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Research paper

Development and programming of Geophonino: A low cost Arduino-based seismic recorder for vertical geophones

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ABSTRACT

The commercial data acquisition systems used for seismic exploration are usually expensive equipment. In this work, a low cost data acquisition system (Geophonino) has been developed for recording seismic signals from a vertical geophone. The signal goes first through an instrumentation amplifier, INA155, which is suitable for low amplitude signals like the seismic noise, and an anti-aliasing filter based on the MAX7404 switched-capacitor filter. After that, the amplified and filtered signal is digitized and processed by Arduino Due and registered in an SD memory card. Geophonino is configured for continuous registering, where the sampling frequency, the amplitude gain and the registering time are user-defined. The complete prototype is an open source and open hardware system. It has been tested by comparing the registered signals with the ones obtained through different commercial data recording systems and different kind of geophones. The obtained results show good correlation between the tested measurements, presenting Geophonino as a low-cost alternative system for seismic data recording.

1. Introduction

Technology grows faster day after day. That makes good equipment become old-fashioned very soon. This issue also affects the equipment used in active seismic exploration. A few decades ago, the commercial seismic exploration seismographs were controlled by simple programs that work under old operating systems (e.g. MS-DOS, Windows 98, Windows XP, etc). Moreover, the data transfer used to be carried out through the RS232 serial port, or even using old HD 1.44 MB disks. Although they are very good quality equipment and they continue working nowadays, its current use becomes very difficult, due to the lack of this technology in the new computers (e.g. operating systems, RS232 serial port, etc). Moreover, due to their storage memory limitations, they are not suited to manage the huge volume of data required by recent seismic experiments, like the ambient noise measurements.

Thus, an updating of the data acquisition equipment is required, by means of new modules of hardware (if it is possible) or new complete systems. In this sense, one of the biggest drawbacks is the high price of these seismic exploration systems. Although it is not necessary to obtain new geophones, the data acquisition and recording equipment is very expensive by its own. Due to such economic constraints, it is not possible for all research groups and universities to maintain modern seismic exploration equipment for only education purposes.

On the other side, laboratories around the world face the need to build custom-made experimental systems to acquire data through sensors. In this way, they can configure the data acquisition system according to their needs.

In the recent years, some research groups have tried to develop their own equipment. For instance, we can find the work of Picozzi et al. (2010), where they developed a dedicated system for seismic arrays, and the proposal of Khan et al. (2012), where the PC sound card is used to digitize seismic signals for educational purposes.

Concerning this issue, the increasing accessibility to microcontrollers and to other electronic components have helped to develop home-made systems at low prices. In this way, one of the most common electronic devices used for electronic prototyping in the recent years is Arduino. Arduino constitutes an open-source electronic platform that allows monitoring and controlling different analog and digital signals, as well as other specific electronic circuits (Koenka et al., 2014). Many studies carried out on this topic (e.g. Savazzi, 2011; Agudo et al., 2014; Koenka et al., 2014; Fuentes et al., 2014) show the suitability of the Arduino platform to solve

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specific needs in different research areas.

In this work we have developed a low-cost Arduino-based seismic recorder for vertical geophones. The system is controlled through a user interface developed ad hoc, which includes the parameters needed for the data acquisition and recording. The equipment has been tested using sine waves of known characteristics and compared with other commercial equipments: the DT321 data acquisition card and the RAS-24 exploration seismograph. These systems are well known and have been widely used in previous research projects (e.g. Giner et al., 2012; Rosa-Cintas et al., 2013).

The obtained results demonstrate the suitability of the developed system to acquire and record seismic signals, with the same reliability as the commercial equipment compared in this study. Thus, the presented system provides a low-cost alternative to the commercial systems. Moreover, this is an open-source system, which allows other users to accomplish hardware and software changes, in order to adapt the proposed prototype to their particular requirements. It is appropriate for different educational and research seismic experiments, including the seismic monitoring for long periods of time (e.g. ambient noise measurements).

The article is organized as follows. In Section 2, the different components and equipment used in the present study are described. In Sections 3 and 4, the developed hardware design and the associated software are explained in detail. Finally, in Section 5, different test experiments and their results are shown.

2. Technology overview

The developed prototype is basically formed by four components: an instrumentation amplifier, an anti-aliasing filter, an Arduino board microcontroller, and a SD card shield. Two commercial systems, the RAS-24 exploration seismograph (Seistronix Inc., 2005) and the DT321 data acquisition card (Data Translation Inc., 2010), together with two different types of geophones, have been used to evaluate the prototype.

