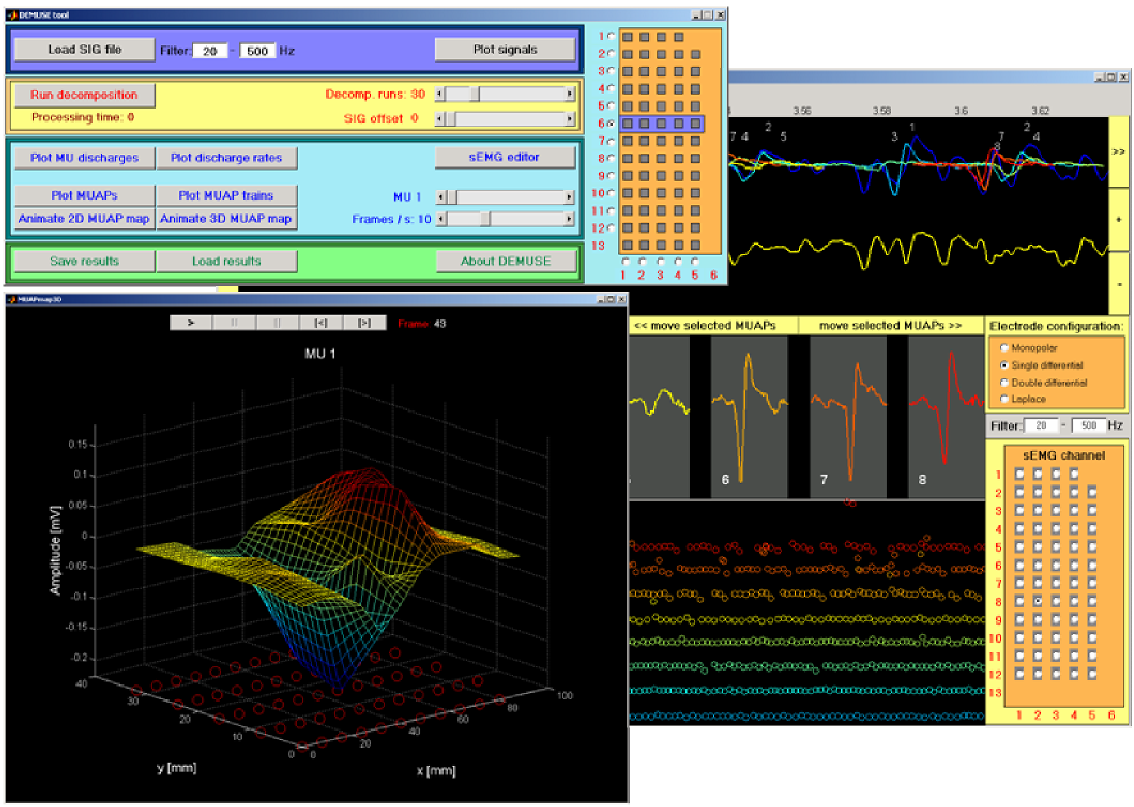
DEMUSE




# DEMUSEtool – user manual

**Version 2.3**

**02/10/2007**

# CONTENTS

1 Introduction ........ 3
2 DEMUSEtool components ........ 3
3 DEMUSEtool installation ........ 4
3.1 Requirements ........ 4
3.2 DEMUSE files and folders ........ 5
4 Using DEMUSE tool ........ 6
4.1 Starting DEMUSE tool ........ 6
4.2 SEMG signal loading ........ 7
4.3 SEMG signal visualization ........ 8
4.4 SEMG signal decomposition ........ 11
4.5 Visualisation and editing of the decomposition results ........ 13
4.5.1 Plotting sEMG signals ........ 14
4.5.2 Displaying instantaneous MU discharge rate ........ 15
4.5.3 Adding a new MUAP occurrence ........ 17
4.5.4 Moving and deleting MUAP occurrences ........ 18
4.5.5 Selecting sEMG channel, spatial filter and cut-off frequencies ........ 19
4.6 Graphical results ........ 20
4.6.1 MU discharge patterns plot ........ 20
4.6.2 Instantaneous discharge rate plots ........ 21
4.6.3 Multichannel MUAP plots ........ 22
4.6.4 2D MUAP map animation ........ 23
4.6.5 3D MUAP map animation ........ 25
4.6.6 Plots of reconstructed MUAP trains ........ 28
4.7 Saving and reloading of the decomposition results ........ 31
4.8 DEMUSEtool acknowledgements ........ 32
5 Technical support ........ 33
References ........ 34

# 1 Introduction

DEMUSEtool® is a matlab [1] program for visualization and decomposition of multichannel surface electromyograms (sEMG), acquired by EMG acquisition software v1.32 [2]. It runs on a standard PC and enables the user to:

- load and visualize the multichannel surface electromyograms;
- decompose the sEMG signals into contributions of individual motor units (MUs);
- inspect and edit the results attained by automatic decomposition;
- display graphs of decomposition results, including plots of the MU discharge patterns, instantaneous discharge rate, motor unit action potentials (MUAPs) and their 2D and 3D animations;
- compare the original sEMG signals to the reconstructed MUAP trains;
- save and reload the decomposition results.

All the graphs are displayed as regular matlab figures and can be freely manipulated by standard matlab graphic tools (i.e., figure resizing, zooming, rotating, printing, etc.). User is referred to matlab documentation for further details on the use of matlab graphic user interface. For further information on EMG acquisition tool see [2].

**Note:** ! *The current version of the DEMUSEtool supports decomposition of isometric sEMG signals only, i.e., the signals, acquired during isometric muscle contraction. Intensive work on decomposition of dynamic sEMG signals is currently in progress. Support for dynamic conditions will be built in the future versions of the DEMUSEtool*

# 2 DEMUSEtool components

DEMUSEtool represents the third layer in three-tier system architecture (**Figure 1**). The first two layers comprise the 128 channel EMG-USB electromyographic signal amplifier [4] and the sEMG acquisition software [2], respectively. sEMG signals under investigation are first acquired with a 2D matrix of electrodes. The matrix is put on the surface of the skin above the investigated muscle and connected to the EMG-USB signal amplifier [4], which amplifies and band-pass filters the signals and send them to the sEMG acquisition software [2]. The acquisition software acquires the sEMG signals, displays them on the screen (for immediate visual inspection of the signal quality), and saves them into so called SIG files [2]. Information about the measurement session, including subject data and technical specifications (i.e., number of channels, sampling frequency, gain, etc.) is saved into purposely designed abstract file [2]. Finally, both SIG and abstract files are loaded into DEMUSEtool and processed off-line (**Figure 1**).

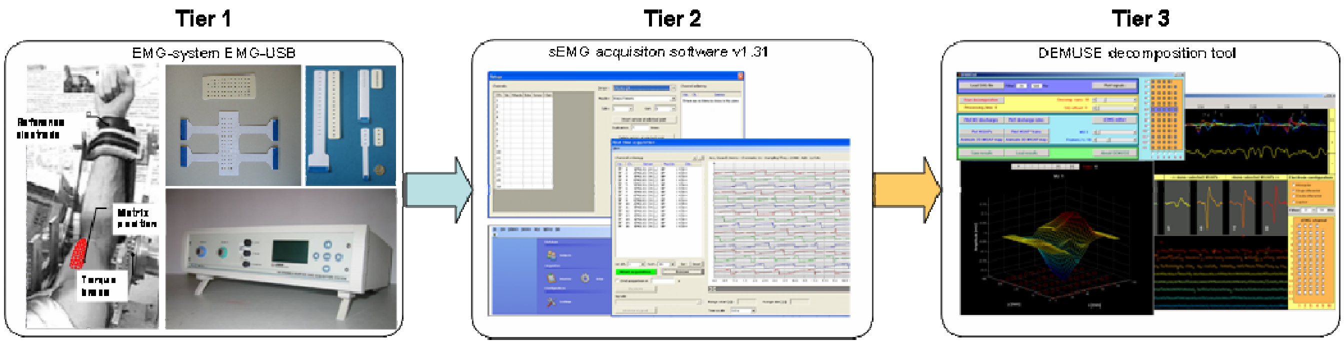



**Figure 1:** Three-tier architecture (with indicated data flows) of the sEMG decomposition system

# 3 DEMUSEtool installation

DEMUSEtool v2.3 is still a prototype and runs in the matlab programme environment [1]. As such, it is supported by several personal computer (PC) platforms, including Windows, Linux and Mac OS. It does not require any special hardware configuration. However, in the case of large number of channels and long sEMG signals, a sufficient amount of RAM (512 MB or more) should be installed on the system in order to prevent extensive swapping of the memory space.

## *3.1 Requirements*

Minimal hardware configuration:

- 1 GHz CPU;
- 20 MB disk;
- 512 MB RAM.

Recommended hardware configuration:

- 2 GHz CPU or higher;
- 100 Mb disk;
- 2 MB L2 cache or more;
- 1 GB RAM.

To run DEMUSE tool following software should be properly installed:

- matlab [1], version 6.5 or higher.

## *3.2 DEMUSE files and folders*

DEMUSEtool comprises several matlab's *.m and *.fig files which are located in the directory

`..\DEMUSEtool\programs\`

Program documentation is located in the directory

`..\DEMUSEtool\documentation\`

To install DEMUSEtool, copy both directories to your hard disk (e.g., to `c:\DEMUSEtool` directory) and set the path in matlab environment to `..\DEMUSEtool\programs\`

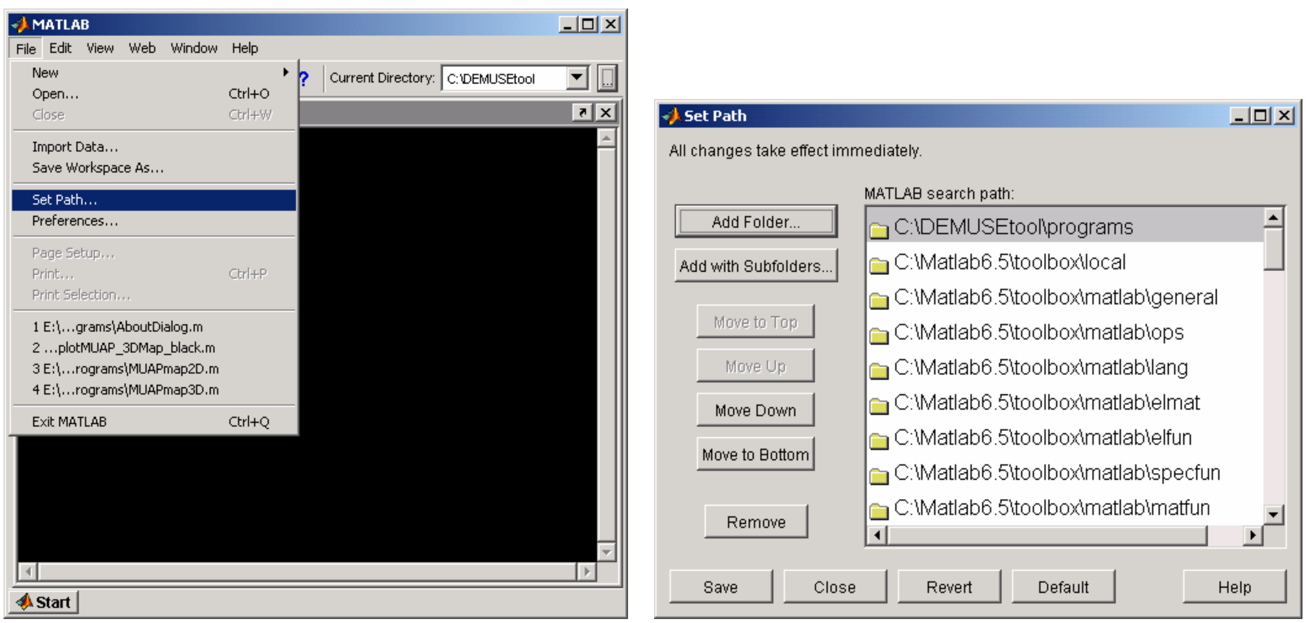



**Figure 2:** Setting the path in matlab programme environment (in this case, DEMUSE tool was copied to the directory `c:\DEMUSEtool`).

# 4 Using DEMUSE tool

## 4.1 Starting DEMUSE tool

To start the DEMUSEtool, type the following command to matlab command window:

```
>> DEMUSEtool
```

The main DEMUSEtool window appears (**Figure 3**). This window comprises the following four groups of commands for:

- loading, band-pass filtering and visualization of the acquired sEMG signals;
- decomposition of acquired sEMG signals;
- graphical plots and animations of the decomposition results;
- saving and reloading of the decomposition results.

