New Data Recording Plugin for the Integration of an Integrated Circuit for Neural Recordings into the Electrophysiology Open Source User Interface Open Ephys

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The research of various diseases like epilepsy or schizophrenia requires an accurate study of bioelectrical signals. An Application Specific Integrated Circuit (ASIC) for the recording of neural signals from neonatal mice was developed [1]. To integrate the developed ASIC into Open Ephys, an open source electrophysiology user interface, a specific plugin is presented. It enables simple configuration of the ASIC, recording of biomedical signals and enables the utilization of many of Open Ephys' functions. The user interface is well known to neuroscientific researchers and the presented plugin simplifies the use of the integrated circuit for the researchers dramatically. It also enables the use of the ASIC to other kind of applications like neural recordings from mammalians or recordings for brain computer interfaces.

INTRODUCTION

Recording of bioelectrical signals is a fundamental instrument for studying the early development of the brain. For further investigations, an Application Specific Integrated Circuit (ASIC) for the recording of bio signals from neonatal mice has been developed [1].

To enable a live display of recorded signals, a high-speed digital interface and acquiring system has been developed [2].

The recording systems for bioelectrical signals need to allow high flexibility, an easily operable user interface, and preferably additional functions such as instant filtering of the signal or detection of spikes. The open source electrophysiology system Open Ephys enables many of the desired features and allows the development of further extensions, called plugins, and the integration of other acquisition systems [3]. A screenshot of the Open Ephys user interface is shown in Fig. 1.

Fig. 1 *Open Ephys user interface with selectable plugins (left column) and signal chain (bottom).*

A Plugin is presented that integrates the custom designed ASIC into the Open Ephys user interface. The Open Ephys System is widely known and used in neuroscientific research. The integration of the custom designed ASIC into this tool makes the use much easier to the researchers due to a well know environment and enables the use of many existing functions. The most prominent functions of Open Ephys are, live display of recorded neurological signal data or prerecorded samples.

METHODS

A block diagram of the current setup for interacting with the neural recording ASIC and enabling live viewing of the measured bio signals is shown in Fig. 2. Here the ASIC and a Xilinx FPGA are mounted on a single board. Using a C++ control program, the FPGA configuration file is loaded into the FPGA. The same program then sets up the ASIC and initiates the measurement of the 16 channels. The bioelectrical signals are sampled and the data are continuously written into a *.dat* file. This file contains the individual samples of each channel in binary format [2].

While the control program is writing data into the *.dat* file, the same file can be loaded into Neuroscope [4]. Neuroscope allows for live viewing of the latest data that is being written into the file.

Fig. 2 *Current setup for interacting with the ECoG ASIC and enabling live viewing of the measured signals* [2].

Data Recording Plugin: A block diagram of the Data Recording Plugin is shown in Fig. 4. The structure is similar to the current approach. The idea is to make use of the existing Open Ephys 'Filereader' plugin, which can be used to read a *.kwd* file. This is the data file format used by the klusta software [5]. It makes use of the file format HDF5 [6], which is also a type of binary file format. The main difference is that the *.kwd* file includes a header above the binary sample data. This header contains information about the acquired data, such as number of samples and channels, number of bits per sample, and the voltage per bit. See Fig. 3 for a comparison of the *.kwd* and *.dat* file type.

Fig. 3 *Comparison of *.kwd file type used by the 'Filereader' plugin and *.dat file type used by Neuroscope.*

The control program was modified using the source code and functions from the HDF5 software [6]. It creates a **.kwd* file instead of a **.dat* file. The plugin enables the recording of neural data that is saved into the file. After the recording the data can be displayed inside the Open Ephys tool using the preinstalled plugin '*Filereader*'. The Open Ephys enables additional functionalities. The neurological signal data can be manipulated using simple analogous filtering or analyzed using spike or phase detector plugins for faster and easier evaluation of the data. Moreover additional functions can be implemented if needed.

