Data acquisition system of 16-channel EEG based on ATSAM3X8E ARM Cortex-M3 32-bit microcontroller and ADS1299

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Data Acquisition System of 16-channel EEG Based on ATSAM3X8E ARM Cortex-M3 32-bit Microcontroller and ADS1299

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Abstract. The prototype of the EEG (electroencephalogram) instrumentation systems has been developed based on 32-bit microcontrollers of Cortex-M3 ATSAM3X8E and Analog Front-End (AFE) ADS1299 (Texas Instruments, USA), and also consists of 16-channel dry-electrodes in the form of EEG head-caps. The ADS1299-AFE has been designed in a double-layer format PCB (Print Circuit Board) with daisy-chain configuration. The communication protocol of the prototype was based on SPI (Serial Peripheral Interface) and tested using USB SPI-Logic Analyzer Hantek4032L (Qingdao Hantek Electronic, China). The acquired data of the 16-channel from this prototype has been successfully transferred to a PC (Personal Computer) with accuracy greater than 91 %. The data acquisition system has been visualized with time-domain format in the multi-graph plotter, the frequency-domain based on FFT (Fast Fourier Transform) calculation, and also brain-mapping display of 16-channel. The GUI (Graphical User Interface) has been developed based on OpenBCI (Brain Computer Interface) using Java Processing and also can be stored of data in the `*.txt` format. Instrumentation systems have been tested in the frequency range of 1-50 Hz using MiniSim 330 EEG Simulator (NETECH, USA). The validation process has been done with different frequency of 0.1 Hz, 2 Hz, 5 Hz, and 50 Hz, and difference voltage amplitudes of 10 μV, 30 μV, 50 μV, 100 μV, 500 μV, 1 mV, 2 mV and 2.5 mV. However, the acquisition system was not optimal at a frequency of 0.1 Hz and for amplitude potentials of over 1 mV had differences of the order 10 μV.

INTRODUCTION

An electroencephalogram (EEG) is medical instrument which are widely used in neuroscience research and clinical practice for monitoring and describe the functionality of brain, whereas qEEG (Quantitative EEG) for identifying specific purposing to visualize based on mathematical processing for their specific brain functions [1]. EEG instrument is an important biomedical diagnostic technique for medical including a portable EEG detection system based on gain or filtering interleaved architecture [2]. EEG is much cheaper than fMRI (Functional Magnetic Resonance Imaging), encourages small clinics and health-care facilities [3] Moreover, a portable EEG system can record multichannel EEG signals with low-power consumption [4].

EEGs signals were recorded due to electrical activity of the brain including in telemedicine applications [4]. There are many applications based on EEG data acquisition, such as medical imagery technologies, the diagnostic method of brain injury, the brain-computer interface (BCI) techniques and other signal processing methods [5]. Most of the systems based on CPU (Central Processing Unit) compatible instruction set to processing element mechanism [6], and portable EEG have to use ultra-low power on Integrated Chips (ICs) [7]. The ADS1299 (Texas Instrument, USA) is an analog front-end chip which can be cascaded a daisy-chain configuration into the digital data format. EEG acquisition system based on two daisy-chained has been successfully implemented using ADS1299, a TI-MSP430 microcontroller 16-bit, and wireless communication and developed in a laboratory scale [8]. The custom

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platform the 8-channel data acquisition system based-on ADS1299 and MSP430 microcontroller have been verified for BCI tasks [9] and the study of BCI has grown dramatically [10].

Basically, the ADS1299 can convert analog signals of EEG / ECG / EMG (biopotential measurement) into the digital data format and equip with the filter element and signal gain [11]. In this study, the 16-channel EEG acquisition system has been developed with daisy-chain technique 32-bit microcontroller ATSAM3X8EARM Cortex-M3 using open source software of OpenBCI – Processing GUI (Graphical User Interface) application. On previous, our research group result has been successfully developed a prototype system of data acquisition to 8-channel EEG [12]. In this paper, the EEG prototype based on 16-channel electrodes would be the basis for further study of the 32-channel data acquisition and also integrate with previous studies of stroke identification [13-15].