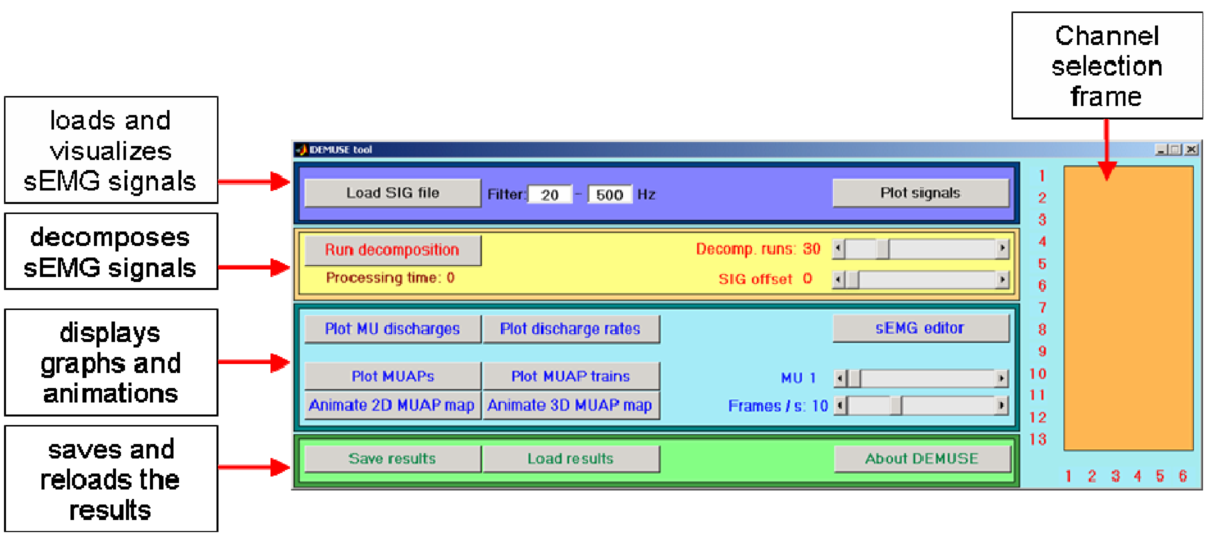



**Figure 3:** Main DEMUSEtool window with explanations of different command groups.

Each group of commands is depicted in different colour (**Figure 3**). Channel selection frame, displayed on the right-hand site in **Figure 3**, allows selection of different rows or columns of acquired sEMG channels. Its detailed description is provided in Subsections 4.2, 4.3 and 4.6.6.

## 4.2 SEMG signal loading

To load acquired sEMG signals into DEMUSEtool click on "`Load SIG file`" button (**Figure 4**,left panel). "`Load SIG file`" dialog window appears (**Figure 4**, right panel). Chose the SIG file and click on "`Open`" button.

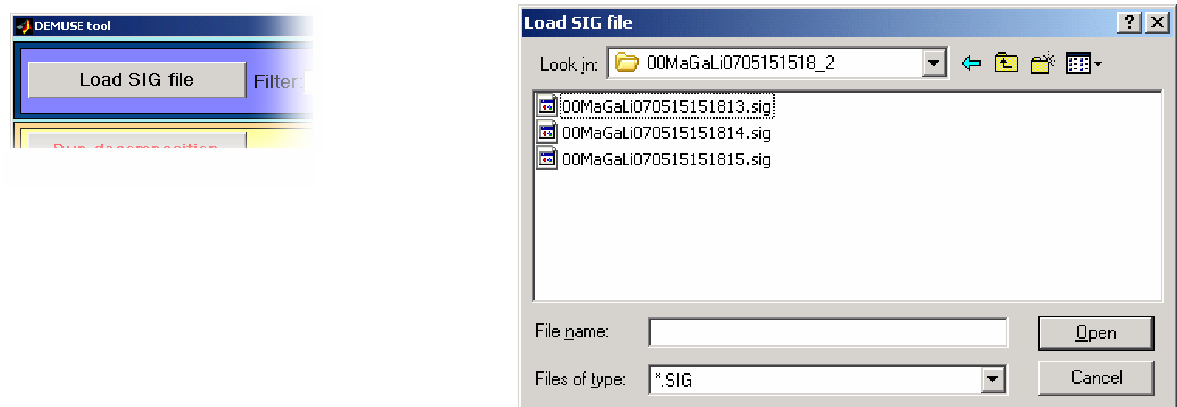



**Figure 4:** "`Load SIG file`" button (left panel) and "`Load SIG file`" dialog window (right panel).

DEMUSE tool automatically loads all the required technical information (e.g., sampling frequency, dimensions of the acquisition system, electrode configurations, etc.) from the corresponding measurement session abstract file [2]. The number of acquired channels and their relative spatial configuration is displayed in Channel selection frame (**Figure 5**).

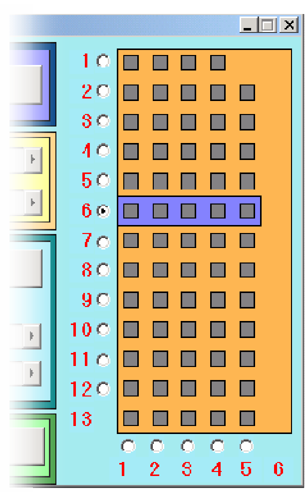



**Figure 5:** Channel selection frame; the number of acquired channels and their relative spatial organization is displayed (grey rectangles). Red numbers at the left hand site and at the bottom denote the corresponding rows and columns of electrodes, respectively.

DEMUSEtool uses 4th order Butterworth band-pass filter to filter the raw EMG signals. Filter's cut-off frequencies can be controlled by typing new values into the text labels shown in **Figure 6**. Default cut-off frequencies are set to 20 and 500 Hz, respectively.

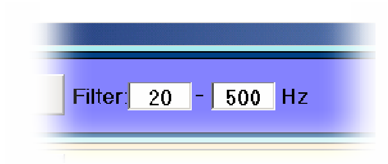



**Figure 6:** Text labels controlling the cut-off frequencies of built-in Butterworth band-pass filter.

## *4.3 SEMG signal visualization*

To display loaded and band-pass filtered sEMG signals, select first the corresponding electrode row or electrode column (**Figure 7**, left panel) and click on "`Plot signals`" button (**Figure 7**, right panel). Matlab figure with selected sEMG channels appears (**Figure 8**).

**Note:** ! *Due to the large number of acquired sEMG channels, only selected row/column of sEMG channels can be displayed in one figure. The number of figures, however, is not limited. You can display all the sEMG channels by consecutively selecting the different electrode columns, for example.*


**Figure 7:** Channel selection frame (left panel) and plot signals button (right panel). 6th electrode row is selected.

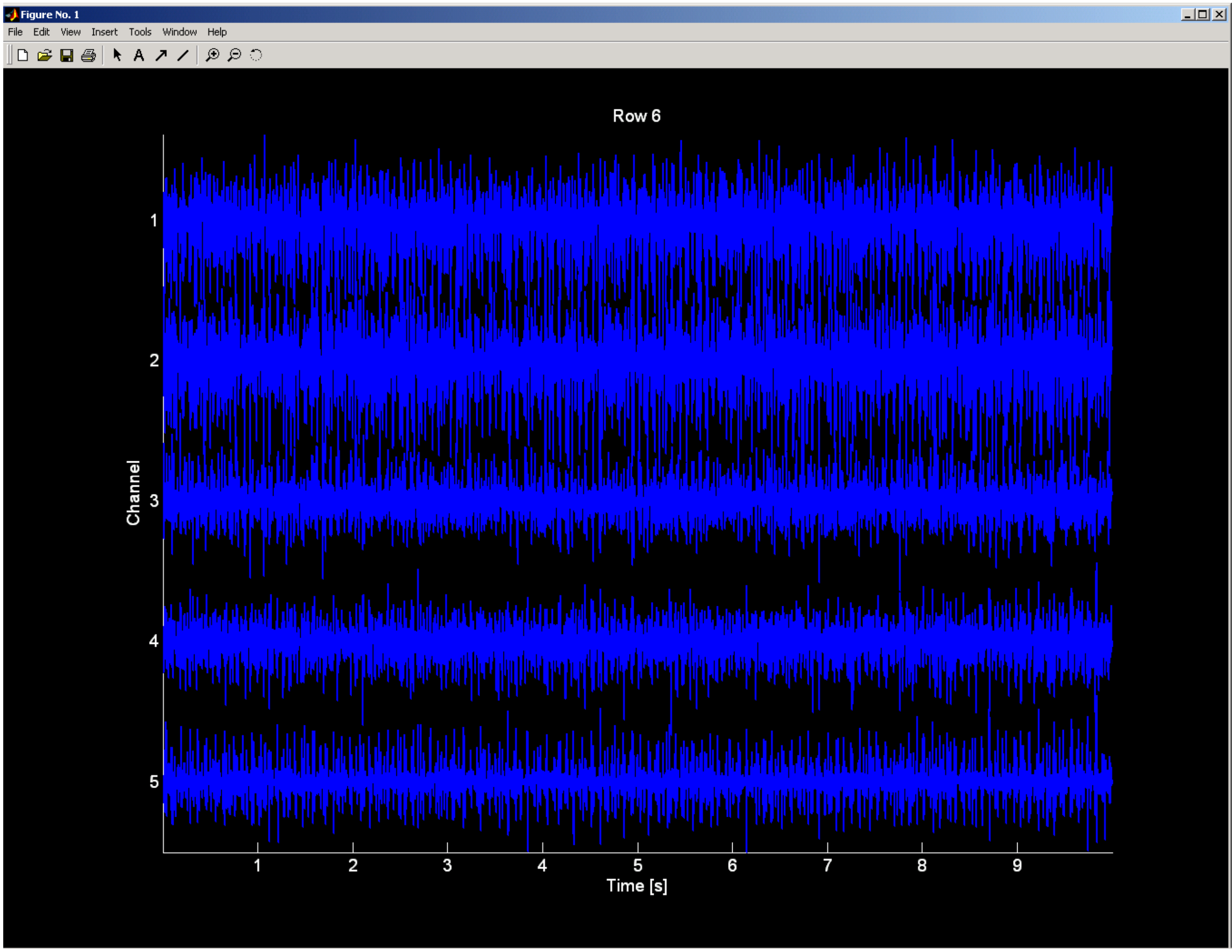



**Figure 8:** Matlab figure with selected sEMG channels

Displayed figures can be manipulated by using standard matlab graphical tools for zooming in/out, for saving and printing the figure (**Figure 9**). Zoomed-in version of **Figure 8** is depicted in **Figure 10**.

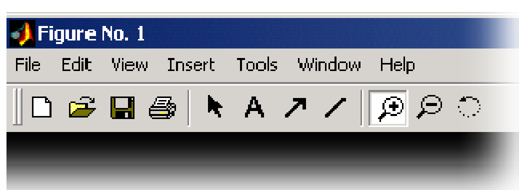



**Figure 9:** Matlab figure toolbar with tools for zooming in/out on a figure, and for saving and printing the figure.

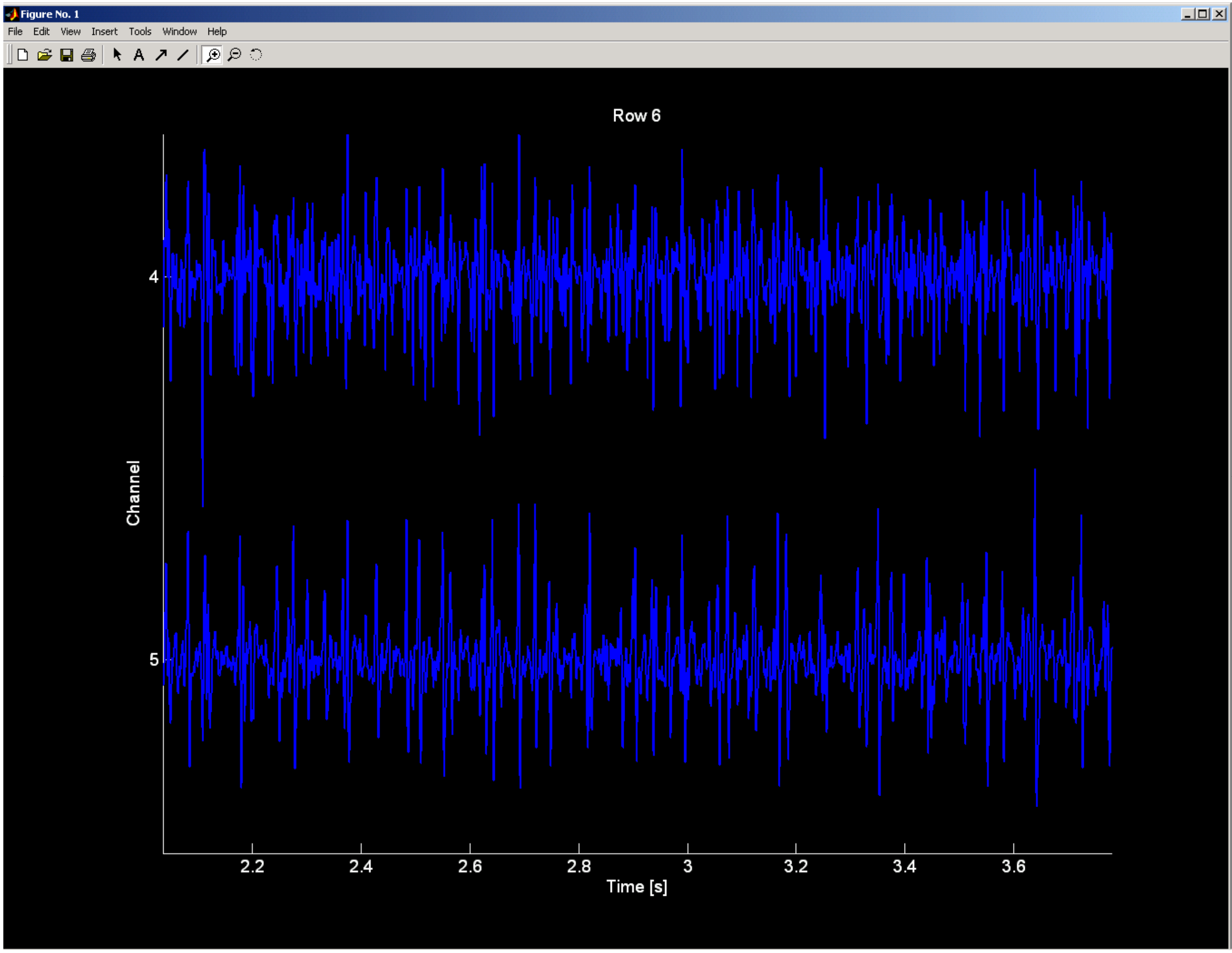



**Figure 10:** Zoomed-in version of **Figure 8**.

Figures can be closed by clicking on a corresponding buttons in the top right corner of each figure (**Figure 11**).

