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PROCEEDINGS

XIII MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU

ZBORNIK RADOVA

Trebinje, June, 06-09, 2024
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CONTENT
SADRŽAJ

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ORIGINALAN NAUČNI RAD – ORIGINAL SCIENTIFIC PAPER

DESIGN AND IMPLEMENTATION OF A SEISMIC DATA ACQUISITION PROTOTYPE SYSTEM INTENDED FOR VARIOUS APPLICATIONS

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ABSTRACT

In this work, we present a prototype of a high-precision and high-resolution seismic data acquisition system (DAQ). This system is designed for real-time monitoring, data acquisition, and visualization of seismic activity, tailored specifically for local and micro-location applications, but not limited to them. The system has various applications, including mathematical modelling of different scenarios based on collected data. These applications are relevant to geophysical research, structural health monitoring, traffic monitoring, industrial safety, household safety, and more. This prototype system acquires seismic data from the geophone or ranger seismometer connected to an analog-to-digital converter (ADC), which then transfers the data to single-board computers (SBCs). Because these SBCs possess all the capabilities of a standard PC, they ensure remote access, real-time monitoring, data acquisition, preprocessing of seismic data, and transfer of data from remote stations to the base station or server for future processing, among other functionalities. In practice, these data acquisition systems can function as standalone systems. Here, the structural components, functionality, and characteristics of this prototype system will be presented.

Keywords: Analog-to-Digital converters, Seismology, Geophone, Toolset, Seismic data.

INTRODUCTION

Geophysical research, an interdisciplinary field, involves studying Earth's physical properties and processes like seismic activity, magnetic fields, and gravitational forces. It relies on collecting and analyzing data from various sources, often integrating computational methods and technologies from computer science to model complex phenomena, analyze vast datasets, and enhance understanding of Earth's systems and dynamics. Computer science plays a vital role in enhancing geophysical research by developing algorithms, software tools, and computational models to process geophysical data efficiently. Geophysical research intersects with a multitude of fields by providing techniques such as ground-penetrating radar and seismic imaging, aiding in assessing structural integrity, traffic flow analysis, hazard detection, and risk mitigation, among other areas, thus enhancing safety and efficiency across various domains.

Seismology, a branch of geophysics, focuses on understanding Earth's structure and seismic hazards. By monitoring and analyzing seismic waves generated by earthquakes, human activities, or other sources, seismologists can discern the properties of Earth's interior, detect and locate earthquakes, assess seismic risk, and contribute to modeling and simulating disaster prediction and preparedness for mitigation efforts. Furthermore, seismological data contribute to the exploration and monitoring of natural resources, such as oil, gas, and minerals, improving our knowledge and understanding of Earth's processes and facilitating decision-making in various areas.

Modern computer technologies, particularly SBCs, are crucial for developing our prototype, handling tasks like data acquisition, remote access, preprocessing, and data transfer. As the name suggests, the SBC is a computer built on a single (printed) board, which essentially functions as a standard PC with all its features. It is imperative for our application to utilize state-of-the-art ADC with high resolution, ideally at least 24 bits, or even more, up to 32 bits. Derived from the name, ADCs are used to convert continuous analog signals, such as those from sensors like geophones or ranger seismometers measuring seismic activity, into digital data for efficient processing, analysis, visualization, and storage by digital systems.

Our subject of interest is developing a high-resolution and accurate DAQ system for real-time monitoring, processing, and visualization of seismic activity, along with seismic event warnings. This prototype is intended for local and micro-location applications but is not limited to them. The goal is to create a mobile, autonomous, standalone, and portable station where all components can be housed within a single box, enabling seismic data gathering regardless of its placement. Another feature will be the ability to create a scalable seismic station network grid. Throughout the prototype development process, a comprehensive suite of necessary software tools was developed.

In addition to the mentioned hardware components, the prototype incorporates a Global Positioning System (GPS) module for precise location determination, time synchronization and accurate geolocation data. Of course, network time protocol (NTP) is necessary for data time stamping. Furthermore, to achieve location independence and ensure continuous operation in remote or off-grid areas, an Uninterruptible Power Supply (UPS) equipped with a solar panel and inverter is necessary. This UPS system provides reliable power backup, allowing the prototype to function autonomously without reliance on external power sources, thus enhancing its versatility and applicability in various environments. Another module and component that can be added is a GSM module, along with a sufficiently powerful wireless module and antenna, to ensure reliable network connectivity.

Before moving on to the next sections, it is important to note that this version of our prototype has limited functionality compared to the previously defined goals. For the sake of initial experiments, the station is static. However, by adding additional modules, we can transform our station to achieve mobility, autonomy, portability, and reliable connectivity.

