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A Signal Acquisition Approach for Implantable Brain-Machine Interface System

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***Abstract*—The implantable brain-machine interface has been extensively applied in recent research. There is a little neural implant designed to record the neural spike signals, which needs a higher requirement of the characteristics. In the work, a novel signal acquisition approach for the implantable brain-machine system is presented. The system architecture is introduced including the hardware and software designs. The experiments demonstrate the designed system has successfully recorded the analog sine wave and spike signals from the signal generator and a digital neural signal simulator.**

I. INTRODUCTION

The brain is the most complicated component in the human body, whose operation principles are explored using brain-machine interface (BMI) technology. BMI can establish a communication channel to transmit the neural signals between the brain and other devices, and helps humans understand the brain's running mechanisms. Furthermore, there are plenty of applications for BMI technology, such as medical, education, game, and entertainment fields, especially the clinical field, which can help patients suffering from various diseases to alleviate symptoms or assisted rehabilitation, for example, paralysis, amyotrophic lateral sclerosis (ALS), spinal cord injury, Parkinson, epilepsy, depressive disorder, anxiety disorder, and so on [1].

Brain neural activities can be recorded through two approaches including invasive and non-invasive ones. Considering the acquisition accuracy and real-time analysis, the invasive BMI is more suitable compared with the non-invasive way, which can record the average electrical activity of surrounding neurons including action potential (AP) and local field potential (LFP). AP generally has signal amplitudes of approximately 5-500 μV_{pp} and frequency of ranges of 0.8-10 kHz, while the amplitude of LFP is larger at around 0.5-5 mVpp and slower at a lower frequency of 1-250 kHz [2]. The AP signal recording is popular with researchers, which reveals plenty of information regarding cell-to-cell communications and networks, and also provides insights into the morphological and biophysical characteristics of the neuron [3][4]. Whereas LFP recording is the average sum of multiple signal components, and is suitable for chronic long-term monitoring [5]. Compared with the LFP, the AP is easier to decode and identify the signal of the targeted neuron, and has much higher temporal and spatial resolution [6]. The AP and LFP signals recording methods are more invasive and harmful to the brain, so electrocorticograms (ECoG) are proposed. ECoG can analyze finger movements and arm trajectories through human clinical experiments [7-10]. However, such ECoG/AP/LFP systems usually need an external computer for data processing with the method of wireless transmission [11][12], which is fundamentally bulky and inconvenient. Accordingly, the BMI system needs to be capable of signal processing, which makes the system more portable and higher functional.

In summary, a signal acquisition approach for the implantable BMI system is still very attractive to explore. The rest of this work is organized as follows. Section II introduces the overview of the system, including the details of the proposed system, the process of data control, and the procedure of design flow. The experiment setup and measurement results are shown in Section III. Finally, Section IV concludes this paper.

II. SYSTEM ARCHITECTURE

A. *Proposed System*

Fig. 1 depicts the simplified architecture of the proposed neural signal acquisition system for the implantable brain-machine interface, which consists of three modules: main controller unit (MCU), analog amplifier unit (AAU), and digital logic unit (DLU). The basic function of the proposed system can detect, magnify, and analyze the user's brain signals for investigating brain neural activities. The details of the three modules are discussed in the following part.

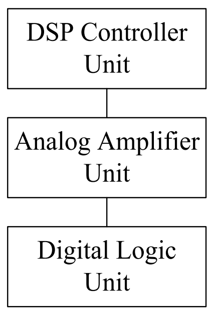

Fig. 1. Configuration of the proposed system.

Firstly, the MCU is the critical component in the whole system, which adopts the digital signal processing (DSP) chip to achieve the main control, data processing, and A/D analog-to-digital conversion functions. DSP TMS320F28335 is chosen, which is a type of TMS320C28X series floating-point DSP controller produced by TI company. Compared with fixed-point DSP, the chip TMS320F28335 has the character of higher precision, lower cost and power, higher performance and peripheral integration, larger data and program storage volume as well as faster and more accurate A/D conversion. It has a clock frequency of 150 MHz, a 5V DC backup supply with 3.3 V Input/Output power, and

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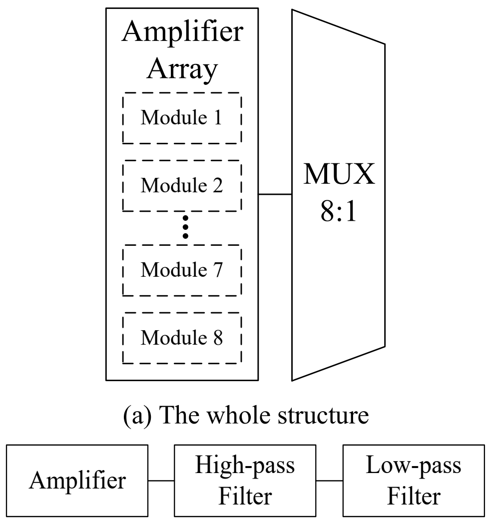
contains six channels of direct memory access (DMA). Especially, it has a 12-bit A/D converter on-chip, which can meet the brain signal acquisition occasion. The chip has 16 analog conversion input channels, and the ADC analog voltage acquisition range is 0~3V. The ADC conversion clock frequency can be configured up to 25 MHz, and the maximum acquisition speed is 12.5 MHz.