**Figure 11:** Buttons for minimization, maximization and closing of the figure.

## 4.4 SEMG signal decomposition

Decomposition of sEMG signals is fully automatic. The user specifies only the number of decomposition runs (**Figure 12**) and (optionally) the initial sEMG signal offset (**Figure 13**).

DEMUSEtool uses the gradient Convolution Kernel Compensation (gCKC) decomposition technique [3]. gCKC is a sequential motor unit (MU) identification method and requires one iteration run per each reconstructed MU. The user can predefine the number of iterations by moving the slider "`Decomp. runs`" (**Figure 12**). As a general rule, the number of iterations should be larger or equal to the number of expected MUs (excluding the small and deep MUs, which contribute the background noise only). As the exact number of MUs is difficult to estimate, the number of decomposition runs should be large (default value is set to 30). DEMUSEtool automatically tests the reconstructed MU discharge patterns against the predefined ranges of physiological variables (i.e., discharge rate, variability of inter-pulse interval, etc.) and discards all the outliers. As a result, from 5 to 15 most reliably reconstructed MUs are taken into consideration. Reconstructed MUs are additionally sorted with respect to the aforementioned degree of decomposition reliability (the first MU being the most reliable one).

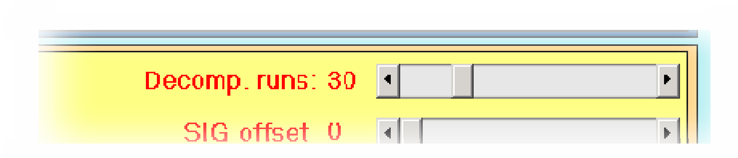



**Figure 12:** Slider for selection of decomposition runs

For practical reasons, the user can also specify the initial signal offset (**Figure 13**). This allows him to discard the initial signal portions where, for example, the contraction level is not yet stabilized, etc. The initial signal offset is measured in seconds.

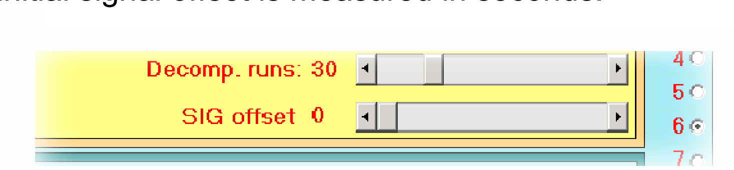



**Figure 13:** Slider for selection of initial sEMG signal offset

The decomposition starts by clicking on "`Run decomposition`" button (**Figure 14**).

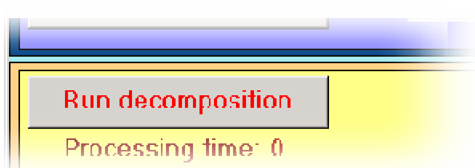



**Figure 14:** "`Run decomposition`" button

During the decomposition, the reconstructed MU discharge patterns are displayed (**Figure 15**, **Figure 16**) and the instantaneous MU discharge rate and inter-pulse interval variability are automatically calculated. The reconstructed discharge pattern is put into the set of reconstructed MUs if and only if the calculated values fall within the expected range of values (i.e., discharge rate between 6 and 45 pulses per second, Coefficient of Variability of inter-pulse interval smaller than 20 %). The selected MU discharges of accepted discharge pattern are depicted by green circles (**Figure 15**). The reconstructed discharge pattern with the calculated values outside the expected range of values is discarded. The selected MU discharge pulses of discarded pattern are depicted by red circles (**Figure 16**).

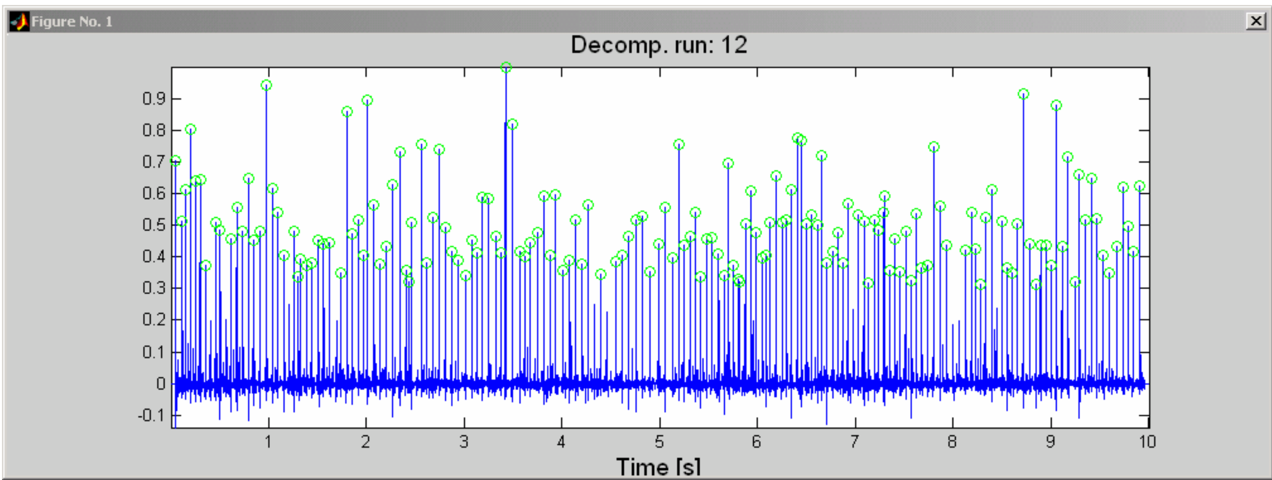



**Figure 15:** MU discharge pattern, reconstructed in the 12th iteration of the gCKC decomposition technique. Each pulse corresponds to a single MU discharge. Average discharge rate and coefficient of variability of inter-pulse interval are within the expected range of values. Thus, the selected MU discharges are depicted by green circles.

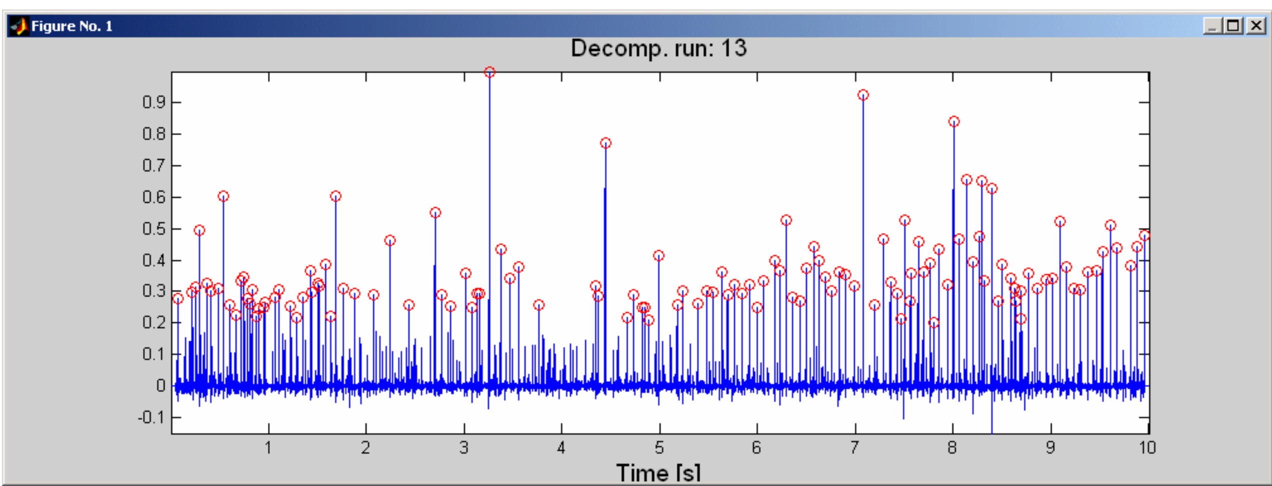



**Figure 16:** MU discharge pattern, reconstructed in the 13th iteration of the gCKC decomposition technique. Each pulse corresponds to a single MU discharge. Average discharge rate and coefficient of variability of inter-pulse interval are outside the expected range of values. Thus, the selected MU discharges are depicted by red circles while the reconstructed discharge pattern is discarded.

When the decomposition ends, the total processing time is displayed (**Figure 17**).

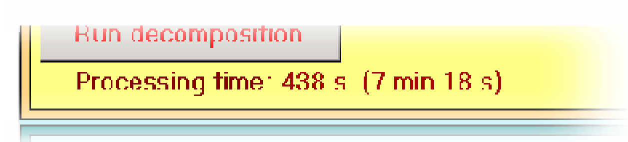



**Figure 17:** Text label displaying the total processing time.

## 4.5 Visualisation and editing of the decomposition results

Decomposition results can be visually inspected and edited by sEMG editor (**Figure 19**). To open sEMG editor, click on "`sEMG editor`" button (**Figure 18**).


**Figure 18:** "`sEMG editor`" button

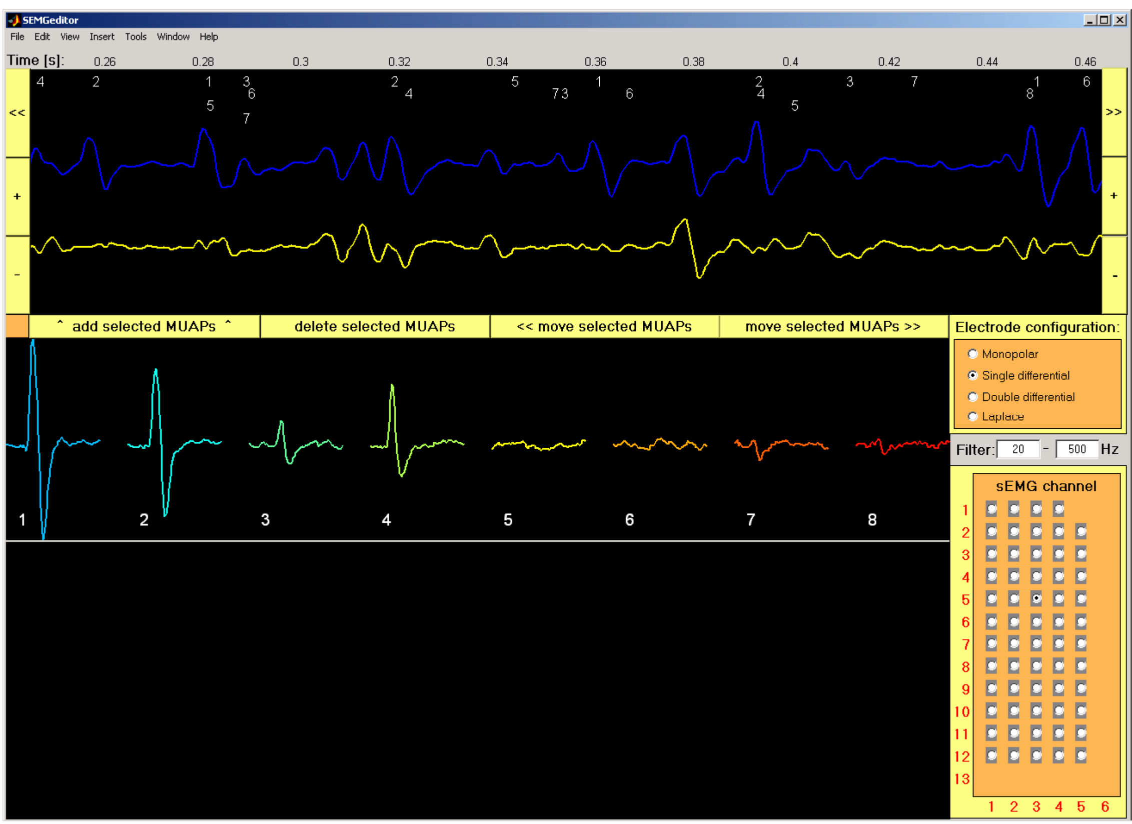



**Figure 19:** "`sEMG editor`" window

### 4.5.1 Plotting sEMG signals

`sEMG editor` window comprises three panels (**Figure 19**). The top panel displays original sEMG channel (blue line) and the residual after subtraction of identified MUAPs (yellow line). The ID of MU discharging at a particular time moment is also depicted (**Figure 20**).

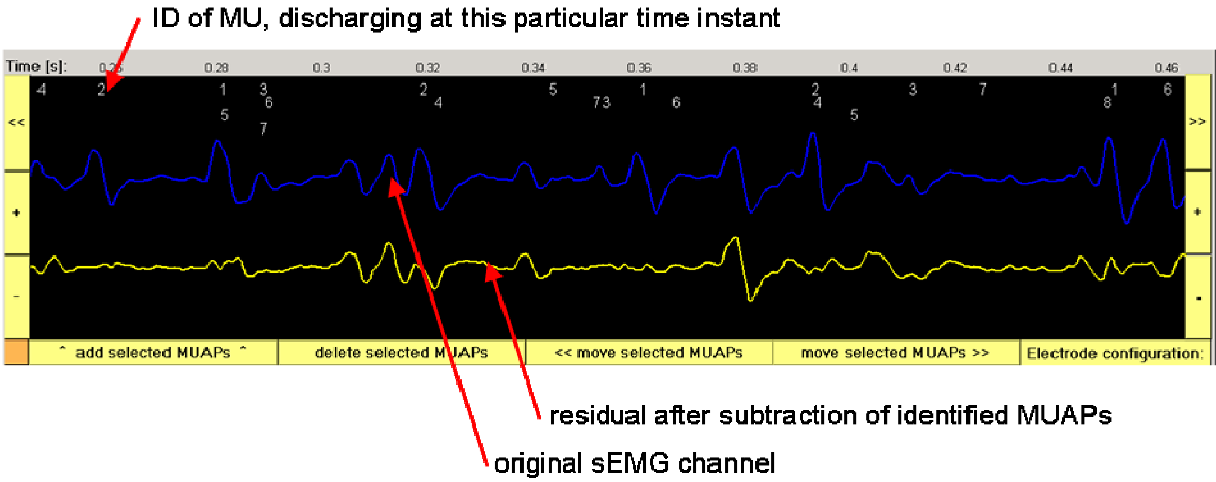



**Figure 20:** The top panel of "`sEMG editor`" window with original sEMG channel (blue line) and residual after subtraction of the identified MUAPs (yellow line)

Buttons at the left and right hand side of the top panel determine the position and the size of the time window being depicted. Buttons "<<" and ">>" move the displayed window left and right, respectively (**Figure 21**). Button "+" ("-") zooms in(out) on a displayed signals (decreases/increases the length of the time window).

