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NEUROSURGERY BY MULTICHANNEL ELECTROPHYSIOLOGY, 3D NAVIGATION, AND CUSTOMIZED DATABASE

K.M.L. Menne[1], A. Folkers[1], H. Schuhart[1], U.G. Hofmann[1]

[1]Institut f. Signalverarbeitung und Prozeßrechentechnik, Lübeck, Deutschland
E-mail: menne|hofmann@isip.uni-luebeck.de

SUMMARY: Accuracy is a main issue in intracranial surgeries like e.g. the implantation of deep brain stimulators. Surgeries are planned on the basis of pre-operative CT- or MR-scans, thus neglecting the intra-operative brainshift. Microelectrode recordings are performed in order to enhance the accuracy. We present an all-in-one solution to assist stereotactic neurosurgeons: Our system records and analysis electrophysiological signals from 32 channels intra-operatively in realtime and presents them related to anatomical structures. Our hardware consists of DSP technology integrated into a standard PC. We wrote our own visualization and analysis software.
So far, only few experienced specialists perform functional neurosurgery. By introducing a customized database into our system, we seek to shorten the "experience gap" between specialists and novices. The database holds electrophysiological signals and describing features related to an anatomical coordinate system, thus presenting the novice what he has to expect in a certain brain region.

INTRODUCTION

People suffering from the Parkinson Syndrome are medically treated with L-Dopa in the first instance. But after some time the medication can become ineffective or severe adverse effects arise. Patients that formerly responded well to L-Dopa treatment can undergo the implantation of a deep brain stimulator (DBS). Placed into the nucleus subthalamicus (STN) or the globus pallidus internus (GPi), and adjusted to the right frequency, the DBS reduces typical Parkinsonian syndromes like tremor. However, the implantation of the DBS is not straightforward. The potential target points are deep brain structures of very small size – the STN for example is rice corn sized. Thus it is difficult to hit them while omitting blood vessels within the brain. The method of choice is framebased stereotaxy (Fig.1). A stereotactic frame is screwed on the patient's head and CT- or MR-scans are made with the mounted frame. The surgery is planned on the basis of these images. However, due to brainshift in the range of up to 2.6 cm the intra-operatvie realities differ from the anatomical facts presented on the images [1]. Intra-operative microelectrode recordings provide for additional orientation, since each brain region elicits its own activity pattern. Until now, a maximal number of 5 channels is used for intra-operative microelectrode recordings [2]. Specialists mentally reconstruct a three-dimensional brain and know from experience which kind of signal is to be expected in a certain region.

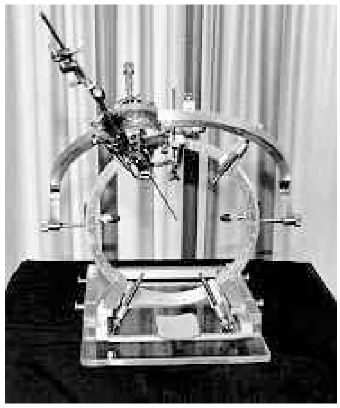

Fig.1: Riechert-Mundinger stereotactic frame (www.neurosurgery.org/cybermuseum/stereotactichall/

Within the framework of the BMBF project navEgate we are currently developing a system that supports the above described neurosurgical procedure at different stages.

MATERIALS AND METHODS

Data Acquisition System: The navEgate data acquisition system is based on the 128-channel data acquisition system that we developed for the EU project VSAMUEL[3]. The navEgate system utilizes newly developed probes with 32 channels (IMM, Germany) instead of micro-machined multi-site recording silicon probes (ACREO AB, Sweden)[4]. The 32 channels are helically arranged in different designs, covering a length

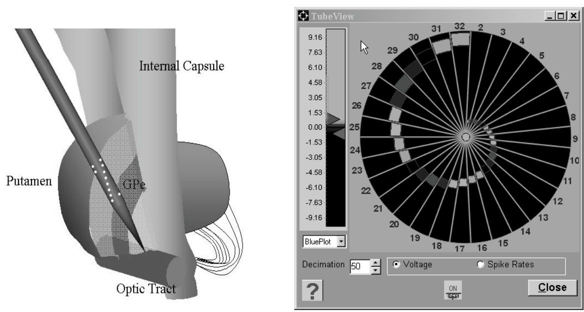

Fig.2: Left: Our probe in relation to target region. Right: Visualization of potential at all channels (different probe design).

