A Novel Approach for Automatic Visualization and Activation Detection of Evoked Potentials Induced by Epidural Spinal Cord Stimulation in Individuals with Spinal Cord Injury

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**S2 Appendix. Pseudocodes of All Algorithms in the Framework**

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| **Algorithm I:** 2-D representation of the raw EMG signals |
| * Find the time intervals between each two consecutive stimulation pulsations using the onset timing of each stimulation
* Use the time intervals to segment the EMG signals into corresponding pieces
* Repeat for all the muscles
* Save the samples of EMG segments into a $m×n×l$ matrix where *m* is the number of stimulation pulsation, *n* is the maximum time interval between consecutive stimulations, and *l* is the number of muscles.
* Use *imagesc* function to visualize each $m×n$ matrix as Colormap image
* Repeat for all muscles
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| **Algorithm II:** Noise reduction |
| * Initialize the GGMRF parameters $σ$, $λ$, $p$, $q$, and $b\_{s,r}$for Eq. 2.1
* Determine the window size for the Eq. 2.1
* Design an all ones $m×n$ mask matrix and set its four borders rows and columns to zero
* Use $m×n$ segmentation matrix, $m×n$ mask matrix, parameters and window size to substitute in Eq. 2.1 and calculate the estimated value for the pixel
* Repeat for all pixels
* Repeat for all muscles
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| **Algorithm III:** Activation detection using SOD method |
| * Select the background noise as the first non-zero segment of the de-noised EMG signal
* Use *mle* function to estimate the Gaussian distribution parameters $σ\_{0}$ and $μ\_{0}$
* For each segment of the de-noised signal use *mle* function to estimate the Gaussian distribution parameters $σ\_{i}$ and $μ\_{i}$
* Calculate $S\_{i}$ using Eq. 2.4 for all segments *i* of the de-noised signal
* Select the baseline as the first event of the de-noised EMG signal
* Calculate $S\_{max}$ and $σ\_{S\_{i}}$ for the selected baseline to find the activation threshold *h* using Eq. 2.5
* Compare each $S\_{i}$ with *h*: **If** $S\_{i}>h$, detect the evoked potential in the $i^{th}$ segment and represent it with 1, **else** there is no evoked potential and represent it with 0
* **If** 50% of the segments inside one *event* is active call the whole *event* active, **else** call it inactive
* Repeat for all *events*
* Find the corresponding stimulation intensity to the first active *event* and assign it as the voltage threshold
* Repeat for all muscles
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| **Algorithm IV:** Feature extraction |
| **Peak-to-peak and min-max interval:*** Divide each segment into 8 pieces and find the maximum $A\_{max}$ and minimum $A\_{min}$ amplitude values inside the first piece and their corresponding timings $T\_{max}$ and $T\_{min}$.
* Calculate the peak-to-peak value ($A\_{pp}=A\_{max}-A\_{min}$) and min-max interval ($T\_{mm}=\left|T\_{max}-T\_{min}\right|$) for each segment $i$
* Repeat for all segments
* Take the average over all $A\_{pp}$ and $T\_{mm}$ values inside one *event*
* Repeat for all *events*
* Repeat for all muscles

**Activation latency:*** Up-sampling the signal to 100,000 samples per second using function interp1.
* Divide each segment, which are detected as active by Algorithm III, into 20 pieces and take the first five pieces as baseline
* Apply the same method in Algorithm III to detect the onset timing of the evoked potential in each segment $L\_{i}$
* Repeat for all segments
* Take the average over all $L\_{i}$ inside one *event* $L$
* Repeat for all *events*
* Repeat for all muscles

**Integrated EMG:*** Rectify each segment of the EMG signal
* Take the integral of the rectified signal $I\_{EMG}$
* Repeat for all segments
* Take the average over all $I\_{EMG}$ values inside one *event*
* Repeat for all *events*
* Repeat for all muscles
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| **Algorithm V:** Visualization |
| * Use *csaps* function (cubic smoothing spline) to interpolate the missing values for $A\_{pp}$, $T\_{mm}, L$ and $I\_{EMG}$
* Assign each feature values to the corresponding stimulation intensity voltage $A\_{pp}$
* Repeat for all *events*
* Repeat for all the muscles
* Use *imagesc* function to visualize each matrix as Colormap image
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| **Algorithm VI:** Activation detection using TKEO method |
| * Segment the signal based on stimulation timings (similar to Algorithm I)
* Calculate the TEKO value for each sample $x\_{ijk}$ inside the segment $TKEO\_{ijk}= x\_{ijk}^{2}-(x\_{i-1jk}.x\_{i+1jk})$
* Repeat for all segments $j$
* Repeat for all muscles $k$
* Take the first *event* after TKEO operation as baseline
* Calculate the baseline maximum and standard deviation and find the activation threshold $h=TKEO\_{base}\_{max}+TKEO\_{sd}$
* Calculate the maximum value for the segment $TKEO\_{max}$
* **If** $TKEO\_{max}>h$, detect the evoked potential in the current segment and represent it with 1, **else** there is no evoked potential and represent it with 0
* Repeat for all segments
* **If** 50% of the segments inside one *event* is active call the whole *event* active, **else** call it inactive
* Repeat for all *events*
* Find the corresponding stimulation intensity to the first active *event* and assign it to be the activation intensity threshold
* Repeat for all the muscles
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