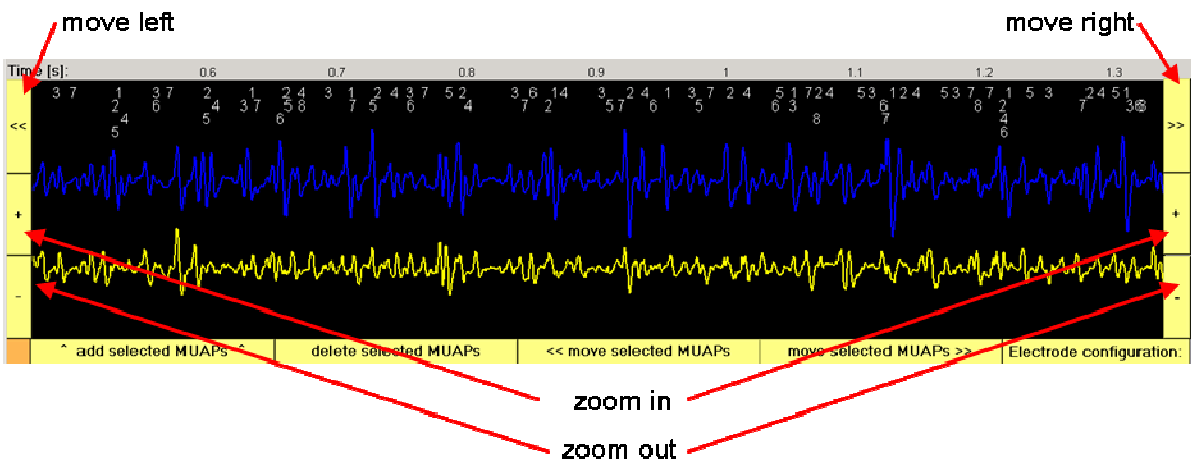



**Figure 21:** The top panel of "`sEMG editor`" window with buttons for moving left/right and zooming in/out on displayed signals.

### 4.5.2 Displaying instantaneous MU discharge rate

The central panel of the "`sEMG editor`" window displays the MUAP templates of different MUs, as estimated by spike triggering averaging of the selected sEMG channel (**Figure 22**). The identified MU discharges are taken as trigger. The length of the averaging window is set equal to 10 ms.

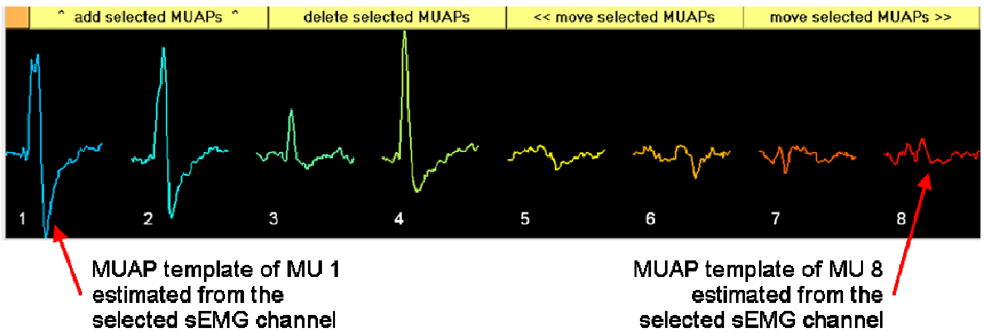



**Figure 22:** The central panel of "`sEMG editor`" window with MUAP templates. MUAP templates are estimated by spike triggered averaging of the selected sEMG channel.

The central panel allows the user to select a particular MU by clicking on corresponding MUAP template. The MUAP occurrences of selected MUs are automatically displayed in the top panel, while the bottom panel displays the instantaneous discharge rate plot (**Figure 24**). Several MUs can be simultaneously selected (**Figure 25**).

Each circle in the bottom panel corresponds to a single MU discharge (**Figure 23**). The horizontal position of the circle denotes the MUAP occurrence time, whereas its vertical position reflects instantaneous MU discharge rate (calculated as the quotient between the sampling frequency and the inter-pulse interval preceding the selected MU discharge). The position and the length of the signal window, displayed in the top panel, is also depicted (grey rectangle). User can move to the time of a particular MU discharge by simply clicking on the corresponding circle.

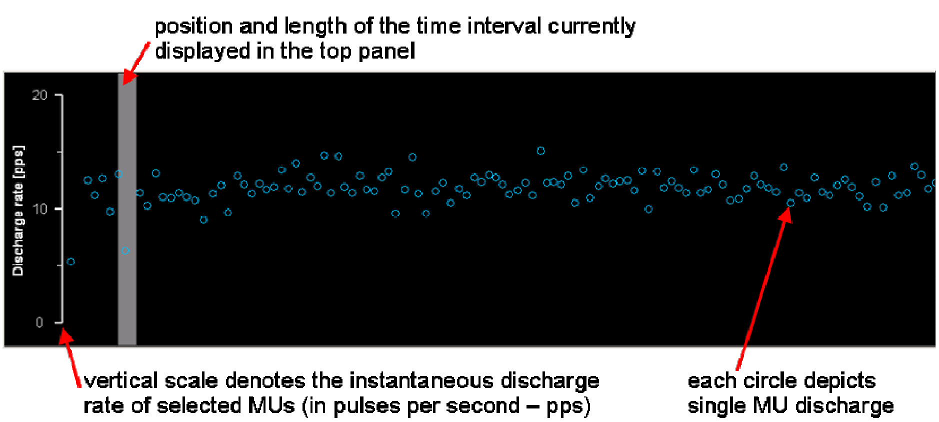



**Figure 23:** Bottom panel of the "`sEMG editor`" window with the instantaneous discharge rate plot of a selected MUs.

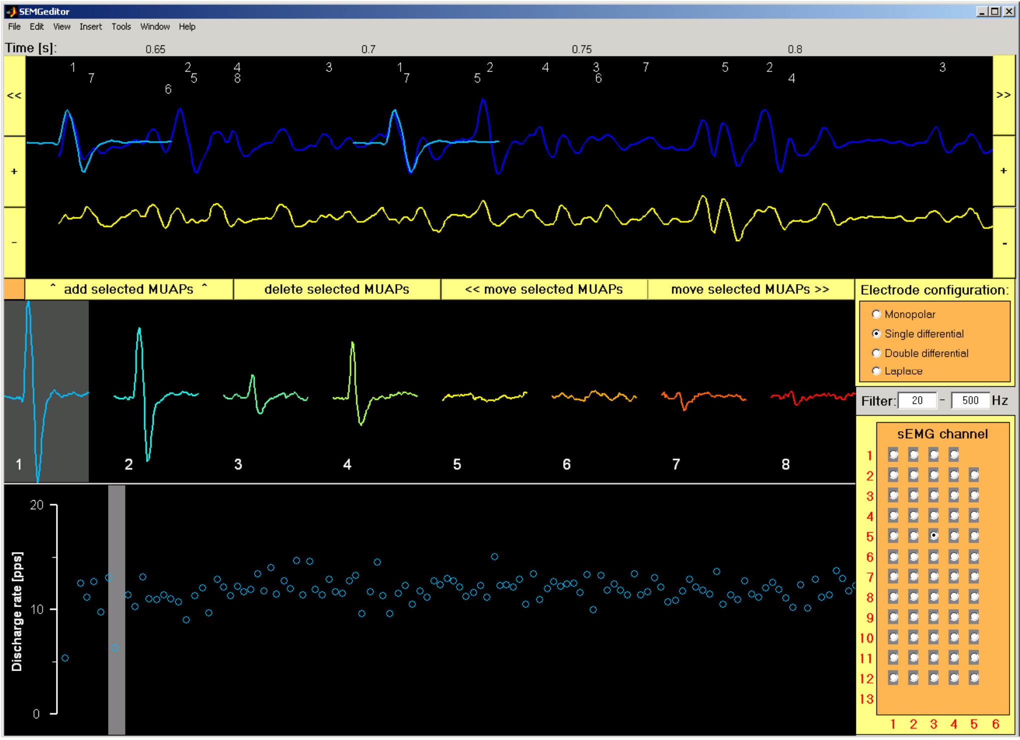


**Figure 24:** MU 1 is selected by clicking on its MUAP template in the central panel. MUAP occurrences and instantaneous discharge rates of selected MU are automatically depicted in the top and the bottom panel, respectively.

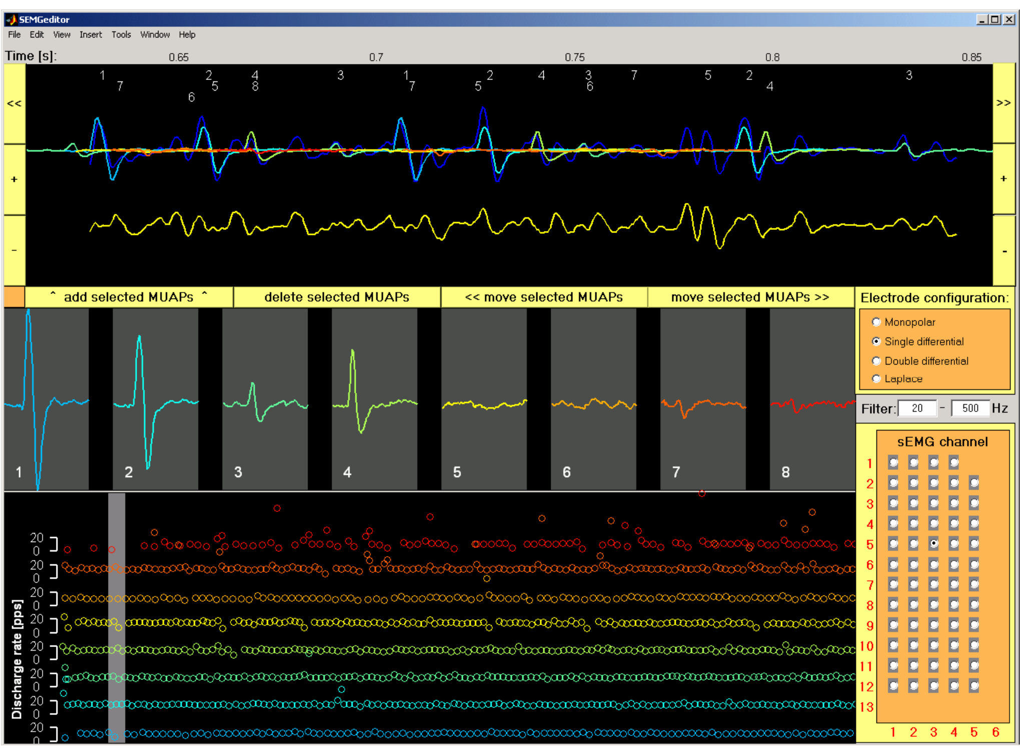


**Figure 25:** The same as in **Figure 24**, with all MUs selected.

### 4.5.3 Adding a new MUAP occurrence

A double click on a MUAP template in the central panel, followed by a click on the "`add selected MUAP`" button adds the MUAP of the selected MU to the top panel. The optimal MUAP position is automatically determined by the minimum squared error between the residual signal (**Figure 26**, yellow line) and the selected MUAP template. In the central panel, the selected MUAP template is denoted by a red rectangle (**Figure 26**, central panel). A further double-click on the already selected MUAP template (e.g., MUAP template of MU 1 in **Figure 26**) deselects the corresponding MU.