Secondly, AAU is composed of a custom amplifier array and multiplexer (MUX), as shown in Fig. 2 (a). The amplifier array contains eight modules, each module is constituted of an amplifier, a high-pass filter, and a low-pass filter, depicted in Fig. 2 (b), which is expressed by the commercial devices. The low-cost and low-power instrumentation amplifier AD620 is altered as the first-stage amplifier, which would amplify the function of the brain signal. The op amp ADA4528 with precision, ultralow noise, and zero-drift is adopted as the filter, which can be configured as the high-pass or low-pass using the different circuit structures. The single 8-to-1 channel multiplexer ADG758 is selected as the MUX, which selects single or multiple modules in the amplifier array to record the neural signals.



(a) The whole structure

(b) The constitution of the single amplifier

Fig. 2. The architecture of the AAU.

Finally, DLU is connected with the MUX in AAU, which is used to control the working sequence of the amplifier array. DLU is achieved using a Field Programmable Gate Array (FPGA), Spartan-6 series, which produces two operating modes to modify the recording sequence of brain signal for the amplifier array, as shown in Fig. 3. In the work, the amplifier array is divided into two groups, group A and group B, and each group has four modules. The first operating mode is that only one group (group A or group B) works in the collecting process. The other operating mode is that all the two groups can record the brain signals, and the working order is that when group A is finished, then switches to group B.

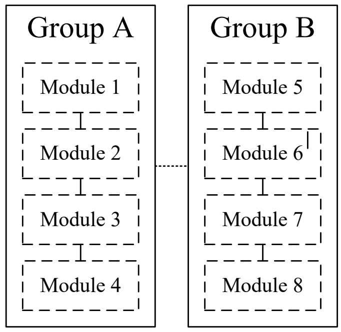


Fig. 3. The introduction of operating modes.

B. *Design Flow*

The objective of the designed system is to achieve the function of recording brain signals. The whole system's networking and intelligence are realized by the combination of hardware and software. The hardware has been presented in Part A, so how to work for the complicated hardware device, which needs the software to coordinate work. The software function design mainly includes signal acquisition, ADC, data storage, and data processing, which can be accomplished by the code composer studio (CCS) software development platform supporting system operation. This design is mainly to complete the AAU and ADC operating process with the standard serial peripheral interface (SPI) communication protocol. Fig. 4 depicts the design flow of control for the system. The MCU configures all the work processes except the MUX configuration shown in the dashed box using the FPGA.

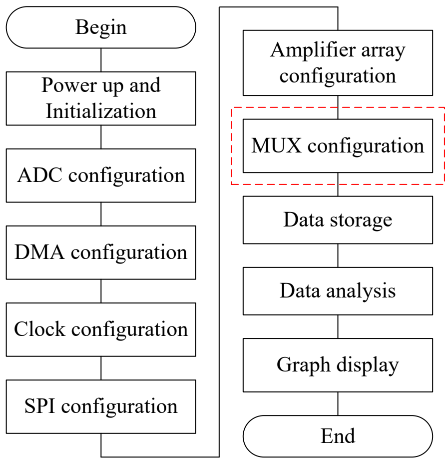


Fig. 4. The design flow of the system control.

III. Experiment

A. *Experiment Setup*

To validate the function of the proposed system, in-vitro measurement is implemented. The experiment setup is illustrated in Fig. 5. The devices shown here are the neural signal simulator, analog amplifier unit, TMS320F28335 DSP development board, and then the FPGA development board from the left to the right. The hardware is initialized after the system is powered AD/DC adaptor. This is to test the system whether it could be acquired correctly signal.

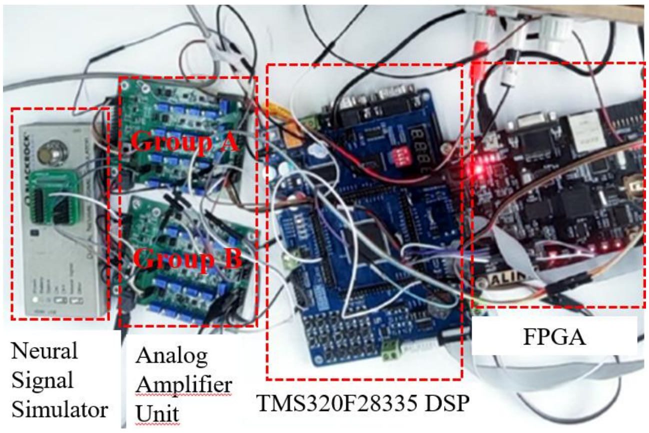


Fig. 5. Experimental setup.