of up to 12 mm (Fig.2). Again, a programmable gain amplifier (Thomas Recording, Germany), Sigma-Delta A/D converters and, in this case only one, commercially available digital signal processing board from the M67 family (Innovative Integration, USA) make up the system. The board acquires signals from 32 channels at a rate up to 50 kHz per channel. Handling the data acquisition only, the board is not working to full capacity. We additionally perform an online wavelet transformation on the DSP board [5]. Raw signals and wavelet coefficients are sent to a standard Windows PC where they are analyzed and visualized. In addition to standard scope display and audio output we now offer the tube view module, that allows to illustrate information like spike rates or voltage related to the respective channels (Fig.2). Concerning the analysis of the signals we offer different possibilities (Fig.3). The raw signal data can either be transformed by a Fast Fourier Transformation (FFT) or by a Discrete Wavelet Transform (DWT). In addition, cross- and auto-correlations (KKF, AKF) and spike rates are calculated. A lot of features describing the signals can be gained from these analysis possibilities. They can be used for clusterplots (Fig.3) and are stored in our database.

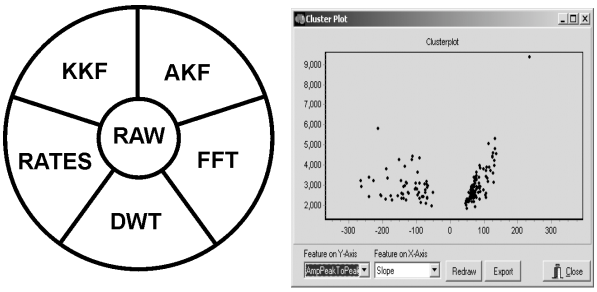

Fig.3: Left: Analysis possibilities. Right: Clusterplot.

3D Visualization: Our 3D visualization tool provides spatial orientation during the surgery (Fig.4). A 3D head model can be reconstructed from an electronic atlas (Thieme) or from a patient-specific MR or CT dataset with the help of the Visualization Toolkit VTK (Kitware, USA). Depending on the course of the planned trajectory an arbitrarily oriented slice can be displayed containing the trajectory. “Arbitrarilly oriented” means that we are not restricted to axial, sagittal and coronal planes[6]. The trajectory is planned with the help of the iPlan software of our co-operation partner BrainLab AG, Germany. During the surgery we get information about the penetration depth of the probe, since we control the feed. By transforming this information into the coordinate-system of the image space we are able to track the position of the probe in the displayed slice. Simultaneously the signal visualization tools present the current signals. Information like spike rates could also be color coded and be presented in the slice itself.

Electrophysiological database: In our database signal features and signal snippets are stored together with coordinates of an anatomical reference system. Patient-specific coordinates are transformed into an AC-

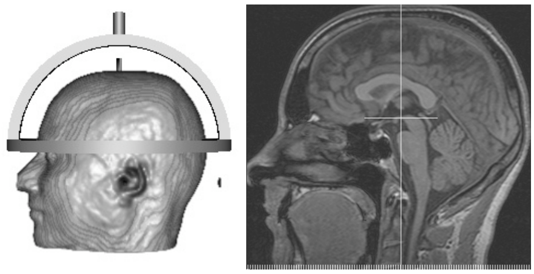

Fig.4: Left: 3D reconstruction of head together with stereotactic frame. Right: Trajectory (vertical line) through target (horizontal line).

PC coordinate system by linear transformation (AC:anterior commissure, PC: posterior commissure) by the iPlan software and are communicated to our system. The anatomical reference system allows for searches for signals and signal features from given brain regions. The comparison of the features of data currently being recorded with the region specific information from the database improves orientation in the brain.

DISCUSSION

Our ultimate goal is to enhance correct targeting in deep brain procedures and maybe even enable novices to perform stereotactic operations with high reliability. The described analysis and visualization tools have now to be tested in clinical trials for acceptance and usefulness. Neurosurgeons and neurologists gave input to the design of our system and will also be asked for suggestions for improvements.

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