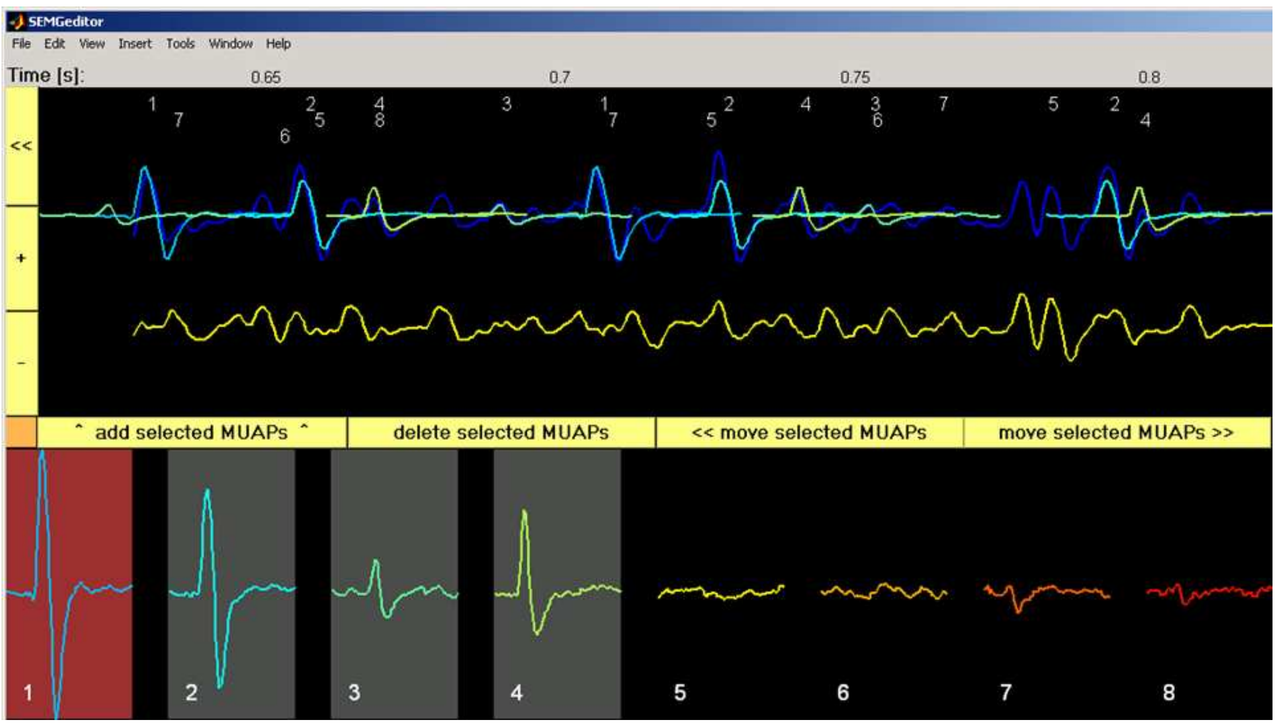



**Figure 26:** Double click on a MUAP template of MU 1, followed by a click on a "`add selected MUAP`" button adds the MUAP to the top panel. The MUAP template selected by double-click is depicted by a red rectangle.

**Note:** **!** *Double-click on a MUAP template could directly result in adding of the new MUAP occurrence to the top panel. However, this would cause errors in the case of unintentional double-clicks on the central panel. Therefore, adding of a MUAP occurrence must be explicitly confirmed by clicking on* "`add selected MUAP`" *button.*

### *4.5.4 Moving and deleting MUAP occurrences*

Each MUAP occurrence, displayed in the top panel, can be manually moved to the left, moved to the right, and deleted, respectively. The user must first click on the displayed MUAP occurrence in the top panel in order to select it. The selected MUAP occurrence is denoted by a thick red line (**Figure 27**). Afterwards, the selected MUAP occurrence can be moved or deleted by clicking on a "`<< move selected MUAPs`", "`move selected MUAPs >>`" and "`delete selected MUAPs`" button, respectively (**Figure 27**).

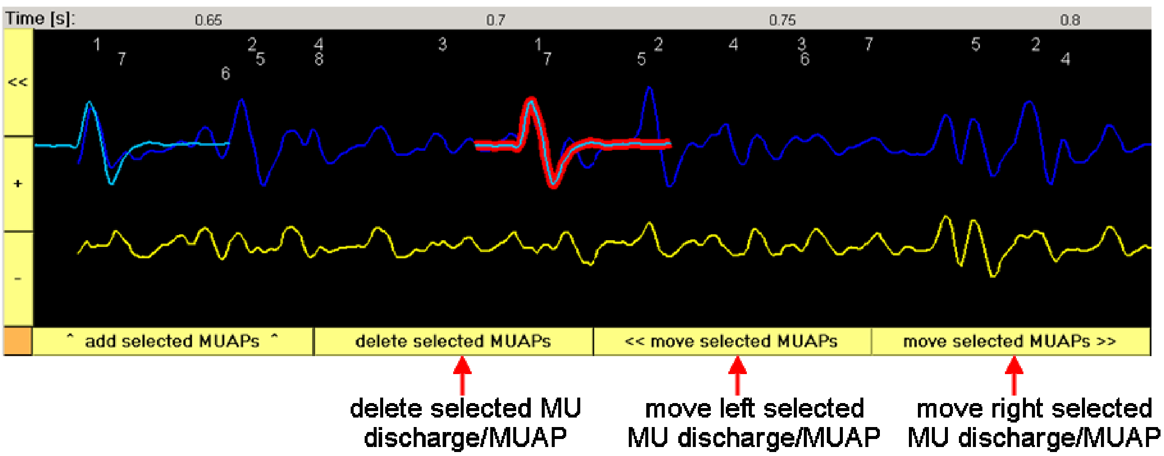



**Figure 27:** Manipulation of selected MUAP occurrence (depicted by red thick line). The selected MUAP occurrence can be moved left/right or deleted

Each user action results in an immediate update of a signal residual and MUAP templates (**Figure 28**). Selected MUAP occurrence can be deselected by a single click.

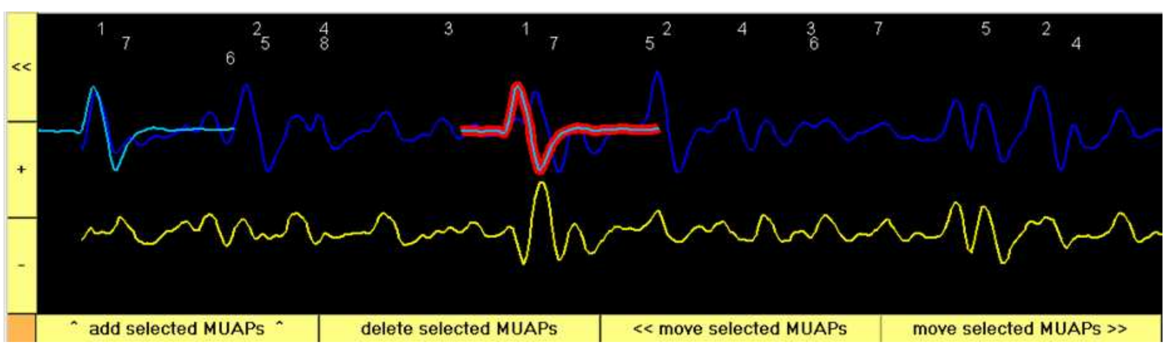



**Figure 28: S**ame as in **Figure 27**, with the selected MUAP occurrence moved to the left. Increase of the sEMG channel residual signal (yellow line) is clearly visible (when compared to **Figure 27**).

**Note:** *Several MUAP occurrences can be simultaneously selected. This saves the user's time and energy in the case of intensive manual editing.*

**!**

### 4.5.5 Selecting sEMG channel, spatial filter and cut-off frequencies

The sEMG channel to be displayed can be selected by clicking on a radio button representing the corresponding channel in the left bottom corner of the "`sEMG editor`" window (**Figure 29**). Electrode rows and columns are denoted by red numbers displayed at left/bottom of the channel selection panel. Text labels right above the "`sEMG channel`" selection panel, display cut-off frequencies of the 4th order Butterworth band-pass filter. Cut-off frequencies can be modified by typing into the aforementioned text labels (**Figure 29**). The sEMG signals and corresponding MUAP templates are automatically recalculated when cut-off frequencies are changed. Default cut-off frequencies values are set to 20 and 500 Hz, respectively.

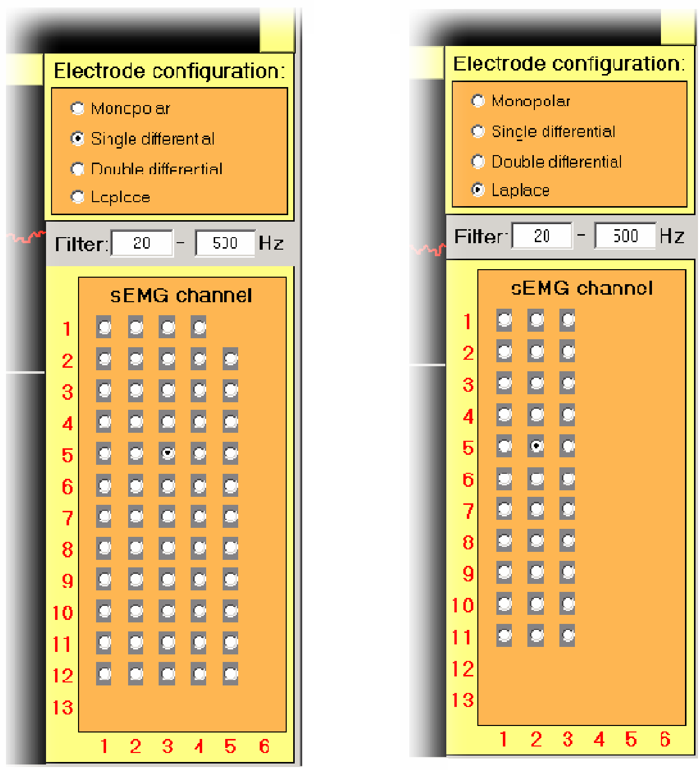



**Figure 29:** Command frame of "`sEMG editor`" with "`sEMG channel`" panel, Butterworth band-pass filter cut-off frequencies and "`Electrode configuration`" panel for single differential electrode configuration (*right*) and Laplacian electrode configuration (*left*).

Above the filter cut-off frequencies, there is the "`Electrode configuration`" panel (**Figure 29**). It allows the user to choose among different spatial filters applied to acquired sEMG signals. The following four spatial filters are currently supported: monopolar, longitudinal single differential (default), longitudinal double differential and Laplacian. "`sEMG channel`" selection panel, sEMG channel displayed in the top panel, and corresponding MUAP templates are automatically updated whenever a new spatial filter is selected (**Figure 29**).

## 4.6 Graphical results

DEMUSEtool includes several tools for graphical representation of the decomposition results. The user can plot the discharge patterns of reconstructed MUs, instantaneous MU discharge rates, multichannel MUAPs and reconstructed MUAP trains. In addition, MUAP generation, propagation and attenuation can be animated for each identified MUs. All the graphical results are depicted in matlab figures and can be easily manipulated by standard matlab's editing tools. In the sequel, description of each aforementioned graphical representation is provided.

### 4.6.1 MU discharge patterns plot

MU discharge patterns are plotted by a click on a "`Plot MU discharges`" button (**Figure 30**). A matlab figure opens with a plot of all reconstructed MU discharge patterns (**Figure 31**). Each circle in the figure corresponds to a single MU discharge. The horizontal position of the circle denotes the time of MU discharge, whereas its vertical position reflects instantaneous MU discharge rate (calculated as a quotient between the sampling frequency and the inter-pulse interval preceding the given MU discharge). Discharge patterns of different MU are depicted one above the other.

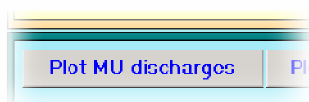



**Figure 30:** "`Plot MU discharge`" button

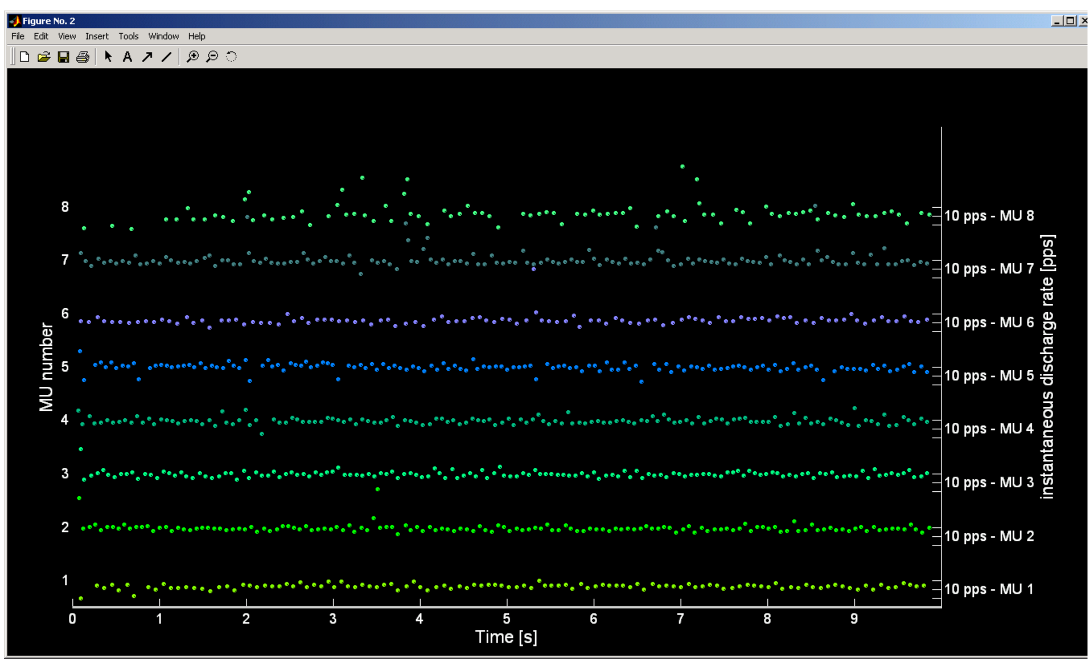



**Figure 31:** Plots of reconstructed MU discharge patterns. Vertical axis on the left displays MU IDs, vertical axis on the right displays the instantaneous discharge rates (in pulses per second - pps). The tick lines on the right denote the discharge rates of 5, 10 and 15 pps, respectively. Discharge patterns of different MUs are depicted one above the other.

### *4.6.2 Instantaneous discharge rate plots*

MU instantaneous discharge rate plots are plotted by a click on a "`Plot discharge rates`" button (**Figure 32**). A matlab figure opens with a different colour lines depicting the instantaneous discharge rates of different MUs (one line per each MU). The thick grey line depicts the exerted muscle force (when measured during the acquisition of sEMG signals). Instantaneous discharge rates are calculated by low-pass filtering of the reconstructed discharge patterns (4$^{th}$ order Butterworth filter with cut-off frequency set to 50 Hz).

