Web Technology Based Microelectrode Characterization Instrument

Zhe Hu[1], Philip Troyk[2], Senior Member, Glenn DeMichele[1], Douglas Kerns[1], Martin Bak[3]

Abstract—**In order to track the on-going changes and ultimate reliability of neural recording and stimulation arrays, it is beneficial to regularly characterize electrode arrays within the use environment. Microelectrodes used for neural stimulation or recording research can have different behaviors *in-vivo* vs. *in- vitro*, and once implanted the success of the experiment often hinges upon knowing the stability, changes, or deterioration of the electrodes. This paper describes a new instrument that is capable of batch characterizing 16 electrodes using cyclic voltammetry, electrochemical impedance spectroscopy and charge injection measurements. The latest web based technology was applied to the software design, which greatly facilitates electrode data sharing among researchers.**

I. INTRODUCTION

Earlier work to characterize implantable multi-electrode array with a large number of microelectrodes by using a combination of commercially available instruments was previously described [1] as the Multi-Electrode Analyzer system (MEA 1.0, formerly known as EAS 1.0). As an improvement, and based upon new design goals and requirements (DARPA contract N66001·12·C-4055), MEA 2.0 is a completely redesigned web-based multi-channel microelectrodes testing instrument. It allows the end user to comprehensively analyze the condition of a Floating Microelectrode Array (FMA) (or other arrays) *in-vitro* and *in-vivo*, using cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS) and current pulsing measurements. In addition to collecting detailed electrode performance "raw" data in SI units, MEA 2.0 PC software can present summary results in a "universal" manner which is meaningful to many neural science researchers. MEA 2.0 facilitates the transition of an electrode array to a research tool rather than a research subject. The MEA 2.0 system also makes it easy for researchers to diagnose electrode cable connection or cross-talk problems.

An important feature of the system is its ability to share the experimental data over the web with other researchers, as well as with the array manufacturer for internal/external reviews. It allows comparison of electrode measurement results between similar electrodes in other preparations, as well as tracking complete history of the electrode array from the point of manufacture through the completion of the end-use experiment. With this unprecedented capability to record comprehensive historical data, the system will provide valuable electrode evaluation over the duration of long-term experiments.

In many neural science recording and stimulation experiments, data are collected via a large number of implantable microelectrodes, over an extended period of time. These electrodes can have very different behavior *in-vitro* vs. *in-vivo* [2]. It is highly-beneficial to regularly monitor their performance, which can be very time consuming and error prone without targeted instrumentation. For example, to manually test 100 microelectrodes with typical off-the-shelf impedance analyzers and to catalog and distill the resulting data would take up a large portion of the precious live animal experimental time. However, not performing these tests regularly is risky. An undetected electrode connection problem could misdirect the subsequent neural recording data towards attributing the issue to, for example, neuronal loss. Or as another example: sending larger stimulation current pulse to a damaged microelectrode might cause the charge injection to exceeding the water window, which might accidentally cause neuronal damage.

Among others, these situations can be mitigated by use of an automated electrode analysis system. The MEA 2.0 system is designed for this purpose. In addition, by collecting the data quickly and sharing it over the web, neural science researchers can be confident of their microelectrodes' performance, as well as contributing to the knowledge of implantable microelectrodes at a much larger scale.

II. SYSTEM ARCHITECTURE

MEA 2.0 system, both hardware and software were designed with the following goals:

- Open, extensible and portable [3]
- Facilitate experimental data sharing

To encourage data sharing among end users, it is important to make the MEA system itself as "open" as possible. By adopting the web browser platform and many of its open standard technologies, we provide the "source code" (i.e. HTML, JavaScript source code, and JSON meta-files) directly to the end user. This "open source" approach also has the benefits that the end users are able to modify and adapt large parts of the system to accommodate different hardware configurations and software needs for their own research laboratories.

A. MEA 2.0 System Diagram

MEA 2.0 system consists of the PC software, a potentiostat/current pulse generator box, and the customizable electrodes connection cable.

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[1] Zhe Hu, Glenn DeMichele and Douglas Kerns are with Sigenics Inc., Chicago IL 60616

[2] Philip Troyk is with the Department of Biomedical Engineering, Illinois Institute of Technology, Chicago IL 60616

[3] Martin Bak is with MicroProbes for Life Science, Gaithersbirg MD 20879

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Figure 1. MEA 2.0 Potentiostat/Current Pulse Generator Box

As shown in Fig. 1, the electrodes connection cable was adapted into a standard 20-pin OMNETIC cable for a 16-electrode FMA. Similar adaptor cable can be made with other forms of electrode array connectors. The system diagram is shown in Fig. 2.

