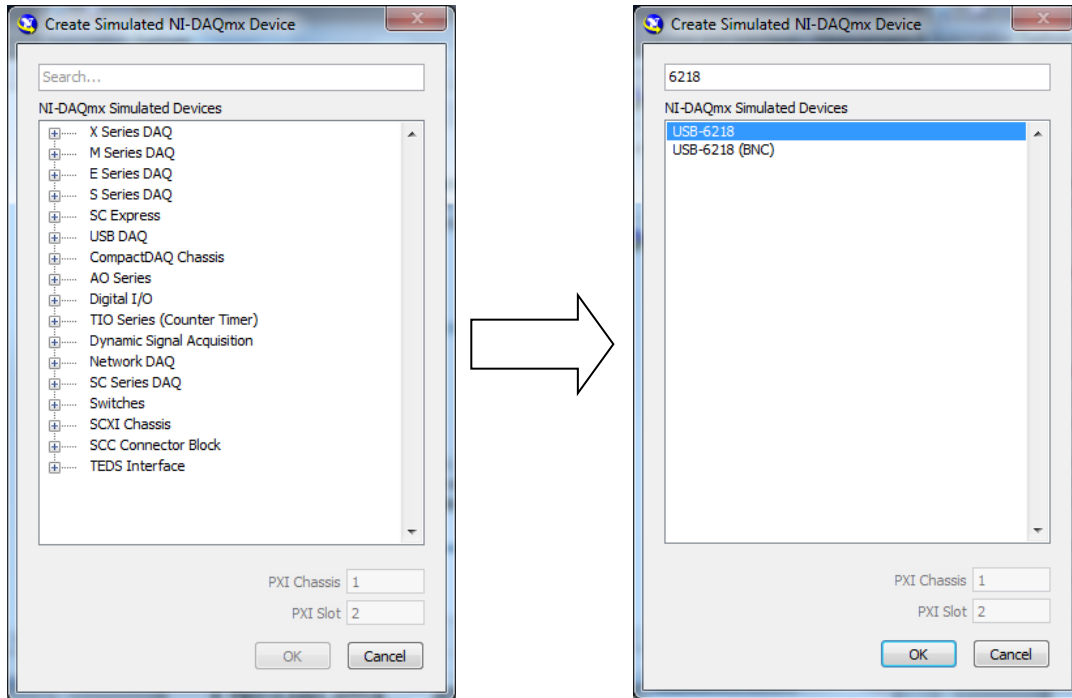


Figure 108. Creating NIRScout simulated device by entering the code USB-6218

After confirming the selection, the device just created should be listed under *Devices and Interfaces* on the Measurement & Automation Explorer main window.