The Data Acquisition System

The block diagram of data acquisition of the developed EEG in this study is shown in Fig. 1. A daisy chain technique is a technique to acquire more channels EEG signals of simultaneously that are implemented on the ADS1299. This chip has an SPI (Serial Peripheral Interface) communication protocol to a digital processor. The ADS1299 has eight channels with a simulaneous sampling of 24-bits, which is designed for biopotential applications such as EEG, ECG, EAP (Audio Evoked Potential), BIS (Bispectral Index) and also Sleep Study. It has low-noise differential input singles, PGA (Programmable Gain Amplifier) selectable to: 1, 2, 4, 6, 8, 12, and 24 with data rate from 250 SPS to 16 KSPS. This chip has criteria low-power consumption of 5mW/channel, input bias current of 300 pA and -110dB CMRR, which works simultaneous and high-precision to acquire the EEG signal in multichannel formats up to 8-channels per-chip elements [11,16]. That device was interchanged amplifier with differential Instrumentation Amplifier (IA) and filter-stages mechanism with High Pass Filter (HPF) and also Dual-Notch Low Pass Filter (DNLPF) [2], along with lead-off detection feature [17].

METHODS

The implementations of biomedical technology based on embedded processors with signal processing element were in a wide range of applications [18]. In this study, the EEG acquisition-system was developed based on embedded-system with FFT (Fast-Fourier Transform) signal processing capability. The embedded processor was used based on ARM Cortex-M3 architecture, and suitable for mapping medical applications requiring ultralow-power consumption using SPI protocol [19].

EEG signals can be considered as a realization of a random or stochastic process [20], therefore it needs embedded-system with a processor based. The data acquisition techniquehas been widely applied based-on ARM Cortex-M3 ATSAM3X8E and ADS1299, which provides powerful computations [21] and connected via a shared bus to a discrete SPI controller [22].

The recorded biological signal conditioning needs a successive analog and digital transformation format, the amplitude and the signal-to-noise ratio (SNR) of the recorded bio-signals require very low. The Common-Mode Rejection Ratio (CMRR) of a differential amplifier as high as possible and a low value of the off-set of current drift [23]. The FFT can be accelerated to extract the band powers mechanism such as the alpha, beta, and delta wave [13, 24, 25] and needs high computational requirements [26]. This study was focus on 16-channels EEG data acquisition system, which was a development from previous studies [12, 15, 27].

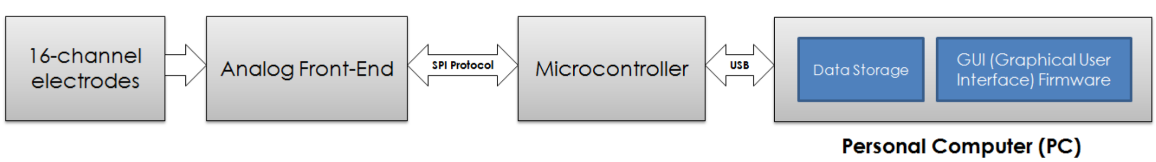


FIGURE 1. The block diagram of EEG data acquisition based-on embedded-system

Standardization SPI Protocol

The standard mechanism to activate the ADS1299 based on the SPI communication protocol standard [11]. The DOUT (Data Output) SPI generates the first MSB (Most Significant Bit) to the first LSB (Least Significant Bit) format data. After 216 SCLK purpose collecting the data afterward the device-1 was reproduced the data acquisition result, and also going to 217 SCLK the device-2 was reproduced the data from DAISY_IN0-DOUT1. The mechanism method of daisy-chained SPI communication protocol can be seen in Fig. 2.

Mechanism of Multi-channel Data Acquisition

The daisy-chain configuration and ADS1299 architecture are shown in Fig. 3. The system consisted of 16-electrodes placed on a human head. The two ADS1299 were connected via daisy-chain configuration through SPI protocol to be connected directly to the ARM microcontroller ATSAM3X8E and the acquired data can be displayed on a visual screen.