The header of the **.kwd* file contains the size of the recording. In a continuous recording, the size of the recording is not finalized until the recording ends. This propriety of the file format causes that it is not possible to simultaneously write and read from a **.kwd* file. Due to this limitation it is possible to use the Data Recording Plugin for recording and display of the neural data, but not for a live view.
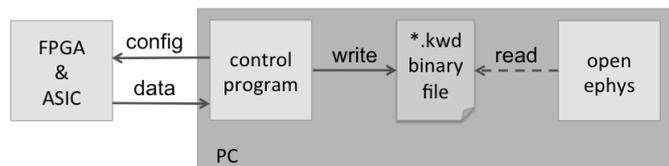
Fig. 4 *Block Diagram of the Data Recording Plugin for interacting with the ASIC and visualizing the data using Open Ephys.*

Extended Data Recording Plugin with Live View Functionality: To enable live view functionality an extended data recording plugin for Open Epyhs is presented. The Plugin is coded in C++. A block diagram is shown in Fig. 5. The plugin configures the FPGA and ASIC using fragments of the control plugin. The data from the neural recording is received by the plugin and forwarded to the next plugin in the signal chain.
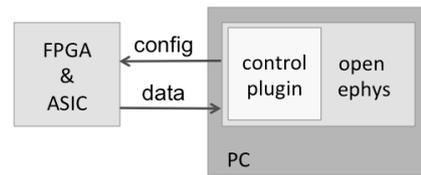
Fig. 5 *Extended Data Recording Plugin for interacting with the ASIC and enabling live viewing of the measured signals in Open Ephys.*

A block diagram of the plugin functionality is shown in Fig. 6. When added to the signal chain, the configuration file is loaded into the FPGA and proper functionality of the FPGA is checked. When recording is initialized, the ASIC is set up using the configurations from the plugin interface and checked for proper functionality again. If the whole system is running correctly, the measurement is initiated. The plugin contains additional functions needed to be able to write the readout data into the internal *sampling buffer* of Open Ephys. This buffer is used for further processing and visualization.
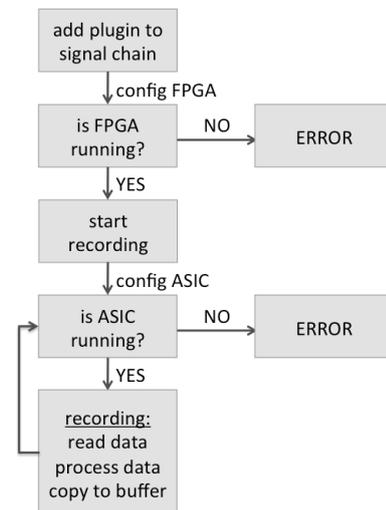
Fig. 6 *Block diagram of 'ECoG Reader' plugin functionality*

The User Interface of the created plugin and possible configuration options needed for the ASIC can be seen in Fig. 7. While the ASIC can be configured in many different ways, only the two most important configuration options were added to the '*ECoG Reader*' plugin window. '*AMP-Setting*' sets the amplification of the ASIC's internal amplifiers and '*ADC-Freq-Div*' configures the ADC sampling frequency divider.
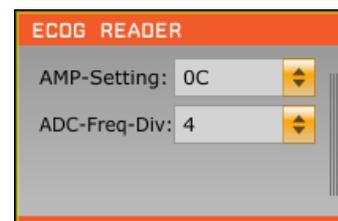

Fig. 7 *The 'ECoG Reader' plugin that was created for Open Ephys and the configuration options for the 'ECoG' ASIC.*

A simplified overview of the Open Ephys buffer handling is shown in Fig. 8. Open Ephys' sample buffer has a variable length and the samples are displayed at 44100 Hz. In contrast to that, the custom designed ASIC returns 256 samples per readout and the sampling frequency is 19972 Hz. To match this, two buffers different approaches were tested. First, the ASIC's samples were expanded/contracted to match the sample buffer length of Open Ephys. Second approach was to create a second buffer, where the ECoG data is appended to at readout, and Open Ephys' sample buffer is filled with the needed number of samples from the beginning of the buffer.
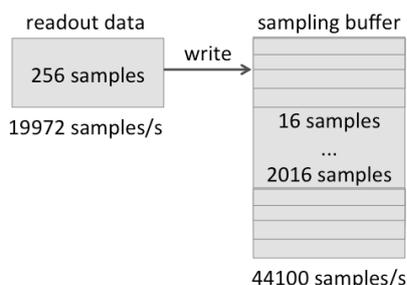
Fig. 8 *Discrepancy between Open Ephys' variable length sampling buffer and FPGA readout data.*