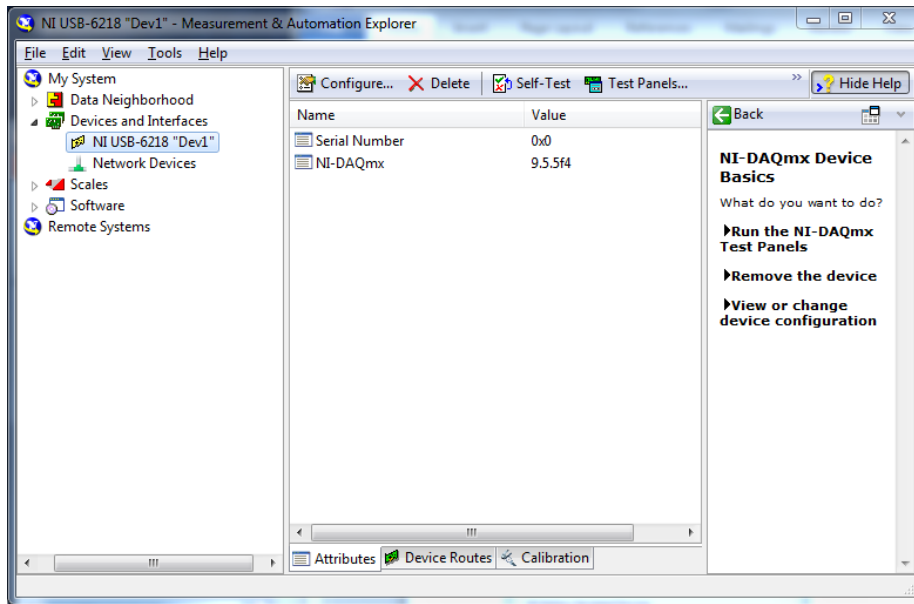


Figure 109. The simulated device (yellow) is now listed under *Devices and Interfaces*

If your computer has more than one device installed, you may identify the simulated device marked in yellow. Real devices will be either green (connected) or white (installed, but not connected).

When launching NIRStar, the software will connect to the first device from this list (alphabetic order). Therefore, in order to avoid confusion between real and simulated devices, it is strongly recommended to rename the simulated device right after creating it, as depicted on the figure below.

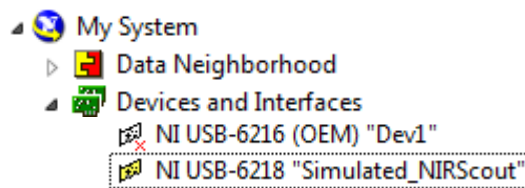


Figure 110. Renaming the simulated device after its

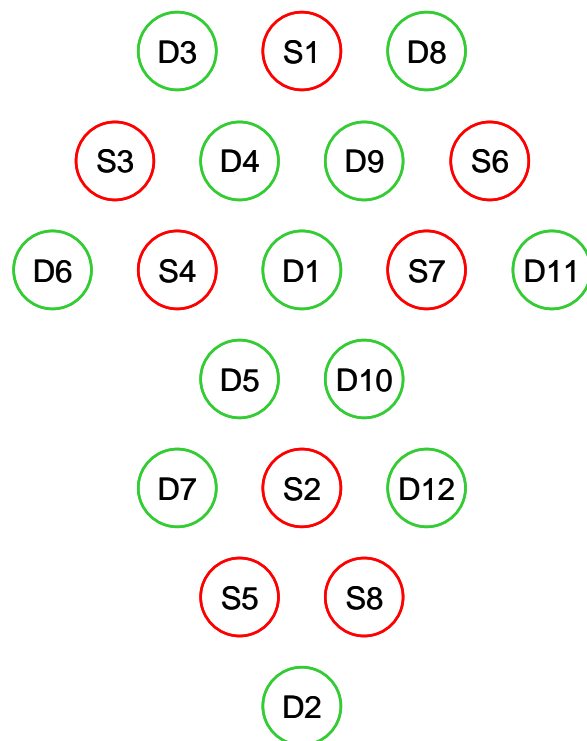
Doing so, if the real device (“Dev1” on the picture above) is plugged to the computer, NIRStar will make the communication to it, because this is the first device of the list. Otherwise, one is still able to run the software with the simulated device.

## Appendix B. How to Generate a Channel-Layout Grid for an Arbitrary Optode Array



Please note that the NIRSite tool provided by NIRx can automatically generate topo layout files along with probeInfo files. Please refer to NIRSite User Manual for further information.