RESULTS AND DISCUSSION

The data-acquisitions system was developed into 16-channel and tested as shown Fig. 4. The research was focused on the development of using two chips ADS1299 based on Daisy-chain configuration to obtain simultaneous 16-channels. The Instrumentation system has successfully captured EEG signals of 1-60 Hz displayed in real-time with their FFT counter parts. For each segment, the signal were averaged and displayed their power spectrum[3]..

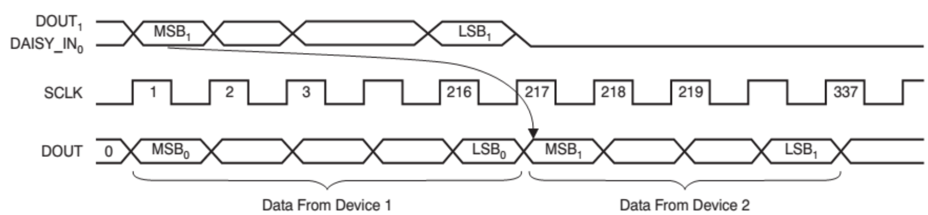
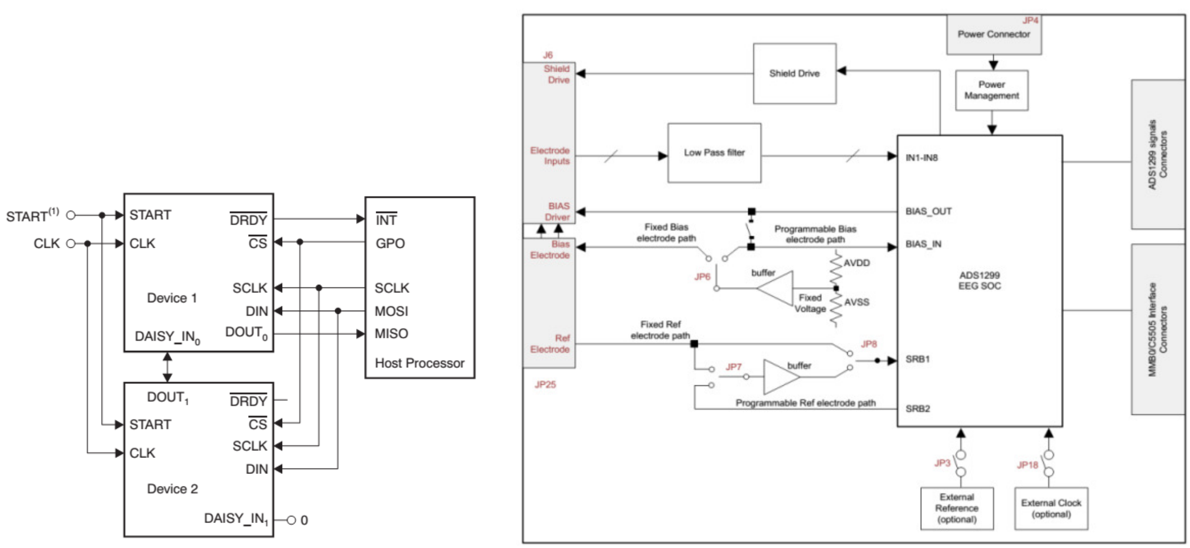


FIGURE 2. The SPI (Serial Peripheral Interface) standard protocol of ADS1299 Daisy-Chain configuration