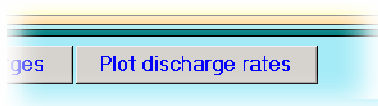



**Figure 32:** "`Plot MU discharge`" button

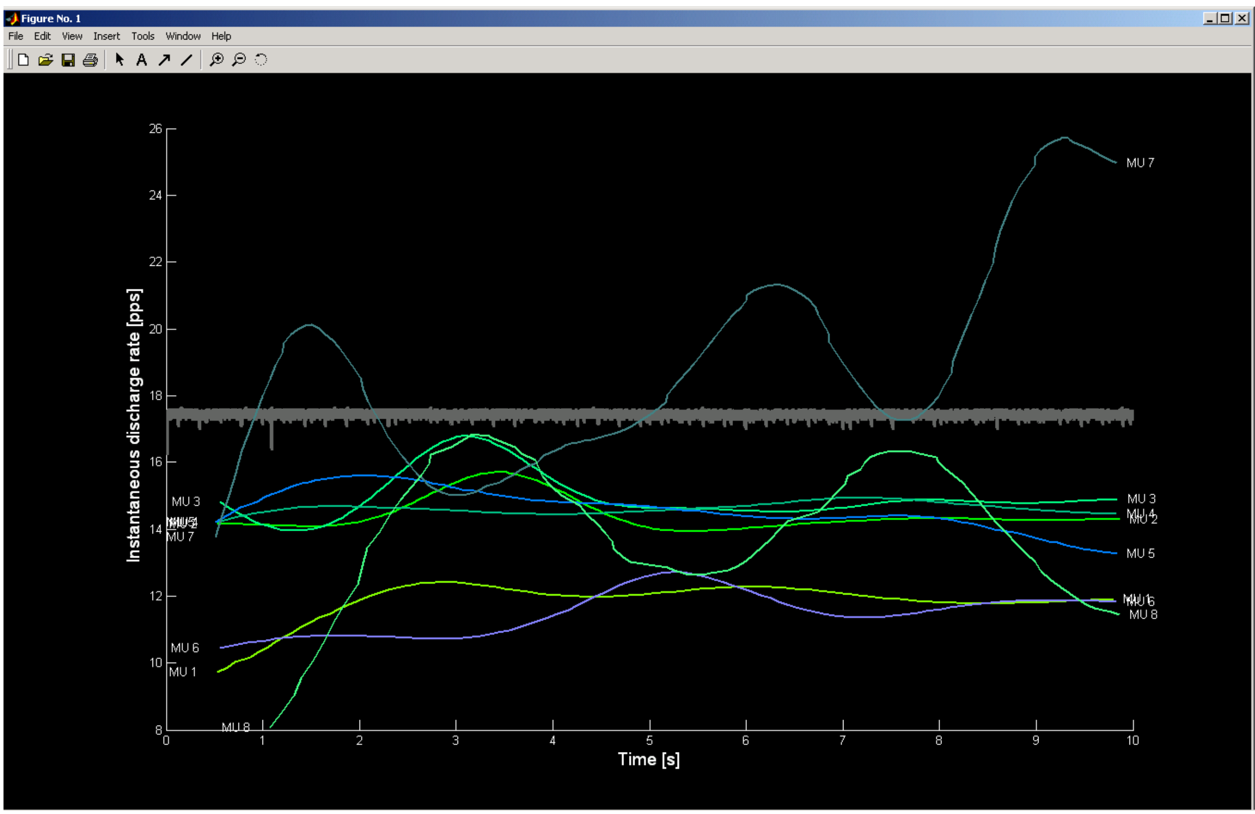



**Figure 33:** Plot of instantaneous discharge rates (coloured thin lines). Vertical axis depicts the instantaneous discharge rates (in pulses per second - pps). Thick grey line depicts the measured muscle force.

### 4.6.3 Multichannel MUAP plots

Multichannel MUAP plots (so called MU fingerprints) can be plotted by clicking on a "`Plot MUAPs`" button (**Figure 34**, left panel). MU to be depicted is selected by a MU selection slider (**Figure 34**, right panel). A matlab figure opens (**Figure 35**) with MUAP shapes as estimated by a spike triggered averaging of each acquired sEMG channel. Displayed MUAPs are spatially organized in rows and columns, reflecting the relative position of pick-up electrodes in longitudinal single-differential configuration.


**Figure 34:** "`Plot MU discharge`" button (left) and MU selection slider (right)

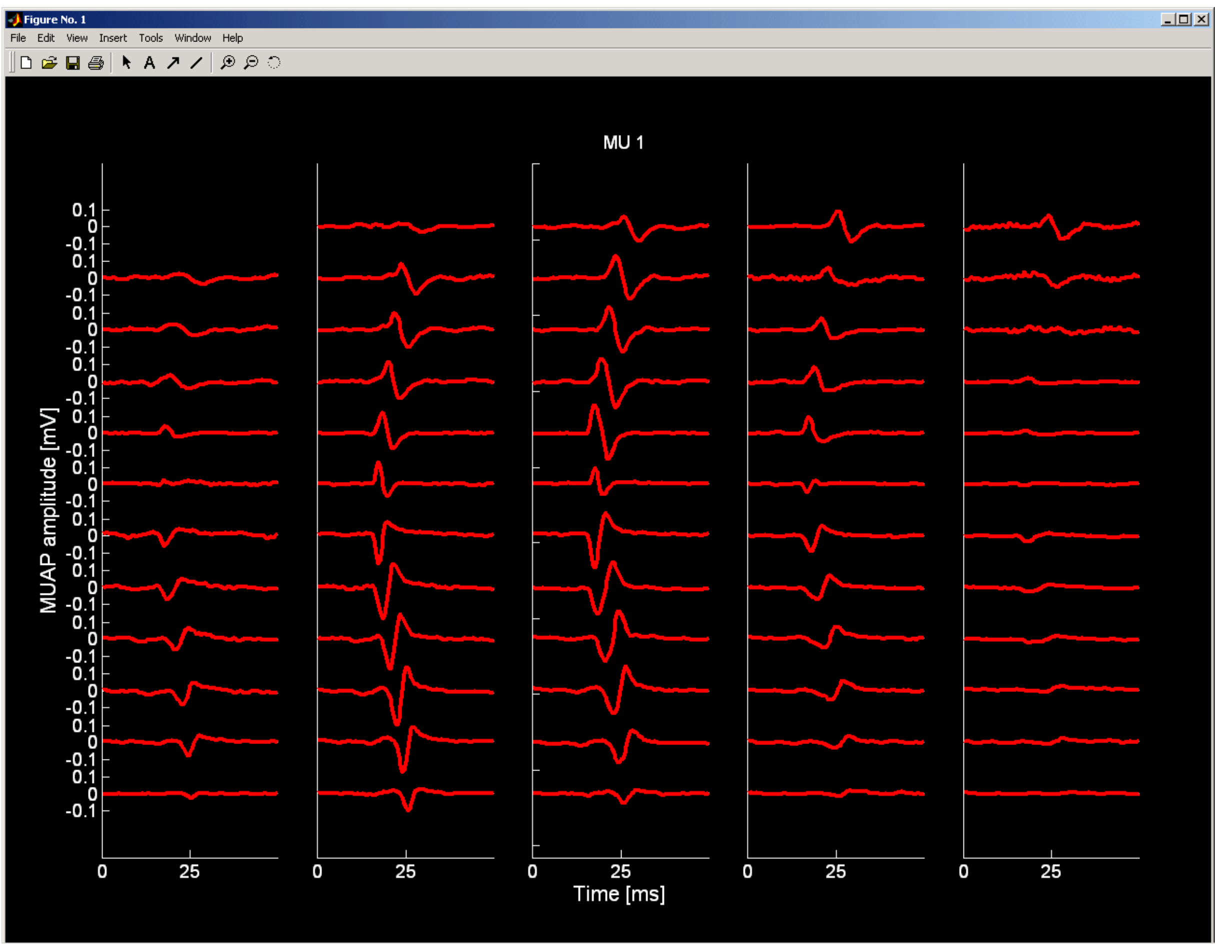



**Figure 35:** Multi-channel MUAPs estimated by spike-triggered averaging of sEMG signals. sEMG signals were recorded with a grid of 61 electrodes arranged in 5 columns and 13 rows. The location of the innervation zone, tendon regions and propagation of motor unit action potentials are visible.

### 4.6.4 2D MUAP map animation

DEMUSEtool offers two animations of MUAP generation, propagation and attenuation process. The first one, so called 2D MUAP map, is a pseudocolor plot of the estimated MUAP amplitude in a given time instant. First, MUAP templates are estimated by a spike triggered averaging of the sEMG channels. sEMG channels are then spatially organized into a discrete 2D map, reflecting the relative position of pick-up electrodes. The amplitudes of MUAP templates at a given time instant specify the colour on this 2D map of channels. The missing intermediate points on the map are calculated by bilinear interpolation of the MUAP amplitudes in four adjacent sEMG channels. In the next animation frame, the animation time is advanced by one sample and the 2D MUAP map is recalculated (**Figure 37**).

The MU and the animation frame rate are selected by the sliders shown in **Figure 36** (right panel). After clicking on the “`Animate 2D MUAP map`” button (**Figure 36**, left panel) animation window opens (**Figure 37**) and the animation starts automatically. The animation begins approx. 5 ms before the actual generation of the multi-channel MUAP and ends approx. 5 ms after the MUAP attenuation. During the animation, the propagation of MUAP along the muscle fibers can be observed (**Figure 37**).

Buttons on the top of the animation window (**Figure 37**) enable the following actions:

- “>” button: (re-)plays the animation;
- “||” button: pauses the animation;
- ”[]” button: stops the animation;
- “[<]” button: animates the previous animation frame (i.e., step backward);
- “[<]” animates the next animation frame (i.e., step forward).

Current animation frame is displayed in the top right corner of the animation window (**Figure 37**).


**Figure 36:** “`Animate 2D MUAP map`” button (left) and sliders for selection of MU and frame-rate (right)

**Note:** *Animation window cannot be closed while the animation is running. Stop the animation (by clicking on “||”or ”[]”button) before you close the figure.*

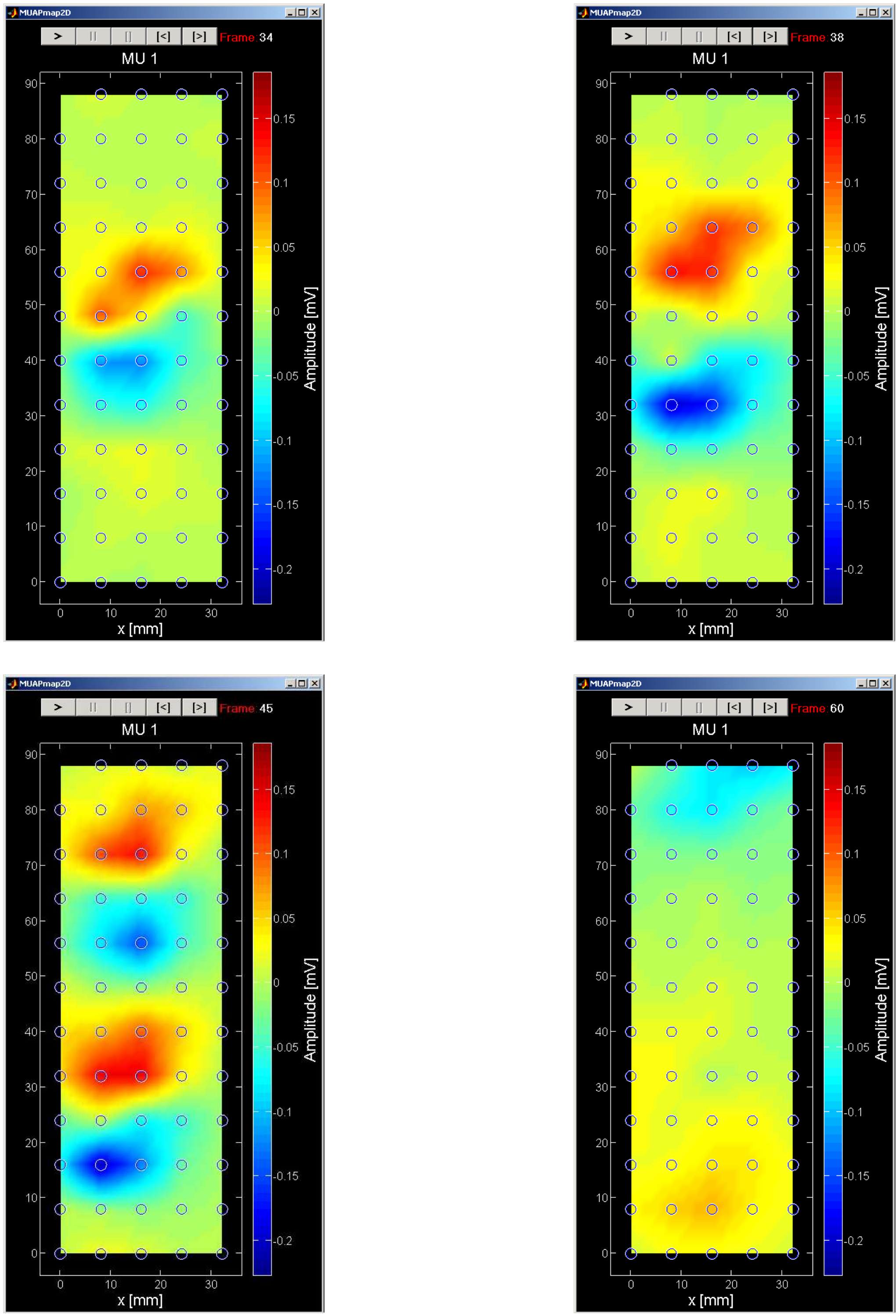



**Figure 37:** Pseudocolor animation of a MUAP generation, propagation and attenuation process. MUAP amplitudes on different sEMG channels (black&white circles) specify the colours of corresponding points on the 2D map. Colours of intermediate map points are calculated by the bilinear interpolation of the MUAP amplitudes in four adjacent sEMG channels.