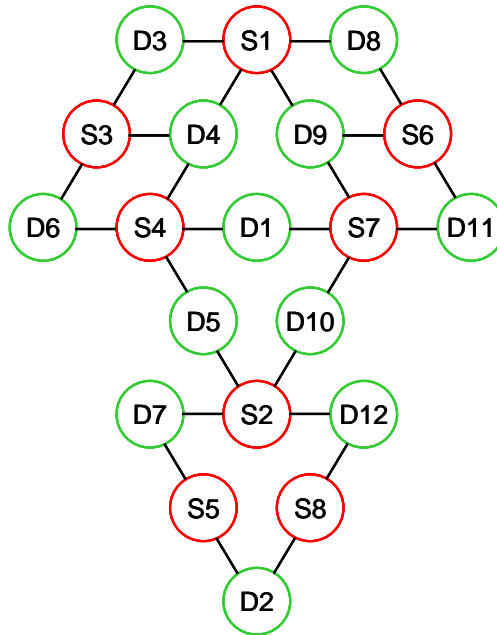
For the example considered in Section 5.4, the optodes were arranged in a manner that corresponded in a rather straightforward way to a simple checkerboard channel layout (Figure 19). However, the arrangement of optodes that is best suited to a particular functional imaging study may have a more irregular character (and a strong point of NIRScout and NIRSport systems is the flexibility they afford users in the positioning of optodes). For concreteness, here we consider a specific example that came from a research group interested in collecting data from a region in the back of the subject's head, overlying the visual cortex. They used 8 sources and 12 detectors, and arranged them in the pattern depicted in the following cartoon:



**Figure 111: Example of a topographic measurement layout.**

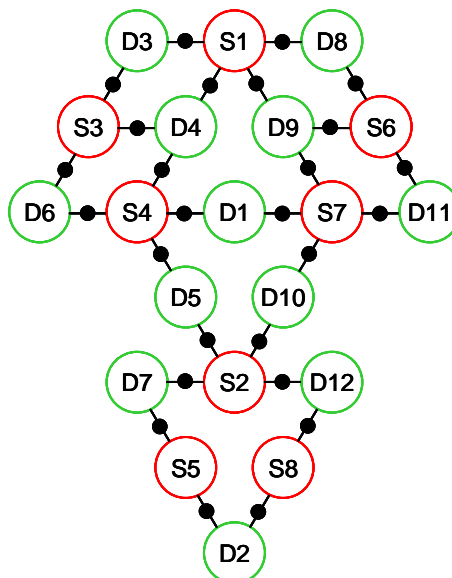
Here we present a set of steps that can be used to generate a channel layout for the array shown, and that has worked as well for every other array tested so far.

1. Draw line segments connecting all pairs of adjacent source and detector optodes (see Higher-Order Considerations, p. 78). Each line segment represents one measurement channel:



**Figure 112: Measurement channels (nearest source-detector neighbors).**

2. Place a mark in the middle of each line segment. These marks indicate the approximate locations of the centers of the volumes of tissue that the channels are sensitive to:



**Figure 113: Indication of channel positions.**

3. Count the number of distinct channel locations in the vertical dimension. This will tell you how many rows to specify in your channel layout:

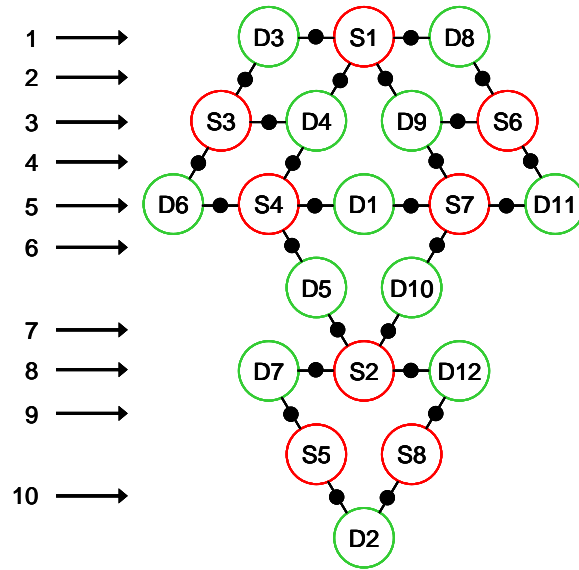


Figure 114: Horizontal Channel locations = number of rows in your layout.