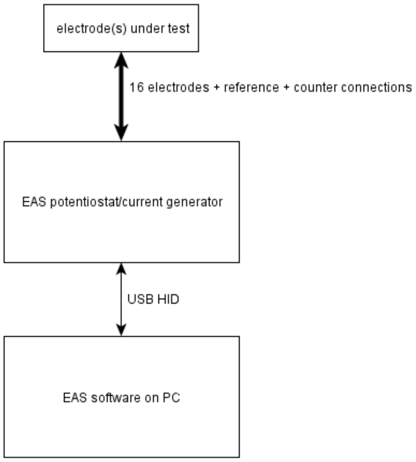


Figure 2. MEA 2.0 System Diagram

B. *Potentiostat Hardware*

The central module of the hardware box is the potentiostat circuitry shown in Fig. 3. In this circuit, the counter electrode is DC biased, which drives the fluid at the reference electrode level. The working electrode is driven by the "controlled voltage source" via the current-sensing amplifier circuit.

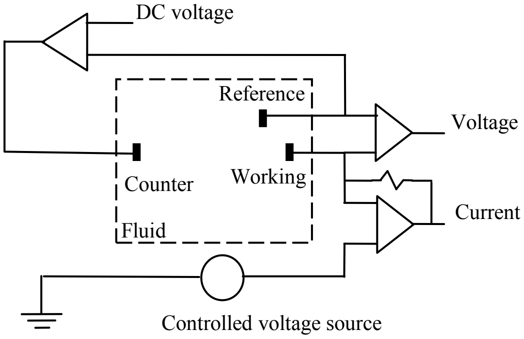


Figure 3. MEA 2.0 Potentiostat Circuit Diagram

This is different from the conventional approach [4] where the counter electrode is driven by a controlled voltage source. In our case, the counter and the reference electrodes can be shared among 16 electrodes; so that there can be 16 independent current sensing amplifier circuits, one for each electrode. During potentiostat measurements, such as CV and EIS that usually take long periods of time, the 16 independent controlled sources can be programmatically driven simultaneously instead of in series. This could speed up data collection by 16 times.

C. *Embedded Software*

The hardware box exposes as a USB HID device to the PC side. Inside the box, a Microchip PIC32 MCU controls the communication, and drives DAC, ADC as well as multiple digital mode switches. The waveform generation and data sampling are synchronized in one timer interrupt routine. The firmware is coded in C with some assembly code for data collection routines.

PIC32 gets the waveform data from the PC into a RAM table. It then spins through the table to generate the analog signal by writing to the DAC, and at the same time collecting the resulting data from the ADC on each timer interrupt. The collected data is stored in another RAM table. After the experiment is completed, the PC side software will query the PIC32 for its data.

Notice that there is no real-time data streaming over the USB. The internal logic of PIC32 firmware is kept simple on purpose. We want the PC software to have the most control, since the PC software is easier to modify than the firmware. For example, the knowledge of different CV sweep rates or EIS frequencies all resides at the PC side. New experiments with different parameters are completely scripted from the PC software.

D. *PC Software*

The PC software is structured into two parts, the GUI and the Kernel. The full software stack is shown in Fig. 4.

Both pieces currently run on the Windows operating system, but can be quickly ported to other platforms due to the programming languages/frameworks we choose to code in.

Instead of chasing the fast changing desktop native GUI framework, we choose the web browser window as our "write once, run everywhere" virtual machine. The GUI runs in a modern web browser, which is almost ubiquitous on Windows, Linux, Mac OS X and mobile platforms. The GUI uses standard web protocols (HTTP/AJAX/Websocket) to communicate with the Kernel.

With the JavaScript helper libraries, such as D3JS for data visualization, and BackboneJS for client side MVC, our web browser GUI produces the look-and-feel of a native

GUI program. Due to web browser security restrictions, the GUI program cannot interact with the local file system, or calling native DLL to drive USB directly. Such service is provided by our Kernel software. Note that some "web-based" operating systems are providing their native service to JavaScript, onto which we can port our Kernel program in the future as well.

This separation of functional modules by network protocols (HTTP, TCP/IP) makes our system architecture extensible.

The Kernel software is written with open source, multi-platform software/framework: NodeJS and Google Go languages. Program in NodeJS exposes a local web server that the GUI in the browser window connects to. NodeJS program then calls Go code to perform the detailed tasks for electrode measurements.