RESULTS

With the Data Recording Plugin neural data can be recorded and saved in a **.kwd* file. This file can be opened in Open Ephys using the integrated plugin '*File Reader*'. An example of the recoding is shown in Fig. 9. The main window of the program shows four channels with a sinusoidal input signal and four channels with a constant signal.
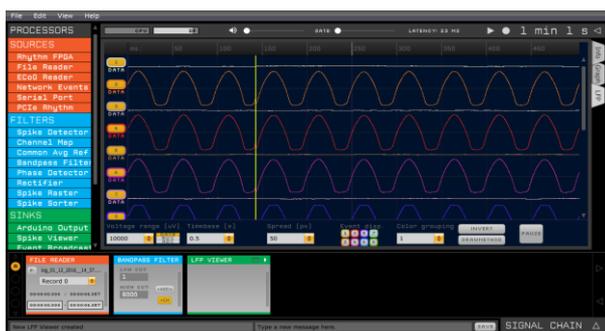
Fig. 9 *Open Ephys user interface build from plugins showing a previously recorded sinusoidal signal using the ECoG ASIC.*

The Extended Data Recording Plugin with Live View Functionality enables simple configuration of the FPGA and ASIC. Moreover the plugin can be added to the signal chain and measured bio signals can be directly filtered and visualized in the Open Ephys window using a visualization plugin. However, due to Open Ephys' internal buffer handling, the visualization does not function properly. The

visualized data does not reflect the recorded data. This becomes apparent in such a way that a delay, which is increasing over time, can be seen in the displayed data.

Both tested approaches are not capable to solve the given problem, but instead introduced a new one. Due to the complex calculations of both approaches data would not be read out fast enough from the ECoG ASIC, resulting in loss of potentially important data.

CONCLUSION

A Plugin for the integration of a custom designed Integrated Circuit into the Open Ephys electrophysiology system has been presented. It simplifies the configuration and the recording of the neural recording ASIC greatly.

The data recording plugin enables the recording or neural signals and after the recording the data can be visualized.

The extended plugin connects the custom designed ASIC to a widely used open source user interface, enables the use of many important functions like filtering or spike detection and enables the use of the chip by many different neuroscientific researchers.

The plugin can be added to the Open Ephys signals chain and configurations can be made within the plugin. The recorded data can be directly visualized, but the visualized data is shown with a delay that increases over time.

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REFERENCES

[1] Bahr A.; Abu-Saleh L.; Hinsch R.; Schroeder D.; Krautschneider W.: 'Small Area, Low Power Neural Recording Integrated Circuit in 130 nm CMOS Technology for Small Mammalians', 2016, IEEE ICM, Cairo, Egypt, 17 - 20 December 2016

[2] Bahr A.; Abu-Saleh L.; Schroeder D.; Krautschneider W.: 'High Speed Digital Interfacing for a Neural Data Acquisition System', *Current Directions in Biomedical Engineering 2016*, Basel Switzerland, 2016

[3] 'Open Ephys open-source electrophysiology', www.open-ephys.org, visited: January 2017

[4] L. Hazan, M. Zugaro, G. Buzsáki (2006). Klusters, Neuroscope, NDManager: a Free Software Suite for Neurophysiological Data Processing and Visualization, J. Neurosci. Methods 155:207-216.

[5] klusta, 'Kwik format', klusta.readthedocs.io/en/latest/kwik/, visited: December 2016

[6] Support HDF Group, 'What is HDF5', https://support.hdfgroup.org/HDF5/whatishdf5.html, visited: December 2016