The details of each device are discussed in the following work.

(a) The neural signal simulator is capable of simulating two waveforms for testing purposes, which are the neural signal and the sine sweep. The neural signals are measured in the work. The neural signal simulator is connected to the analog amplifier unit to provide an input signal. In the actual measured process, the signal generator is also used for the initial system verification.

(b) The analog amplifier unit is divided into group A and group B. In each group, four amplifier modules and MUX are used. Each amplifier module represents an analog acquisition channel. The magnification of the amplifier is set as 500 times by adjusting the values of slide rheostat.

(c) The MCU is the TMS320F28335 development board for the testing, which concludes the ADC, DMA, SRAM, SPI, and other needed modules. It plays an important role of ADC in the whole system, so the relevant setting of ADC is presented. Before the ADC starts to work, it should be initialized first. In the work, the sequential sampling mode of the cascade sequencer is used, and the maximum sampling channel is set according to the different two operating modes including 4 or 8. The signal conversion order is set based on the serial number of the analog acquisition channel, and the working frequency of the ADC is set to the standard of 25 MHz. The acquisition speed is 4.16 MHz. After the configuration is completed, the ADC is turned on, and data acquisition and conversion are performed. Then the results data would be moved into the SRAM for later analysis. Moreover, SPI is used for communication between the DSP and the amplifier unit. Among them, DSP and analog amplifier units are used as master and slave devices, respectively. Configure the DSP to transmit data and send frequency data to be updated to the slave device utilizing the shift register.

(d) The FPGA development board is adopted to control the operating logical sequence of MUX. In the work, two logics are shown, the logic one is only one group (group A or group B) works in the collecting process, whereas logic two is that two groups are used, and the working order is that when group A is finished, then transfer to the group B with the switch frequency is 240 KHz.

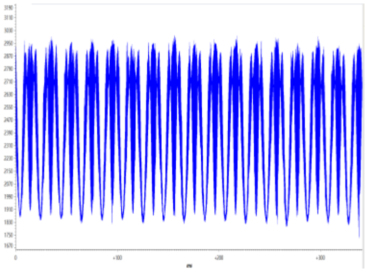
B. *Experimental Results*

To observe the signal acquisition effects of the proposed system, a series of tests with different experimental modes are executed, which are investigated in the following. The experimental trials are shown in TABLE I. Due to the limited data memory, two modules (that is two channels) in each group are altered to simplify the experiment. The switch frequency is 240 KHz.

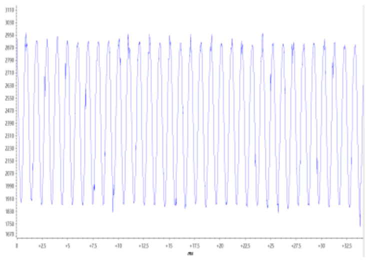
TABLE I. DESIGN OF THE DIFFERENT TRIALS

The types of Input Signals	Trials	
	One	Two
Channel 1 in Group A	Sine wave with 1 KHz	Neural signal
Channel 2 in Group A	Sine wave with 0.5 KHz	Neural signal
Channel 5 in Group B	--	Neural signal
Channel 6 in Group B	--	Neural signal

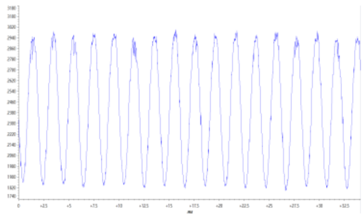
Fig. 6 shows the results of trial one, which uses the signal generator as the input source. Trial one emulates the signal acquisition experiment at different channels in one group. Fig. 6 (a) depicts the final acquisition results, and Fig. 6 (b) and (c) are the separated results for the different channels at 1.0 KHz and 0.5 KHz, respectively. The results demonstrate the validity of the proposed signal acquisition approach.



(a) The combination results



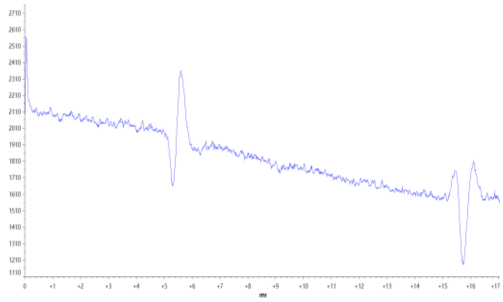
(b) The separated results at 1.0 KHz



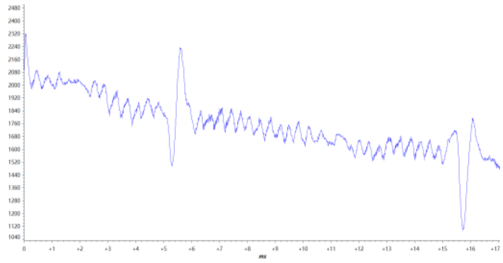
(c) The separated results at 0.5 KHz

Fig. 6. The results of trial one.