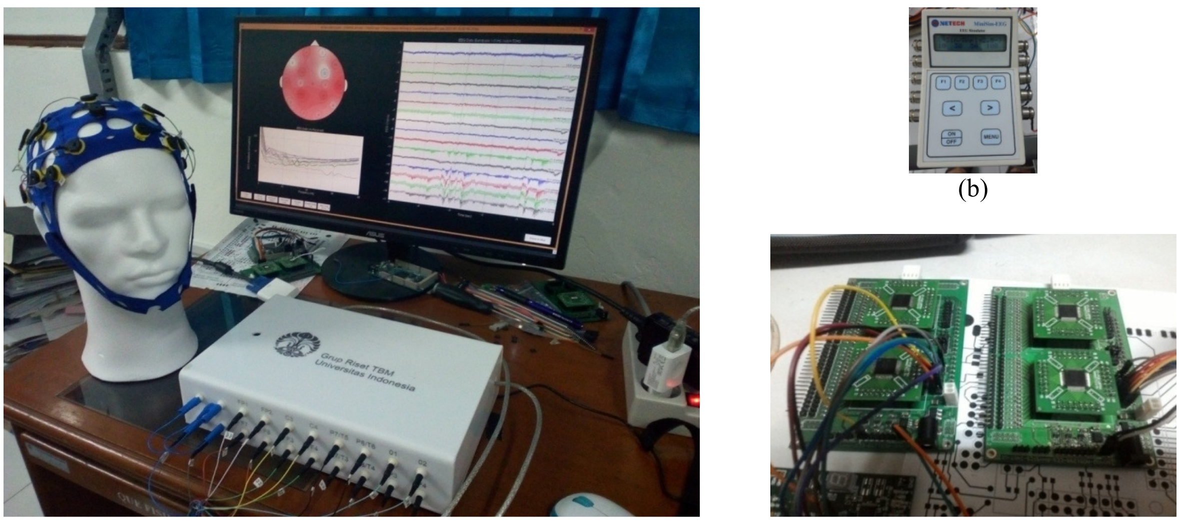
(a) (b)

FIGURE 3. (a) The Daisy-Chain ADS1299 configuration and (b) the Architecture standard of ADS1299 front-end

The EEG data acquisition result may be confounded with different types of noises, such as eye blinks, movements and muscular activates (e.g., the heart beats) [3], and also artifacts movement, half-cell effect, capacitive and electrical signal of 50/60 Hz interference, and others [9]. To achieve a proper interference cancellation be able from SNR (Signal Noise Ratio) [28]. The EEG data acquisition is suggested to use digitized mechanism at 250 SPS (Sampling per Second), a high pass filter of 0.1 Hz, and also low pass filter of 30 Hz [29]. The perturbation effects on the skull are more sensitive to measure the conductivity of the tissue of brain [30].

The SPI signal result ADS1299 front-end has been verified with USB SPI-Logic Analyzer Hantek4032L (Qingdao Hantek Electronic, China) and this is similar with Texas Instrument SPI protocol. The data acquisition system was implemented of OpenBCI (Brain Computer Interface) GUI (Graphical User Interface) Processing Software based to display the data results. That GUI panel can display an EEG signal data acquisition in real-time and simultaneous format. The data-acquisition system has been done and tested on the ADS1299 front-end module consists of 16-channel and whole the process of acquisition can save and display to panel a GUI based.

In the specific average result of calibration for all channels (1-16 channels) are shown in Table 1 and Fig. 5. Calibration error at frequency 2 Hz was < 7.27 % and at frequency 5 Hz was < 6.48 %. In the specific result as were obtained the information of brain functionality of human with EEG Caps. The EEG-Data Acquisition system was



(b)

(a) (c)

FIGURE 4. (a) The data-acquisition system part elements based-on ARM Cortex-M3 ATSAM3X8E, (b) MiniSim 330 EEG Simulator (NETECH, USA) and,(c) The electronics front-end ADS1299 which is made from our Research Group.

TABLE 1. The Data result of calibration with EEG Simulator

Frequency Input EEG-Simulator (Hz)	Voltage Input Simulator (μV)	Acquisition Result-GUI (V_{rms})	Conversion V_{rms} to μV	Deviation (μV)	Error Deviation Acquisition System (%)
2	10	3.48	9.83	0.20	2.01
	30	20.11	28.44	1.56	5.21
	50	33.16	46.89	3.11	6.22
	100	65.58	92.73	7.27	7.27
5	10	3.77	10.65	0.65	6.48
	30	21.63	30.58	0.58	1.93
	50	35.71	50.49	0.49	0.98
	100	70.97	100.35	0.41	0.41