RELATED WORK

In this new era of technological development, where people are increasingly aware of the need for geophysical science, well-established companies produce professional seismic instruments and monitoring equipment, such as Kinemetrics (Kinemetrics, 2024), Guralp Systems Limited (Guralp Systems Limited, 2024), and Nanometrics (Nanometrics, 2024), and others. Budget-friendly alternatives include Raspberry Shake: Earthquake (Raspberry Shake: Earthquake, 2024), GEObit (GEObit, 2024), and various Do-It-Yourself (DIY) Seismometer Kits. Several companies and educational institutions offer DIY kits that typically include all the necessary components and instructions for assembling a basic seismometer at a lower cost.

Apart from the necessary hardware, software tools are also required. Professional equipment usually comes with specialized proprietary software, but there are also open-source seismic software tools available for free use, such as SeisComP (SeisComP, 2024), Seismic Analysis Code (Seismic Analysis Code [SAC], 2024), and others. Additionally, various programming packages, frameworks, or toolboxes are available for developing seismic software tools, including ObsPy (ObsPy, 2024), SeisIO (SeisIO, 2024), Seismic.jl (Seismic.jl, 2024), and SeisLab (SeisLab, 2024).

Global seismic networks like the Global Seismographic Network (Global Seismographic Network [GSN], 2024) and the European-Mediterranean Seismological Centre (European-Mediterranean Seismological Centre [EMSC], 2024) play a crucial role in earthquake monitoring and research. There are also enthusiast-driven seismic contribution networks like the Quake-Catcher Network (Quake-Catcher Network [QCN], 2024) and Raspberry Shake Station View (Raspberry Shake Station View, 2024).

The next paragraph will focus on DIY Seismometer Kits, primarily because many educational institutions, amateurs, and enthusiasts cannot afford professional equipment. However, by building their own seismic monitoring devices, they can gain a deeper understanding of how they work, enabling them to make modifications and add additional features according to their needs. In this era of digitalization, computational resources are widely available, providing a solid foundation for designing and developing seismic DAQ systems from scratch. Numerous implementations of DIY seismometer devices have emerged, and here, we will mention some of them.

Gao proposed a Three Component Seismic Data Acquisition System Based on LoRa (Gao et al. 2018), which includes a station with a geophone, a 24-bit Delta Sigma ADC ADS1274, a low-power MCU STM32F407ZET6, and utilizes LoRa for communication with a monitoring system, typically a PC operating with LabView. Another example is the Low-Cost Seismic Data Acquisition System (SDAS) (Ramdeane et al., 2020), which features a DAQ system with an ADS1220 24-bit Delta Sigma ADC interfaced with a microelectromechanical system (MEMS)-based accelerometer sensor ADXL335, both connected to a Raspberry Pi. Attia and associates proposed another implementation of a seismic system (Attia et al., 2020), utilizing a Geophone Sensor Node (GSN) SM-24 and a gateway unit combined with a Raspberry Pi 2 and AD HAT (ADS1256). These are just a few examples from the several dozen implementations available, providing a solid foundation for starting from scratch and creating one's own seismic device by leveraging the good practices and advantages of existing solutions.

PROTOTYPE DESIGN SCHEME

In this initial experimental phase, our station remains static, serving as the foundation for our research endeavors. In this section, we delve into the components that comprise our prototype system. Specifically, we highlight the utilization of the SBC Orange Pi 5 Plus, an ADS1256 extremely low-noise 24-bit analog-to-digital (A/D) converter, and a Ranger seismometer (SS-1) (Fig. 1.).

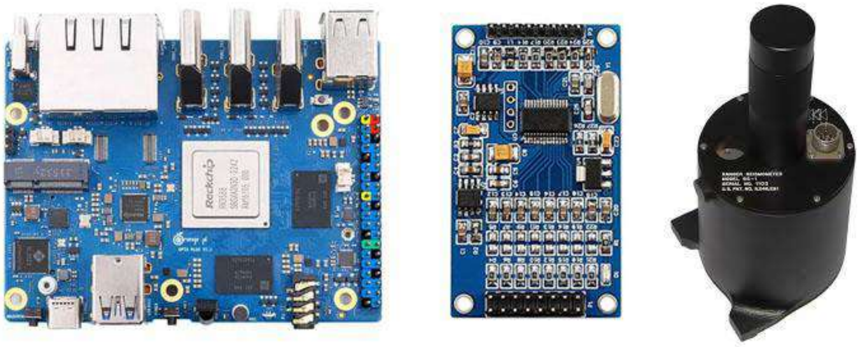

Figure 1. Orange Pi 5 Plus, ADS1256, and SS-1 ranger seismometer.

The Orange Pi 5 Plus (Orange Pi, 2024) (Fig. 1) is a small single-board computer (SBC) and an open-source product brand of Shenzhen Xunlong Software Co., Ltd (Shenzhen Xunlong Software Co., 2024). In 2014, Orange Pi's first open-source product was officially launched and received wide acclaim from the market due to its high-cost performance and excellent user experience. It is widely used in many areas because of its low cost, modularity, and open design. The hardware configuration, operating system, and additional software used with the Orange Pi 5 Plus are described in Table 1.

Table 1. Description of Raspberry Pi, hardware, and software.