### 4.6.5 3D MUAP map animation

The second animation, provided by the DEMUSEtool, includes a 3D plot of MAUP amplitude in time. By analogy with the animation of 2D MUAP map, MUAP templates are first estimated by a spike triggered averaging of sEMG channels. sEMG channels are then spatially organized into a discrete 2D map, reflecting the relative position of pick-up electrodes. The amplitudes of MUAP templates at a given time instant specify the height on this 2D map of channels. Missing intermediate points on the map are calculated by bilinear interpolation of MUAP amplitudes in four adjacent sEMG channels. In the next animation frame, the time is moved forward by one signal sample and the 3D map is recalculated.

To start the 3D animation, select the MU and the animation frame rate (**Figure 38** right panel). After clicking on the "`Animate 3D MUAP map`" button (**Figure 38**, left panel) the animation window opens (**Figure 39**) and the animation automatically starts. The animation begins approx. 5 ms before the actual generation of the MUAP and ends approx. 5 ms after the MUAP attenuation. During the animation, the propagation of MUAP along the muscle fibers can be observed (**Figure 39**).

Buttons on the top of the animation window (**Figure 39**) enable the following actions:

- ">" button: (re-)plays the animation;
- "||" button: pauses the animation;
- "[]" button: stops the animation;
- "[<]" button: animates the previous animation frame (i.e., step backward);
- "[<]" animates the next animation frame (i.e., step forward).

The current animation frame is displayed in the top right corner of the animation window (**Figure 39**). The animation window is a regular matlab figure and can be freely manipulated by all available matlab graphical tools (e.g. zooming, coping, printing etc.).


**Figure 38:** "`Animate 3D MUAP map`" button (left) and MU selection and frame-rate sliders (right)

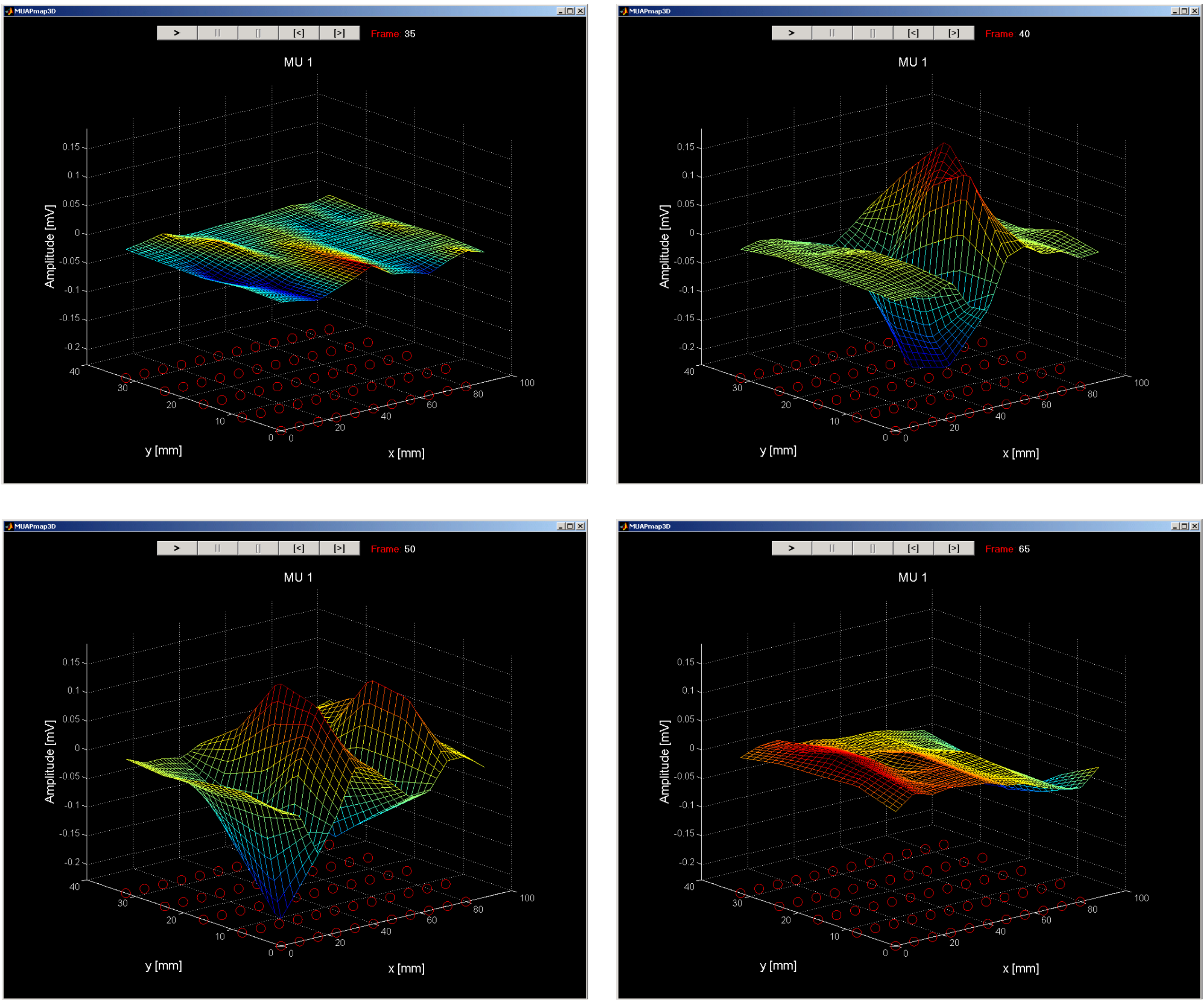



**Figure 39:** 3D animation of MUAP generation, propagation and attenuation. MUAP amplitudes on different sEMG channels (red circles) specify the height of corresponding points on a 2D map (heights of intermediate map points are calculated by the bilinear interpolation of the MUAP amplitudes in four adjacent sEMG channels).

**Note:** ! *Animation window cannot be closed during the run of animation. Stop the animation (by clicking on “||”or ”[]”button) before you close the figure.*

During the 3D animation, the axes of the 3D plot can be freely rotated. To rotate a 3-D axes, click on the axes and drag the cursor in the direction you want to rotate. When you release the mouse button, DEMUSEtool redraws the axes in the new orientation (**Figure 40**).

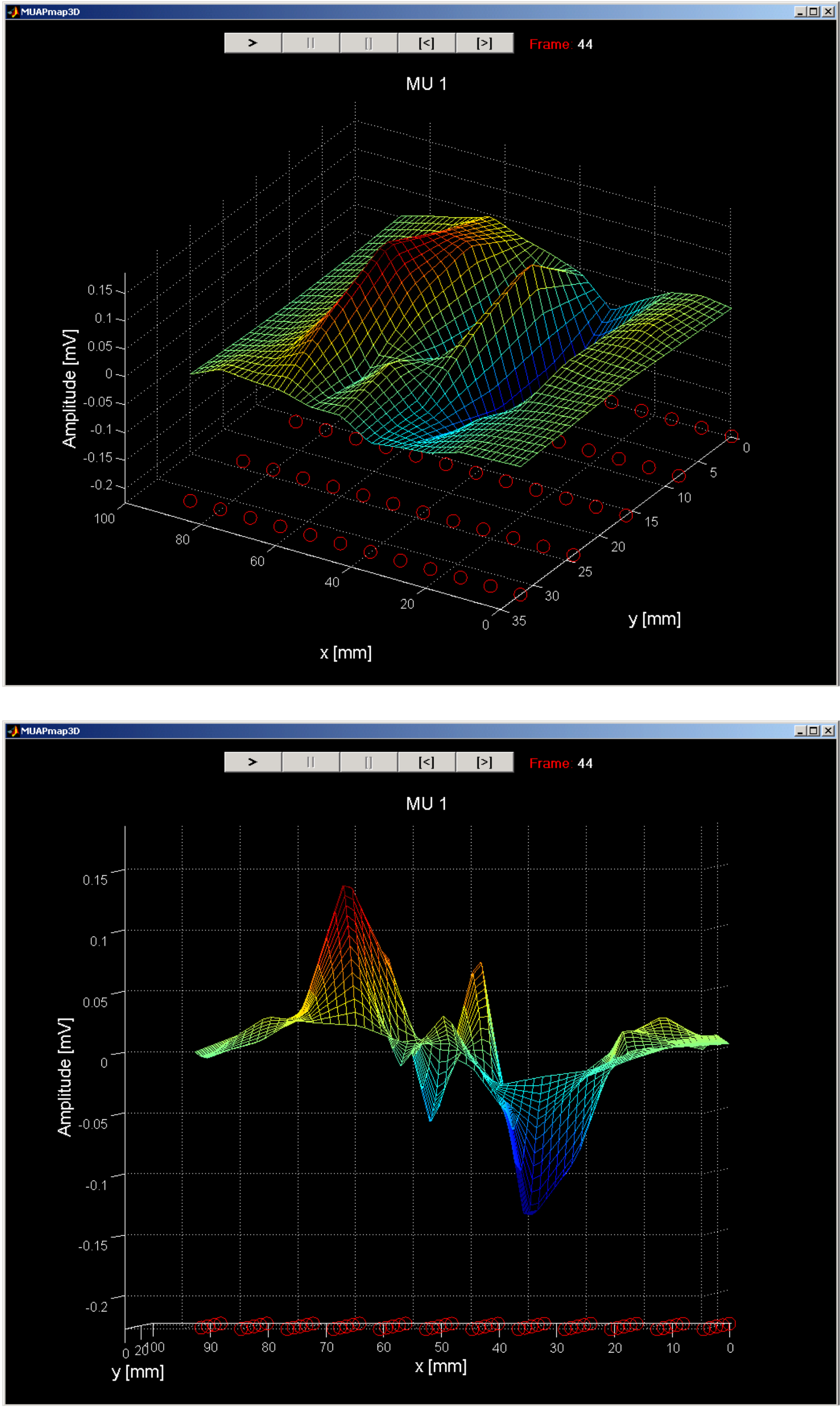



**Figure 40:** 3D rotation of the axes; the axes of the 3D plot can be freely rotated by clicking on the axes and dragging the cursor in the direction you want to rotate the plot.

### 4.6.6 Plots of reconstructed MUAP trains

DEMUSEtool provides tool for plotting the sum of reconstructed MUAP trains superimposed to the original sEMG signals. This proves beneficial when evaluating the efficiency of the decomposition process. In surface EMG, there are many small and deep MUs which cannot be recognized. They contribute the background (physiological) noise. The second source of noise is so called instrumentation or thermal noise, which originates from the instrumentation's parasite capacities, line interference, etc. All together, these sources add to the measurement noise and affect the efficiency of the sEMG decomposition. By comparing the sum of the reconstructed MUAP trains to the original sEMG signal one can estimate the relative proportion of recognized sEMG components and, hence, speculate on the power (and even on the nature) of the measurement noise.

In the DEMUSEtool, the reconstructed MUAP trains are calculated as follow. Firstly, the MUAP shapes are estimated by spike triggered averaging of the acquired sEMG channel, using the identified MU discharge instants as trigger. The estimated MUAP shapes are then convolved with the identified MU discharge patterns and summed together. The sum of MUAP trains is subtracted from the original sEMG signals and the following signal-to-interference ratio (SIR) between the original sEMG signals and the residue after the subtraction is calculated:

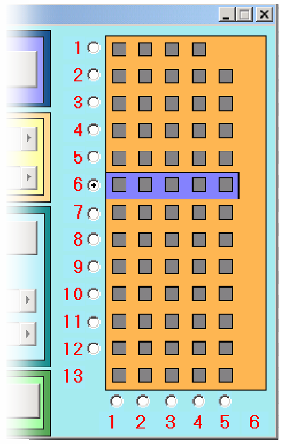
$$SIR(i) = \left(1 - \frac{E\left[(x_i(n) - \sum_j z_{ij}(n))^2\right]}{E\left[x_i^2(n)\right]}\right) \cdot 100\,\%$$

where $x_i(n)$ denotes the *i*-th sEMG measurement, $z_{ij}(n)$ stands for the *j*-th MU's MUAP train reconstructed from the *i*-th sEMG measurement and $E$ stands for sample mean. Finally, the range of SIRs of depicted sEMG channels is displayed together with the reconstructed MUAP trains (**Figure 42**).

To display reconstructed MUAP trains, select the corresponding electrode row or electrode column (**Figure 41**, left panel) and click on "`Plot MUAP trains`" button (**Figure 41**, right panel). Matlab figure with selected sEMG channels and corresponding MUAP trains appears (**Figure 42**).