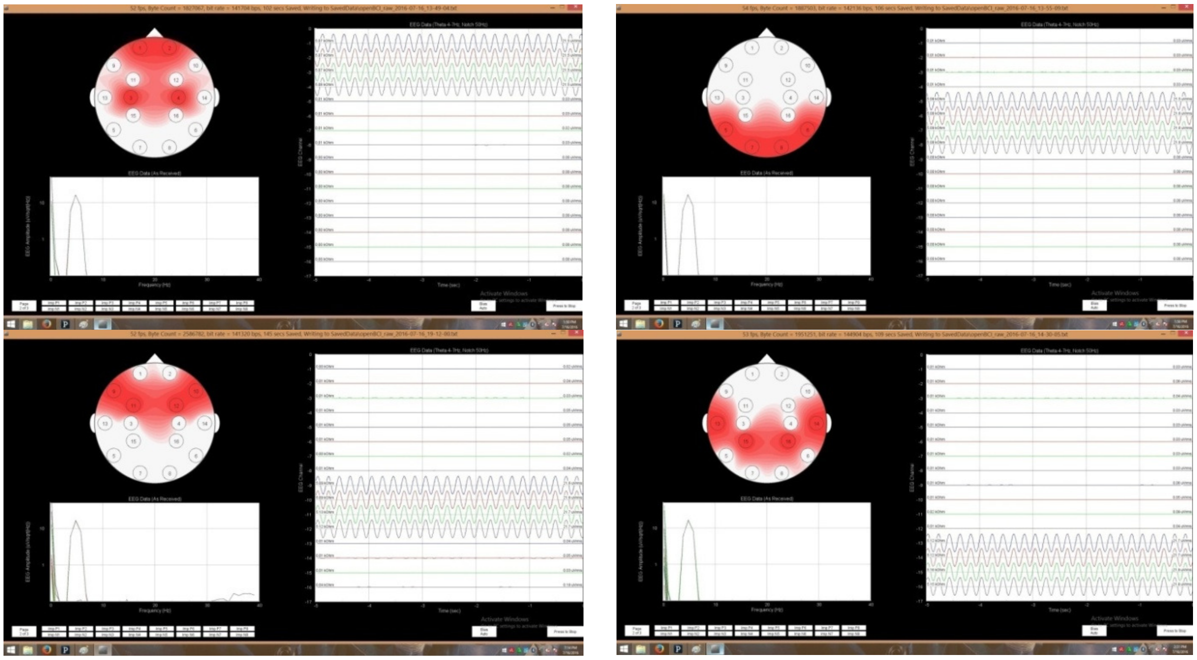


FIGURE 5. The capture signal results of 5 Hz, 30 µV calibration process per channel (1-16 channels) from MiniSim 330 EEG Simulator (NETECH, USA) (with ± 2 % accuracy)

successfully tested and the data results are presented in real-time with three parts, namely EEG waves, FFT, and Brain Mapping. The data-acquisition results were interpreted of brain signals by ADS1299 based with μV_{rms} and FFT frequencies. The Raw Data of EEG signal are presented in V_{rms} unit and also can display the impedance values for each electrode, that waveform was filtered with band-pass at 0.5-30 Hz with maximum deviation error 7.27 % at 2 Hz, and manually inspected to identify any movement or muscle artifact, electrical impedance fluctuation, cable movements, bad contact of wire electrodes, and also conductivity influence from electrodes paste.

CONCLUSIONS

The EEG data acquisition prototype has been developed based on 32-bit microcontroller ARM Cortex-M3 ATSAM3X8E and Analog Front-end ADS1299 for acquiring a brain signal activity with accuracy greater than 91 %. An acquisition system was successfully implemented in a portable size and synchronous simultaneous processing. The prototype has been implemented to configure an EEG data acquisition of 16-channels. The system was implemented of using daisy-chain configuration protocol a SPI with the synchronous communication process. The acquired signals, the FFT signal processing were displayed in a real-time graph and saved into data storage.

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