Fig. 7 depicts the results of trial two, which uses the neural signal simulator with the neural signal as the input source. Trial two emulates the signal acquisition experiment between the different two groups A and B with two channels in each group. Fig. 7 (a) and Fig. 7 (b) are the separated results for channel 1/2 at group A and channel 5/6 at group B, respectively. The results show that the spike signal could be detected clearly.



(a) The results of channel 1/2 at group A



(b) The results of channel 5/6 at group B

Fig. 7. The results of trial two.

IV. Conclusion

In this work, a signal acquisition approach for the implantable brain-machine interface system has been described, which allows reliable signal acquisition between the system and the computer. In the vitro experiment, the analog sine wave signals and neural spike signals are successfully collected and detected with the corresponding channels. In the following work, the in-vivo experiments in rats will be explored to verify the function of the proposed system in practical implantation applications.

References

[1] Y.-C. Wu, Y.-S. Liao, W.-H. Yeh, S.-F. Liang, and F.-Z. Shaw, “Directions of deep brain stimulation for epilepsy and parkinson’s disease,” Frontiers in Neuroscience, vol. 15, 2021.

[2] G. Benoit, “Recent advances in neural recording microsystems,” Sensors, vol. 11, no. 5, pp. 4572–4597, 2011.

[3] L. López-Jury, R. C. Meza, M. T. C. Brown, P. Henny, and C. C. Canavier, “Morphological and biophysical determinants of the intracellular and extracellular waveforms in nigral dopaminergic neurons: A computational study,” J. Neurosci., vol. 38, no. 38, pp. 8295–8310, Sep. 2018.

[4] K. H. Pettersen and G. T. Einevoll, “Amplitude variability and extracellular low-pass filtering of neuronal spikes,” Biophys. J., vol. 94, no. 3, pp. 784–802, Feb. 2008.

[5] N. Ahmadi, M. L. Cavuto, P. Feng, L. B. Leene, M. Maslik, F. Mazza, O. Savolainen, K. M. Szostak, C.-S. Bouganis, J. Ekanayake, A. Jackson, and T. G. Constandinou, “Towards a distributed, chronically-implantable neural interface,” Proc. 9th Int. IEEE/EMBS Conf. Neural Eng., Mar. 2019, pp. 719–724.

[6] R. Muller, H. P. Le, W. Li, P. Ledochowitsch, S. Gambini, T. Bjorninen, A. Koralek, J. M. Carmena, M. M. Maharbiz, E. Alon, and J. M. Rabaey, “A minimally invasive 64-channel wireless μECoG implant,” IEEE J. Solid-State Circuits, vol. 50, no. 1, pp. 344–359, Jan. 2015.

[7] T. Pistohl, T. Ball, A. Schulze-Bonhage, A. Aertsen, and C. Mehring, “Prediction of arm movement trajectories from ECoG-recordings in humans,” J. Neurosci. Methods, vol. 167, no. 1, pp. 105–114, 2008.

[8] G. Schalk, J. Kubánek, K. J. Miller, N. R. Anderson, E. C. Leuthardt, J. G. Ojemann, and J. R. Wolpaw, “Decoding two-dimensional move ment trajectories using electrocorticographic signals in humans,” J. Neural Eng., vol. 4, no. 3, pp. 264–275, 2007.

[9] K. J. Miller, S. Zanos, E. E. Fetz, M. den Nijs, and J. G. Ojemann, “Decoupling the cortical power spectrum reveals real-time representation of individual finger movements in humans,” J. Neurosci., vol. 29, no.10, pp. 3132–3137, 2009.

[10] T. Yanagisawa, M. Hirata, Y. Saitoh, H. Kishima, K. Matsushita, T. Goto, and T. Yoshimine, “Electrocorticographic control of a prosthetic arm in paralyzed patients,” Ann. Neurol., vol. 71, no. 3, pp. 353–361, 2012.

[11] H. Ando, K. Takizawa, T. Yoshida, K. Matsushita, M. Hirata and T. Suzuki, “Multichannel neural recording with a 128 Mbps UWB wireless transmitter for implantable brain-machine interfaces,” 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Milan, Italy, 2015, pp. 4097–4100.

[12] C. S. Mestais, G. Charvet, F. Sauter-Starace, M. Foerster, D. Ratel and A. L. Benabid, “WIMAGINE: wireless 64-Channel ECoG recording implant for long term clinical applications,” IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 23, no. 1, pp. 10–21, Jan. 2015.