4. Count the number of distinct channel locations in the horizontal dimension. This will tell you how many columns to specify in your channel layout:

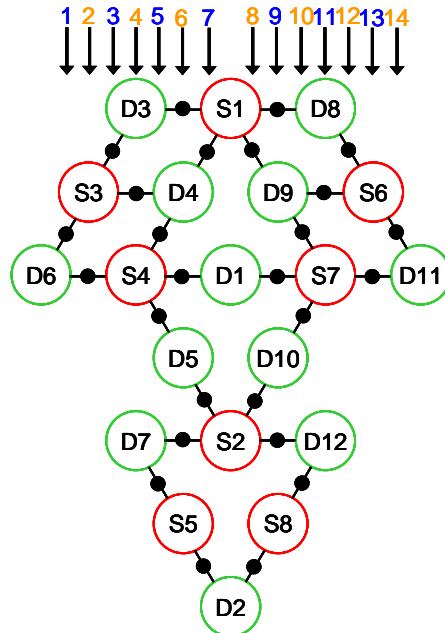


Figure 115: Vertical Channel locations = number of columns in your layout.



5. Give each channel a numerical label,  $m-n$ , where  $m$  is the source number and  $n$  is the detector number:

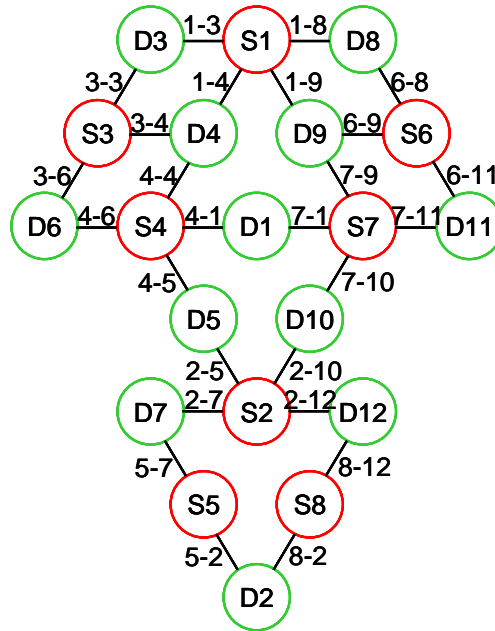


Figure 116: Labeling the channels.

6. In the *Topo Layout* tab of the *Configure Hardware* menu, specify a layout array containing  $M$  rows and  $N$  columns (here,  $M = 10$  and  $N = 14$ ) and fill in the channel-layout squares that correspond to the row and column indices identified in Steps 3 and 4. Use the channel labels identified in Step 5:

Figure 117: Transfer the schematic to the layout editor

The 6-step method for generating a channel layout is straightforward to implement for nearly any optode array. A possible downside is that it can lead you to generate a grid containing large numbers of rows and columns (10 and 14 for the example above), with only a small percentage of the grid cells occupied by channels (26 out of 140, or ~19%). Once you have attained proficiency in generating layouts this way, you may want to experiment with collapsing rows and/or columns, on a freehand, case-by-case basis, in order to achieve a smaller grid size (while sacrificing some spatial accuracy in the channel locations). One way in which this sort of grid-size economy can be achieved for the optode array we are considering here would be:

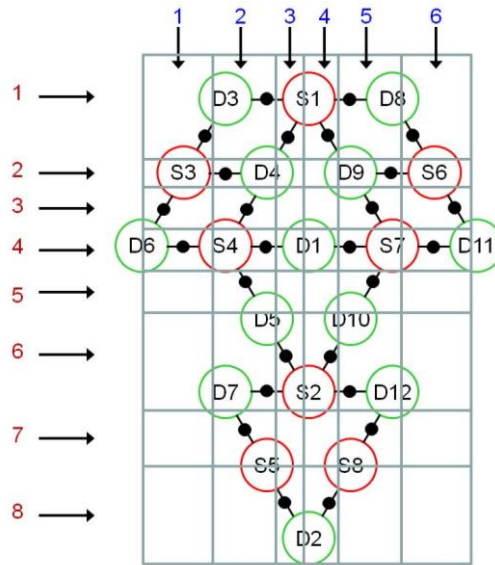


Figure 118: Freehand example, arranging channels more economically on an irregular grid.