2.1. Arduino Due microcontroller

Arduino Due is an inexpensive multipurpose open-source hardware platform based on the Atmel SAM3 × 8E ARM Cortex-M3 CPU. It is the first Arduino board based on a 32-bit ARM core microcontroller. The Arduino Due can be programmed using the C++ language. Moreover, a lot of libraries are available to connect the main board with other systems and extend its functionality. The open-source nature of the platform and its huge user community provide access to a large collection of software code; making it relatively simple to build new prototypes, even with little previous programming experience. The Arduino Due is equipped with 68 inputs/outputs and can be programmed to work with different sampling frequencies. The analog-to-digital converter (ADC) integrated in the Arduino Due board provides a maximum resolution of 12 bits and a dynamic range from ground to the ADVREF pin voltage, which is connected to +3.3 V by default (Atmel Corporation, 2012). Its 32-bit 85 MHz processor with 96 Kb of memory provides enough computing power for real-time data processing. The Arduino Due supports multiple communication protocols, such as 2 USB-ports and 4 UARTs (hardware serial ports), which can be used to communicate with other instruments (Ruytenberg et al., 2014). Additionally, the modularity of Arduino boards is guaranteed through a wide variety of modules (shields) that extend the functionality of the system and adapt it to the desired requirements. Besides, we have the possibility to develop new modules with specific purposes (e.g. Fuentes et al., 2014).

Ardunio Due was selected from the existing range of Arduino boards due to the following reasons: 1) It presents the higher frequency clock from the available Arduino boards at the present moment, i.e. 84 MHz, which allows a theoretical maximum sampling frequency of 1 MHz, as it is pointed out in the application note published by Atmel Corporation. (2011). 2) It has two analog outputs, what allows controlling different types of chips by software, e.g. voltage controlled gain amplifiers. 3) Finally, this board is implemented with a 512 Kb Flash memory and 96 Kb SRAM memory, which ensures enough memory to store larger buffer data during the acquisition. Its characteristics allow implementing a highly scalable system, in terms of the type and number of sensors and in terms of the software development.

2.2. Geophones and data acquisition equipment (Testing equipment)

Two types of geophones have been used to test the performance of the developed prototype. One of the sensors used, the SN4-10V, is an electromagnetic 10 Hz vertical-geophone, which is commonly used for seismic prospecting. The other sensor used in this work is a Mark L4-C. This geophone presents, according to the manufacturer, a sensitivity of 280 V/m/s, a mass of 1 Kg, a natural frequency of 1 Hz, and a coil resistance of 5500 Ω.

In order to test the workability of the designed device, we have compared the recorded data with the ones obtained through two commercial data acquisition systems. First one is the RAS-24 system, an excellent and contrasted equipment, specially used for refraction and reflection surveys. However, for other kind of experiments, based on seismic noise recordings, it presents some drawbacks. The available RAS-24 system uses the RS-232 port for the data transfer with the computer, which implies a very low-speed connection.

Moreover, it has a limited buffer for data acquisition that limits the maximum recording time to 64 s, for the minimum sample rate of 250 Hz. It is not a problem for refraction or reflection seismic data acquisition but it becomes a serious handicap when we want to obtain larger registers, as it is the case of the seismic noise recordings.

The other commercial data acquisition system employed with the geophones is the DT321 card, which is a PCI data acquisition card that can be connected to any computer tower and used for different general purposes. It provides a 16-bit analog-to-digital conversion. The data acquisition and recording is controlled through the Data Acquisition Toolbox developed for Matlab.

3. Hardware implementation

The hardware scheme of the developed prototype is shown in Fig. 1. Basically, it is composed of four main blocks: 1) the instrumentation amplifier (i.e. the INA155 chip); 2) the anti-aliasing filter (i.e. the MAX7404 chip); 3) the Arduino Due, which controls the acquisition, processing and recording processes and; 4) the SD (Secure Digital) card shield that stores the seismic data. One important characteristic of these four blocks is that they can all work with the same single power supply, i.e. 3.3 V. This allows the use of a common battery for all blocks and makes the prototype suitable for portable applications. The wiring scheme of the system is shown in Fig. 2.

In the first stage, an instrumentation amplifier is extremely recommended for the proposed prototype. The differential signal provided by the geophone is directly connected to the amplifier, which provides an amplified single-mode output signal, referenced to the ground of the complete system. In addition, the amplification stage allows adapting the amplitude of the signal to cover the dynamic range of the analog-to-digital converter of the Arduino Due, i.e. the 3.3 V.