**Note:** !

*Due to the large number of acquired sEMG channels, only selected row/column of sEMG channels can be displayed in one figure. The number of figures, however, is not limited. You can display the MUAP trains on all the sEMG channels by consecutively selecting the different electrode columns, for example.*



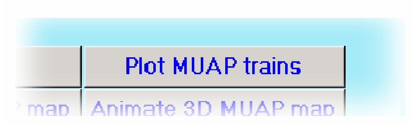




**Figure 41:** Channels selection frame (left) and "`Plot MUAP trains`" button (right).

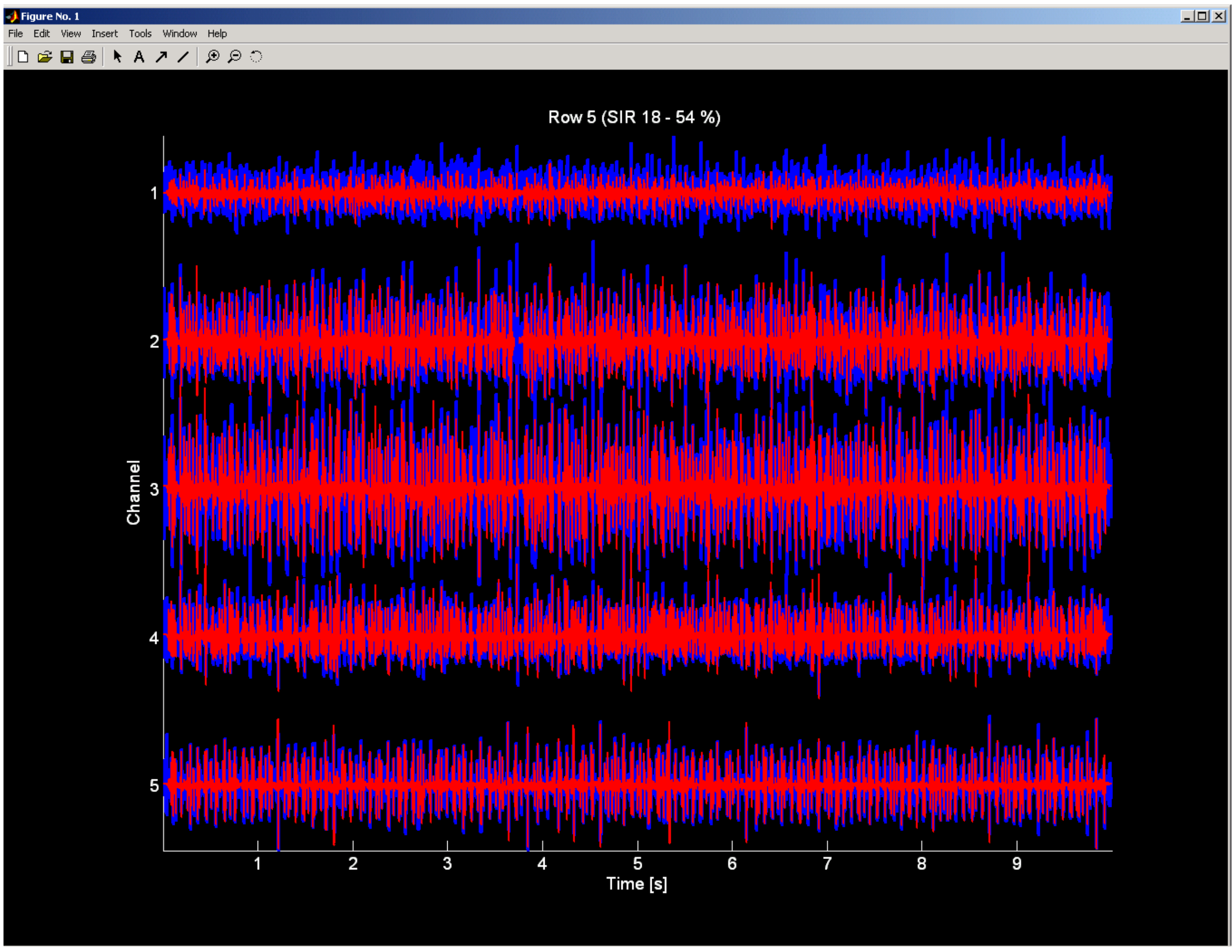



**Figure 42:** Matlab figure of selected sEMG channels and corresponding reconstructed MUAP trains. The range of SIRs of the depicted channels is displayed on the top of the figure.

Plots of reconstructed MUAP trains are displayed as matlab figures and can be freely manipulated by matlab figure editing tools (i.e., figure resizing, zooming, rotating, printing, etc.). Zoomed-in portion of **Figure 42** is depicted in **Figure 43**. The user is referred to matlab documentation for further details on the use of the matlab's graphic user interface.

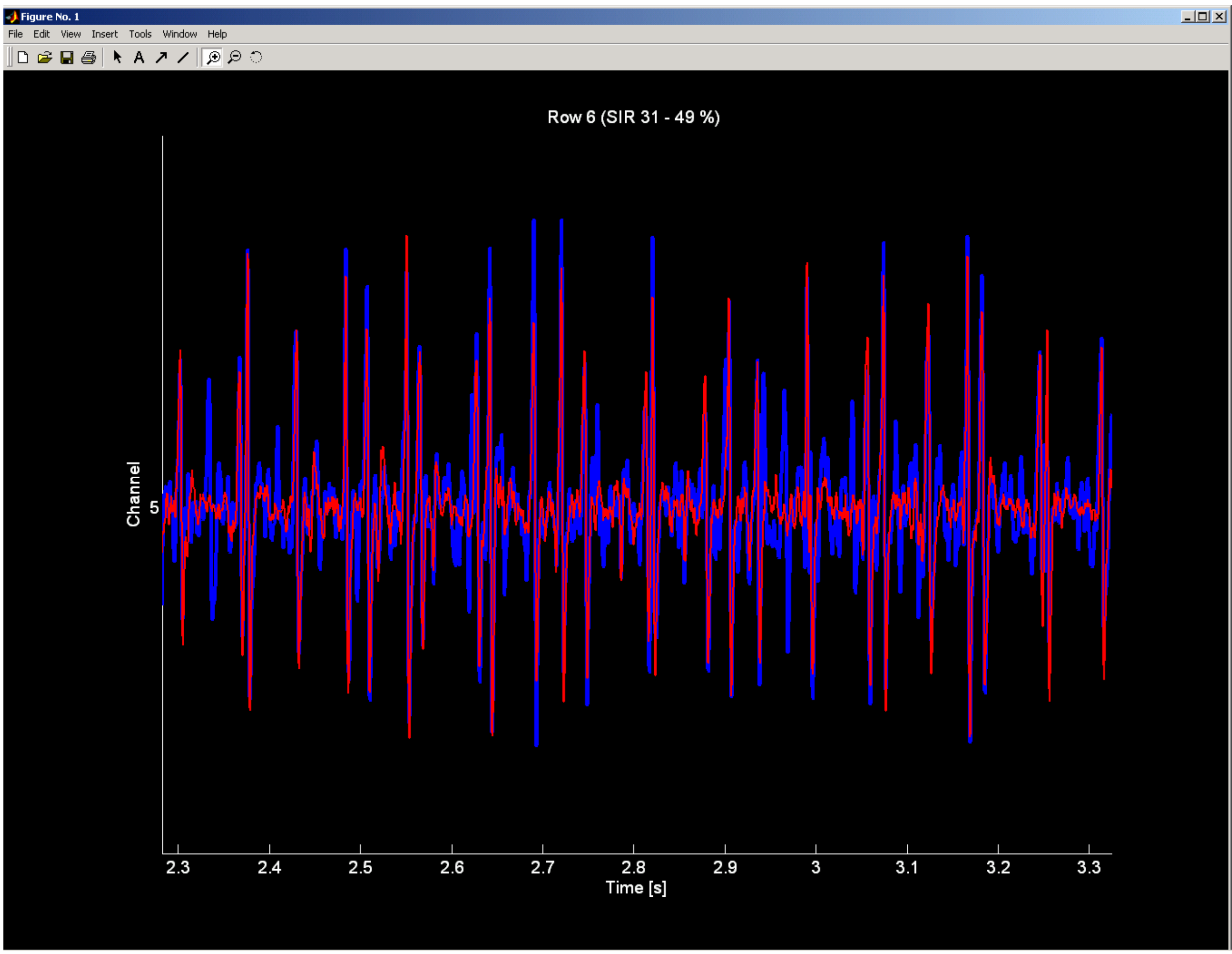
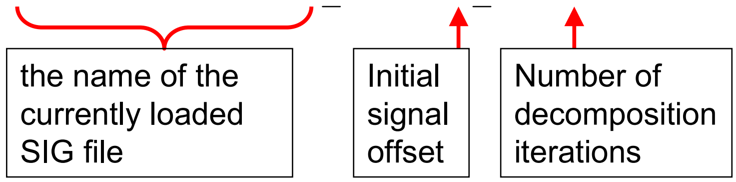



**Figure 43:** Matlab figure with selected sEMG channels and corresponding MUAP trains (short signal segment from the signal shown in **Figure 42**)

## *4.7 Saving and reloading of the decomposition results*

Decomposition results can be saved by clicking on the "`Save results`" button (**Figure 44**). The results are automatically saved into the directory containing the currently loaded SIG file. The following file naming convention is used:

`NameOfTheSIGfile_offsetN_runsM.mat`




where `NameOfTheSIGfile` stands for the name of the currently loaded SIG file, `N` is the initial signal offset (in seconds - see Section 4.4 for details) and `M` is the number of decomposition runs (see Section 4.4). The decomposition results of a SIG file `Subject1.SIG` with initial signal offset set equal to 0 and number of decomposition iterations set equal to 30 is saved in the following matlab file:

`Subject1_offset0_runs30.mat`

Saved results can be reloaded by clicking on the "`Load results`" button (**Figure 44**). "Load results" dialog window opens (**Figure 45**). Choose the `*.mat` file and click on "`Open`" button. Once reloaded into the DEMUSEtool, results can be freely edited and displayed (graphical representations and animations of the reloaded results are fully supported).


**Figure 44:** "`Save results`" button (left) and "`Load results`" button (right).

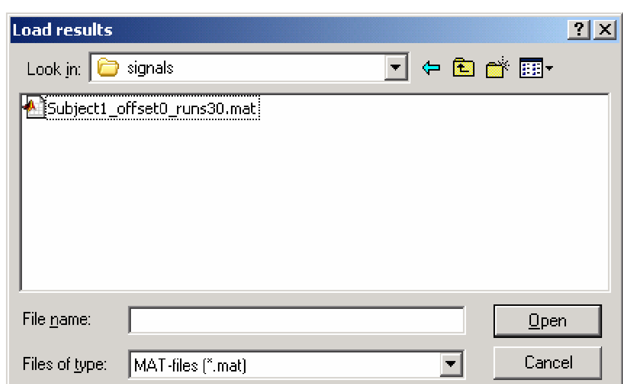


**Figure 45:** "`Load results`" dialog window.

## 4.8 DEMUSEtool acknowledgements

Information about the DEMUSEtool version, copyrights and author's acknowledgement are displayed by clicking on the "`About DEMUSE`" button (**Figure 46**). "`About DEMUSE`" dialog window opens (**Figure 47**).

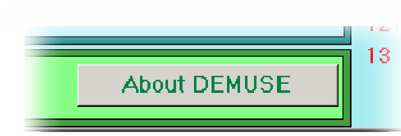



**Figure 46:** "`About DEMUSE`" button.

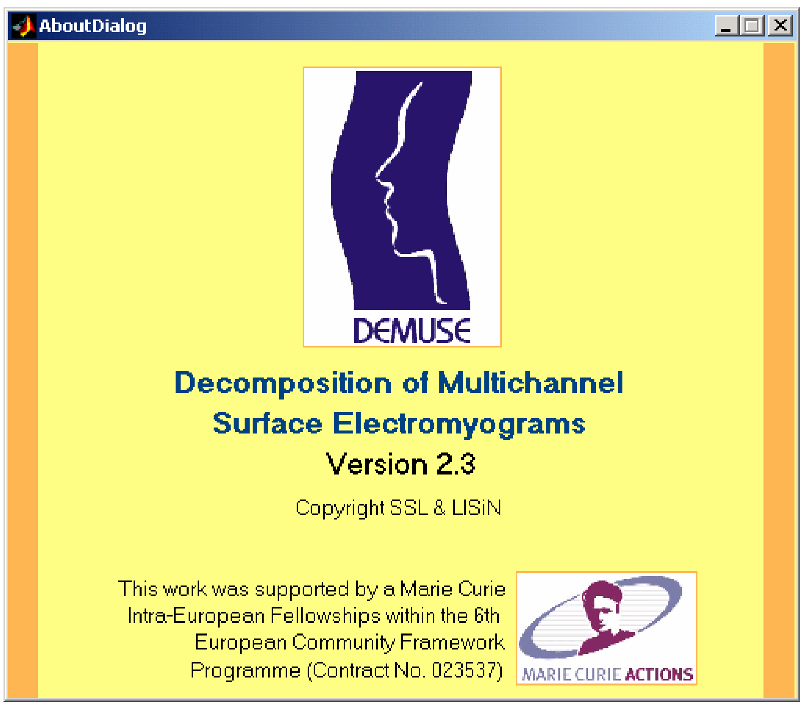



**Figure 47:** "`About DEMUSE`" dialog window.

# 5 Technical support

DEMUSEtool is copyrighted by the System Sofware Laboratory (SSL) from University of Maribor, Slovenia, and Laboratory of Engineering of Neuromuscular System and Motor Rehabilitation (LISiN) from Politectnico di Torino, Italy. Its development was supported by a Marie Curie Intra-European Fellowship within the 6th European Community Framework Programme (DE MUSE, Contract No. 023537).

For further technical assistance and support, please contact

ales.holobar@delen.polito.it

or

ales.holobar@uni-mb.si



This work was supported by a Marie Curie Intra-European Fellowship within the 6th European Community Framework Programme (DE MUSE, Contract No. 023537).

# References


1. Matlab, the language of technical computing, MathWorks Inc., web address: http://matworks.com

2. Acquisition Software, User Manual v1.62, OT Bioelettronica, SIRIO Automazione srl and LISiN – Bioengineering Center Politecnico di Torino, February 2007.

3. A. Holobar, D. Zazula: Gradient Convolution Kernel Compensation Applied to Surface Electromyograms, ICA 2007, LNCS 4666, pp. 617–624, 2007.

4. EMG-USB electromyographic signal amplifier, User Manual v.1.32, OT Bioelettronica, SIRIO Automazione srl and LISiN – Bioengineering Center Politecnico di Torino, September 2006.