A NOVEL SYSTEM FOR STEREOTACTIC FUNCTIONAL NEUROSURGERIES

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Abstract *The system presented here improves stereotactic implantations of deep brain stimulators of Parkinson's patients. The complete system consists of a planning software, a novel 32-channel probe , 32-channel data acquisition hardware (50 kHz and 16 bit data resolution for 32 channels) and software and a database serving as expert system support in the background. While preclinical studies of the complete system are pending, we present details about the probe and an analysis tool to support targeting based on functional recordings. This tool is called* **histogram flatness** *and is applied to interspike interval histograms, showing differences of activity within different brain regions, thus enabling automated targeting.*

Keywords *surgical navigation, multi-site microelectrode recording, histogram flatness measure, database*

Introduction

Last year we presented the goal of the BMBF project navEgate [1]: Revolutionizing the field of computer-aided navigation in functional neurosurgery by means of a novel 32-channel probe for intra-operative recordings [2], 32-channel data acquisition hardware (Thomas Recording GmbH, Germany) and data acquisition software with online analysis capabilities. The data acquisition software "navEgate DAQ" communicates with the planning software iPlan (BrainLAB AG, Germany) and with the "navEbase" database holding characteristic signal features with respect to their highly detailed anatomic origin. Our medical application area is the implantation of deep brain stimulators for the treatment of patients suffering from Parkinson's disease.

This year we present the novel probe type in detail and one of our analysis methods that we found to be useful to compactly describe the qualitative shape of so-called interspike interval histograms (ISIs) - the histogram flatness measure [3]. While preclinical studies of our system are on the way at the time of this writing, presented analysis results are gained from single channel data recorded from Parkinsonian patients undergoing the implantation of a deep brain stimulator into the subthalamic nucleus.

Materials and methods

Data Acquisition: Intraoperative recordings were performed with a 4 channel microelectrode-recording unit (Leadpoint®; Medtronic Inc., Minneapolis, MN, USA) with conventional tungsten single-electrodes (microtargeting electrode 291A; FHC, Bowdoinham, ME, USA; impedance 0.5-1.5 Megaohm). The bandpass-filtered (500-5000Hz) signals are digitized at 24 kHz. All patients gave free and informed consent.

Data Analysis: Before integrating any new algorithm into the navEgate DAQ software, we test their suitability with the help of MATLAB (The Mathworks, Inc.). The results presented in the following section were generated using MATLAB. We analyzed data gained in three different surgeries. Signals have a duration of 30 seconds. In the following we limit the presented results to inter-spike interval (ISI) histograms together with a descriptive feature for ISIs called histogram flatness measure (hfm). Spike detection was performed by means of threshold detection, where the threshold was chosen to be 2.5 times the root mean square value of data contained in a sliding analysis window of 1 second duration. The ISI histograms were calculated as a sum of occurrences from non-overlapping windows. We introduce the histogram flatness measure according to the spectral flatness measure (sfm) that is used for power spectral densities. hfm and sfm, respectively, are defined as *geometric mean / arithmetic mean* [4]. Geometric mean and arithmetic mean, respectively, are calculated starting from the bin that contains the maximum bin count up to the next bin with 0 count, excluding this one. We express the hfm value in dB.

Results

32-channel probe: The most outstanding feature of the probes fabricated by the Institut für Mikrotechnik Mainz is their ability to record from 32 electrodes simultaneously on one trajectory track. One electrode is located at the tip of the probe, the remaining 31 electrodes are distributed either linearly or helically on the shaft. The distance between the first and the last of the 31 electrodes on the shaft is called array length and can be seen on Figure 1.

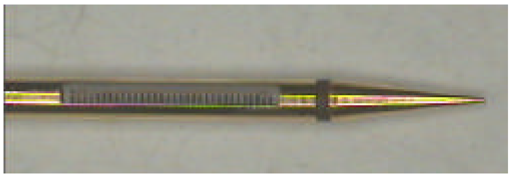

Figure 1: 31 electrodes linearly arranged on one shaft.

It defines how long a stretch of brain tissue and thus layered neuronal activity can be recorded from. Depending on the center-to-center electrode distance it can amount to 1 cm. The impedance of the electrodes is on average

0.66Megaohm at 1 kHz. Table 1 lists some more specifications of the probes.

Table 1: Technical specifications of the probes. "Pitch" denotes the center-to-center electrode distance of the 31 electrodes on the shaft.

	Simple Helix	Linear Array
Length	340 mm	340 mm
Diameter	530 µm	650 µm
Tip Angle	15°	15°
Electrode Diameter	20 µm	42 µm
Pitch	typically 100 µm	typically 100 µm
Array Length	about 3 mm	about 3 mm

Histogram flatness measure: For up to 5 channels - the number of channels currently used - it is feasible to visualize the raw signals together with their interspike interval histograms. But dealing with 32 channels, one soon runs into the problem that even a big monitor is too small to represent 32 histograms and that the neurological practitioner cannot cope with the wealth of information. We found the hfm to be suitable to indicate relative changes of the ISI histograms in one value. Figure 2 lists 5 different signals of 1 second duration together with their ISI histograms calculated for the complete 30 second signal each case.

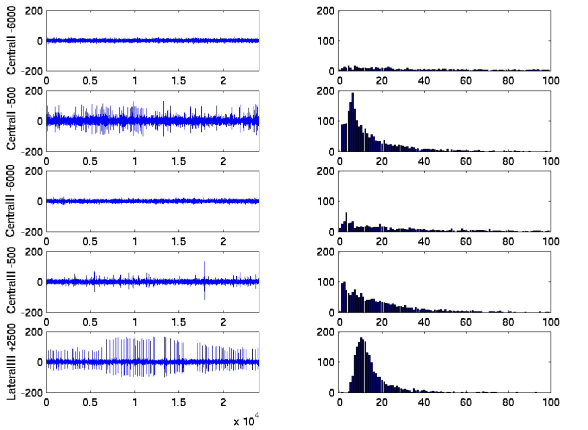

Figure 2: STN and SNr activity together with ISI histograms. The bin labels indicate the interspike intervals in ms.

'Central' and 'Lateral' indicate the position of the probe within the recording unit. Penetration depths of the planned target point at position 0 are marked by a minus sign, those after the target point by a plus sign. The second and fourth presented signals are attributed to the nucleus subthalamicus (STN) by neurological practitioners, the last one to the substantia nigra (SNr) and the first and third one to none of these two. The hfm values for the 5 ISI histograms are, in the order of appearance:

-0.86 dB	-2.6 dB	
-1.19 dB	-2.52 dB	-4.32 dB

About 90 analyzed signals that were adjusted to neither STN nor SNr have a rather flat ISI histogram, characterized by hfm dB values greater than -2 dB. As soon as the STN or SNr is reached, the values become considerable smaller.

Discussion

Our working hypothesis was to differentiate STN activity from neighbouring SNr activity by means of the simple hfm measure. At the moment we have too few datasets to be absolutely sure about this matter. In particular STN activity can vary from irregular to tonic, and also SNr activity is not always the same [5], so we need to significantly enlarge our data set, which is due to origin not an easy and time consuming task. But even if it turns out that the hfm values cannot serve as the only absolute measure, they help to identify high activity regions.

Easy to calculate measures like the hfm value are important for the success of the complete navEgate system. They not only help to handle the wealth of data, but are readily stored in the navEbase database.

Neurological practitioners as well as patients will benefit from the improved electrophysiological navigation possibilities offered by 32 channels and easy to handle data analysis. The required time for intraoperative recordings can be reduced, because a neural signal depth profile is available at one glance.

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