Software deployment to the end user is simply a folder copy without any installation steps. The GUI code exists in text-based HTML and JavaScript files. The Kernel program is either compiled into a single executable (in the case of Google Go program), or JavaScript files (in the case of NodeJS web server program) as well. At the lower level, USB HID driver (e.g. USB mouse and keyboard are USB HID devices) is native to most operating systems, so there is no extra driver installation step either.

To facilitate sharing of the electrode experiment data, we use the peer-to-peer sharing technology: BitTorrent Sync. After an electrode experiment is performed, the data files are first saved locally as CSV files on the experimenter's computer in a designated folder, along with a meta-file in JSON format describing all the experiment parameters. Once the experimenter's computer obtains the internet connection, BitTorrent Sync will automatically upload the data files in that local folder to the MEA manufacturer's computer, as well as other peer-to-peer sharing machines. The end user software is deployed and updated, if needed, along in the same manner.

For an internal reviewer, such as the electrode manufacturer, their computer folder is loaded with the latest data as well as the complete PC software via BitTorrent Sync. The reviewer can use the PC software to view the data in exactly the same way the end user does. Note that because the raw data are still saved as CSV files on the local machine, the end users are not giving up any control of managing the data or processing the data in their own ways. For example, the end user may choose to delete the data files of an incomplete experiment. Those files will be automatically removed from the other peer-to-peer sharing computers as well.

For an external reviewer who doesn't have the authorization to join peer-to-peer sharing, he/she can still look at the data via a web browser. This is because the Kernel program is essentially a web server. Once its local port is exposed on the web (via services such as ngrok), the external reviewer can go to a web address and load the same GUI program in a web browser, which communicates directly with the Kernel program over the web.

In fact, if the Kernel program of the end user exposes its local port and has the hardware box connected, another user on the web can conduct the electrode experiments remotely. In this way, multiple researchers at different locations can jointly participate in the same electrode experiment at the same time. This function may prove very effective and useful for electrode diagnosis.

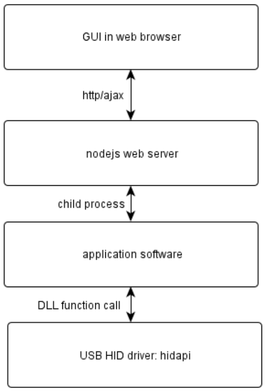


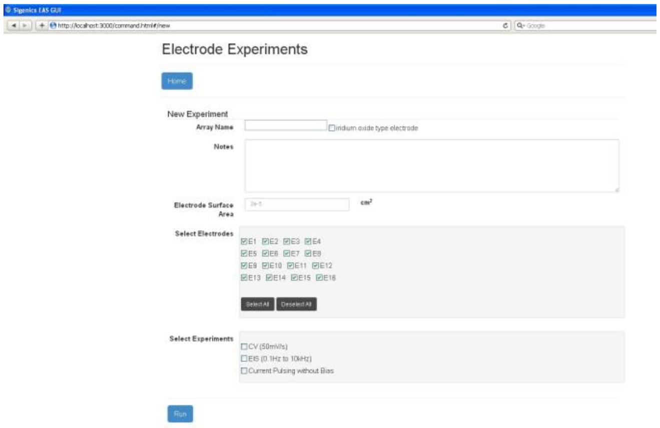
Figure 4. MEA 2.0 PC Software Stack

III. ELECTRODE EXPERIMENTS

The MEA 2.0 system has been tested at the electrode manufacturer site and at some neural research laboratories. A demonstration of how a large number of electrode data can be collected, shared and analyzed, has been made.

A. *Web-based GUI*

Fig. 5 shows one view of the GUI, which initiates a new electrode experiment. Once the "Run" button is clicked, the experiment settings are saved into a JSON format meta-file. The Kernel program then controls the hardware box to perform the corresponding electrode experiments based on that meta-file.