This corresponds to the following 8x6 *Topo Layout*, which has channels in more than half of the grid:

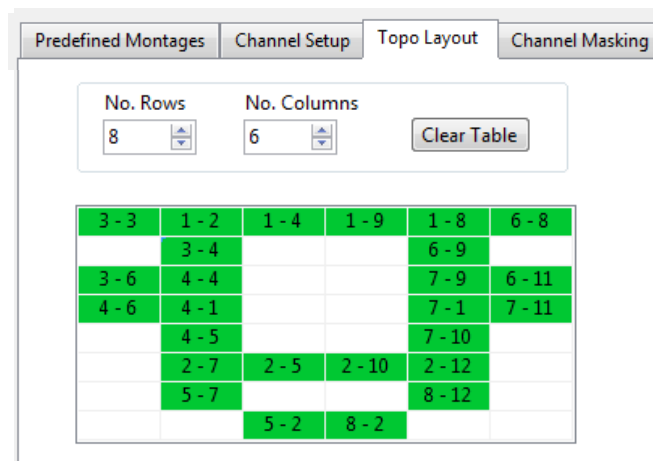


Figure 119: Layout editor entry corresponding to the previous example.

### Higher-Order Considerations

Implicit in the instructions presented above is the idea that you will want to define channels for all pairs of nearest-neighbor sources and detectors, and only for these pairs. In our experience the assumption usually is correct, but you may find that for a particular analysis you either do not want to include every possible nearest-neighbor pair, and/or that you do want to include channels defined by optode pairs that are not nearest neighbors. In the former situation, all that is needed is to modify Step 1: instead of connecting *all* possible nearest-neighbor pairs with line segments, connect only the ones that you want to include in your analysis. Then proceed with the remaining steps as written.

The latter situation may require a more careful approach. Suppose, for example, that we decide to add some longer-distance channels to the array we have been considering, as shown in the following figure:

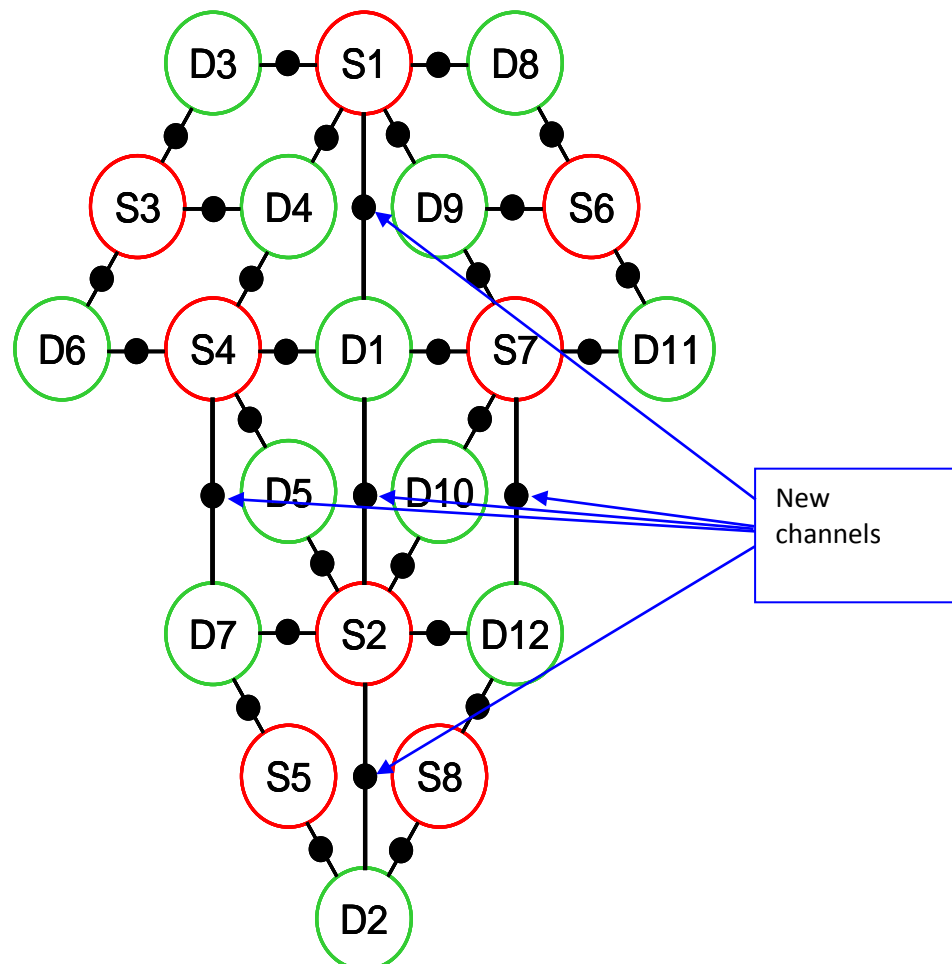


Figure 120: considering non-nearest neighbor channels.



Likewise, the grid can be collapsed into a 9x5 one, by merging pairs of adjacent rows and columns:

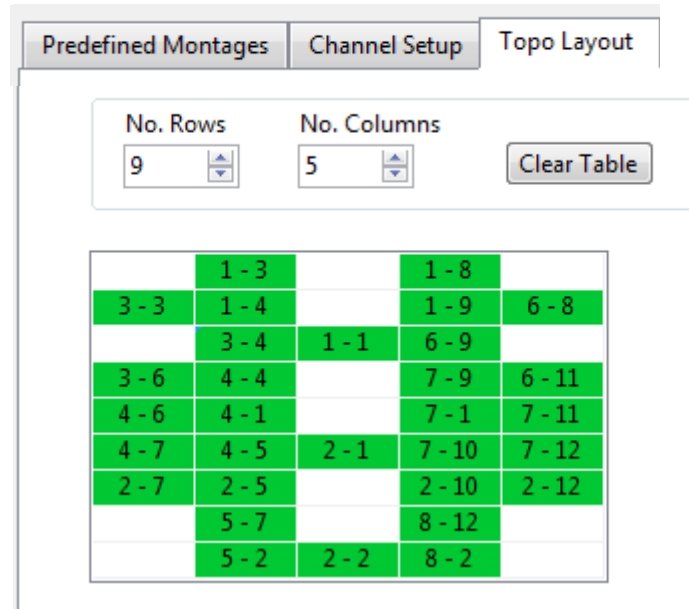


Figure 122: a more compact grid with nearest and non-nearest channels.

So the new channels can be incorporated into the method presented here for specifying a channel layout. But there is a significant caveat. You might have already noticed that the distance between the source and detector optodes is noticeably larger for the 5 new channels than for the 26 nearest-neighbor channels we had originally. Since the channel distance is crucial to the calculation of the concentration changes (Hb/HbO), we recommend that if you want to include multiple source-detector separation distances in your data analysis, you should also enter the corresponding distances in the *Display Setup* tab (see Section 17), as depicted in the figure below:

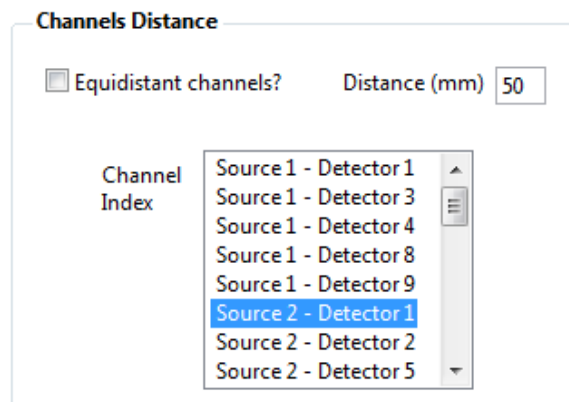


Figure 123: Specifying individual source-detector-distances.

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