

Supplementary Material to: Extending Bioelectric Navigation for Displacement Detection

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1 Parameters of Elmer Simulation

- Mesh.MeshSizeFactor = 0.06
- Mesh.MeshSizeMin = 0.0
- Mesh.MeshSizeMax = 20
- Mesh.Format = 2
- Mesh.MshFileVersion = 2.0

- Geometry.OCCFixDegenerated = 1
- Geometry.OCCFixSmallEdges = 1
- Geometry.OCCFixSmallFaces = 1
- Geometry.Tolerance = 0.1
- Geometry.AutoCoherence = 1
- Mesh.Smoothing = 100
- Mesh.MeshSizeFromCurvature = 3
- Mesh.MeshSizeFromPoints = 1
- Mesh.MeshSizeFromParametricPoints = 1
- Mesh.MeshSizeExtendFromBoundary = 1
- Mesh.Algorithm = 6
- Mesh.Algorithm3D = 10
- Mesh.Optimize = 1
- Mesh.OptimizeNetgen = 0
- Mesh.HighOrderOptimize = 0
- Geometry.OCCParallel = 1
- General.NumThreads = 32

2 Synchronization of the Oscilloscopes

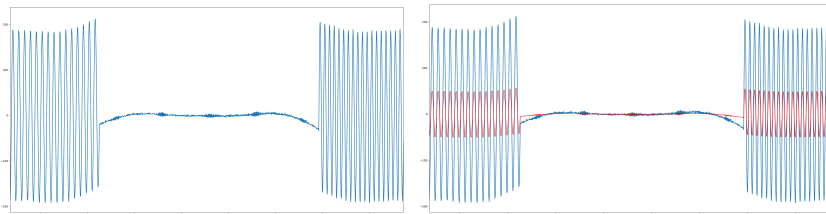
The synchronization procedure is designed to account both for a time delay between the measurements of oscilloscope A and oscilloscope B, as well as for slight differences in sampling rates. Even when both oscilloscopes are set to the same nominal sampling frequency (e.g. 50 kHz), slight differences in sampling rates can occur when using multiple oscilloscopes. Over time, these can lead to the measurements of the two oscilloscopes slowly drifting out of synchronization.

The basic idea of the procedure is to interrupt the sinusoidal stimulation current at the start and the end of each recording. We do this in order to artificially create features in the recorded waveforms that we can easily identify. We detect these "start" and "end" features in both the waveform recorded by oscilloscope A as well as the waveform recorded by oscilloscope B. We can use the "start" features in order to compensate for a time delay between the start of the recordings of both oscilloscopes. Additionally, we can use "start" and "end" features to identify and compensate for differences in sampling frequencies.

For the latter, we count the number of samples recorded between "start" and "end" by each respective oscilloscope. We expect both oscilloscopes to record the same number of samples in an identical period of time, so any difference in the number of recorded samples must be due to the described difference in sampling periods. From the number of recorded samples, we can thus estimate the difference in sampling frequencies and compensate for it. To create the "start" and "end" features for synchronization, ideally we would have simply switched on/off the stimulation current at two defined points in time. Our oscilloscopes do not support enabling and disabling their output

during a recording, though. Instead, we chose to change the stimulation frequency at two defined points in time, and detect these changes as features for synchronization. More specifically, the procedure works as follows:

1. We start the recording with a stimulation frequency of 800 Hz. After 5 seconds, the stimulation frequency is switched up to 1 kHz ("start" feature), and after 55 seconds, back down to 800 Hz ("end" feature). An exemplary recording containing the switch from 800 Hz to 1kHz can be seen in the Figure below, on the lefthand side. Notice that the switching causes a short interruption in the oscilloscope output. We filter the signals with a 4th order Butterworth bandpass filter, with high and low cutoff frequencies of 50 Hz and 10 kHz, to ease the further signal processing.



2. We crop two intervals of 0.5 seconds from the signal recorded by oscilloscope A, centered around the points in time where we expect the "start" and "end" features to occur (one at 5 seconds and one at 55 seconds).
3. We find the location of maximum correlation of these intervals with the signal from oscilloscope B. The indices of maximum correlation provide us with two sample indices in signal B that each correspond to one of the indices in signal A from which the intervals were cropped. An exemplary visualization of signals from oscilloscope A and B at their maximum correlation can be seen in the Figure above, on the righthand side.
4. We know the number of samples between the identified indices in the signal from oscilloscope A, N_A . We also know the number of samples between the corresponding indices in the signal of oscilloscope B, N_B . We calculate the sampling period of oscilloscope B, Δt_2 , as $\Delta t_2 = \Delta t_1 \cdot \frac{N_A}{N_B}$, with $\Delta t_1 = \frac{1}{50k\text{Hz}}$. We crop the signals of both oscilloscopes between the "start" and "end" features, to obtain only the segments containing the 1kHz stimulation signal. Then we resample the signal of oscilloscope B with the corrected sampling frequency. Based on these cropped and resampled signals, we then perform the displacement computations as described in the paper.