Electrode Experiments

New Experiment

Array Name ☐ iridium oxide type electrode

Notes

Electrode Surface Area cm^2

Select Electrodes

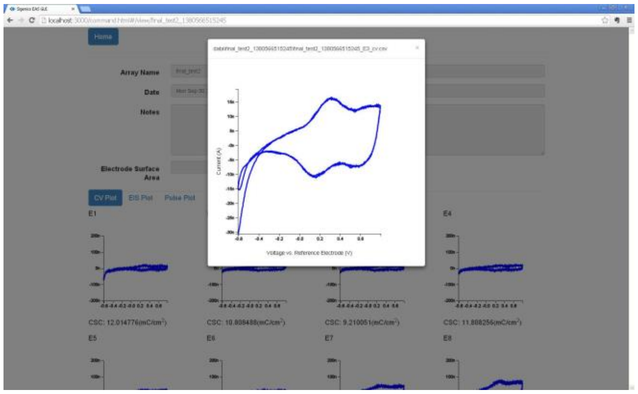
☑E1 ☑E2 ☑E3 ☑E4
☑E5 ☑E6 ☑E7 ☑E8
☑E9 ☑E10 ☑E11 ☑E12
☑E13 ☑E14 ☑E15 ☑E16

Select Experiments

☐ CV (50mV/s)
☐ EIS (0.1Hz to 10kHz)
☐ Current Pulsing without Bias

Figure 5. MEA 2.0 GUI (new experiment view) in a Web Browser Window

Fig. 6 shows the data visualization view of 16 CV data plots. The software uses D3JS JavaScript helper library to plot the data. The zoomed CV plot is that of a typical iridium oxide microelectrode.



CSC: 12.014776(mC/cm²)
CSC: 10.808488(mC/cm²)
CSC: 9.210051(mC/cm²)
CSC: 11.808256(mC/cm²)

Figure 6. MEA 2.0 GUI (data view) in a Web Browser Window

B. Comparison with Gamry Potentiostat

As a comparison, an iridium oxide microelectrode (about 2000 µm^2 exposed tip area) was tested in a beaker with both MEA 2.0 and the Gamry potentiostat system. The 50mV/s CV result comparisions are plotted in Fig.7 and EIS results are plotted in Fig. 8.

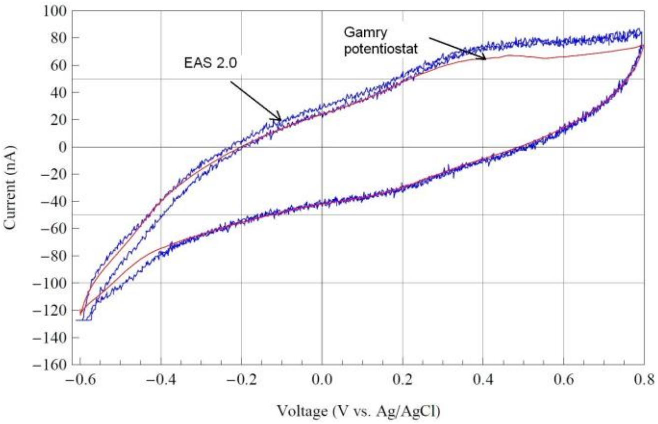


Figure 7. CV (50 mV/s) measurements of an iridium oxide microelectrode

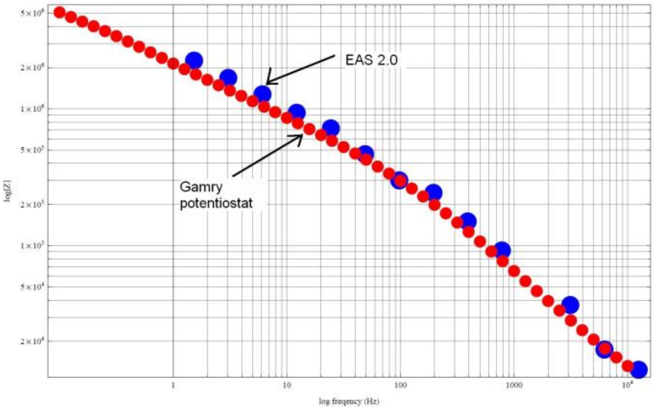


Figure 8. EIS measurements of an iridium oxide microelectrode

IV. RESULTS AND DISCUSSION

The electrode experiments show that for a regular CV and EIS test, MEA 2.0 system performs similarly to the commercial scientific instrument such as the Gamry potentiostat system. However, with the open design and data sharing approach, MEA 2.0 is capable of comprehensive microelectrode characterization on a much larger experimental scale.

Openly sharing of scientific data is not only important for reviewers evaluating the validity of the end results, but also essential for continuous improvement and longer lifetimes of electrode arrays. As a web-based instrument, MEA 2.0 makes an effort to encourage and facilitate data sharing towards these goals.

V. CONCLUSION

We have developed a new web-based laboratory instrument that is able to measure, analyze and share electrode experiment data. The wide use of this and such similar instruments would potentially benefit the research community in a lot of ways.

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