Component equipment	Orange Pi
Product Model:	Orange Pi 5 Plus
CPU	8-Core, 64-bit, Rockchip RK3588, 2.4GHz
Memory	16GB LPDDR4
OS	Ubuntu 22.04 LTS
Kernel Version	5.15.0
Compiler	gcc 11.4.0
IDE, Programing languages	Code::Blocks, Arduino IDE, C, Python
Graphing Utility	Plotly
Remote Access	SSH, X client

The ADS1256 (Texas Instruments, 2024) (Fig. 1), is a high-resolution, low-noise ADC commonly used in precision measurement applications such as instrumentation, data acquisition, and sensor interfacing. With its 24-bit resolution and programmable gain amplifier, the ADS1256 offers exceptional accuracy and sensitivity, making it ideal for capturing small signals with high fidelity. Its integrated features, including an on-chip voltage reference and temperature sensor, contribute to its versatility and reliability in demanding measurement environments. The detailed specifications are described in Table 2.

Table 2. ADS1256 details specifications.

Component equipment	ADS1256
Resolution	24 (Bits)
Sample rate (max)	30 (ksps)
Number of input channels	8
Interface type	SPI
Architecture	Delta-Sigma
Input type	Differential, Single-ended
Multichannel configuration	Multiplexed
Input voltage range (max)	5.25 (V)
Input voltage range (min)	0 (V)
Features	50/60 Hz Rejection, GPIO, PGA
Operating temperature range	-40 to 85 (°C)
Power consumption (typ)	36 (mW)
Analog supply (min)	4.75 (V)
Analog supply voltage (max)	5.25 (V)
Digital supply (min)	1.8 (V)
Digital supply (max)	3.6 (V)

The SS-1 Ranger seismometer (Fig. 1), widely utilized for its high sensitivity, comprises a stationary coil and a robust permanent magnet acting as the seismic mass. This mass is upheld by annular springs positioned at both the top and bottom of the magnet's movement. The SS-1 offers versatility, as it can be employed in both horizontal and vertical orientations, with the seismic mass's support adjusted by the annular springs accordingly. Technical specifications are described in Table 3.

Table 3. Technical specifications of SS-1 ranger seismometer.

Component equipment	SS-1 ranger
Natural frequency	1Hz
Critical damping ratio	70%
Power	none
Weight	5 kg
Dimensions	5.5" diameter x 12" height
Housing	Cast aluminum

Figure 2 shows the general block diagram of our seismic DAQ system. The Ranger seismometer is linked to the ADC, which detects seismic activity, vibrations, or oscillations. The ADC then converts the input analog signal from the Ranger to a 24-bit digital representation. The programmable gain amplifier (PGA) on the ADC is configured to a range of ±1.25 V, corresponding to the input range of the analog signal. Additionally, the ADC is configured to sample at a rate of 100 samples per second, all with a high resolution of 24 bits. Communication between the ADC and the main control block utilizes the serial peripheral interface (SPI). This interface facilitates communication between the microcontroller (Arduino Uno) and the ADC, while the Arduino controller connects to the main control block (Orange Pi) via a universal serial bus (USB). In the subsequent phase of prototype development, the Arduino controller will be omitted to enhance system accuracy. The main control block, represented by the SBC Orange Pi 5 Plus, preprocesses and stores seismic measurements. Network connection is established through either an Ethernet or wireless interface. This allows us to access the seismic station locally or configure network settings for remote access using remote access software such as an X client or similar software.

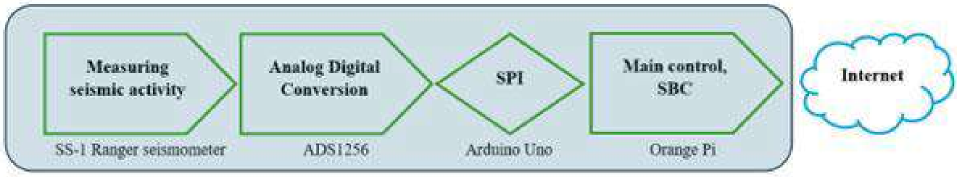

Figure 2. DAQ system general block diagram.

The atypical device component structure necessitates a specific programming toolset tailored to the needs of this initial experimental phase. Since the Arduino Uno serves as the interface between the ADC and the SBC, a variant of the C++ programming language is utilized for programming the microcontroller. The code is written in C++ with additional special methods and functions. These functions are defined for establishing a connection to the SBC, initializing settings such as the PGA, data rate, and input type on the ADC, and finally determining how measurement data is to be read and transmitted to the SBC.

On the SBC side, the entire required toolset is written in Python, utilizing various libraries to meet different needs. Given our processing of seismic data, the ObsPy framework is essential. We employ the pySerial module to facilitate access to the serial port where the SBC reads seismic data. For visualizing seismic data, the Plotly library is employed. Additionally, to preprocess, manipulate, and analyze seismic data, the Pandas and NumPy libraries prove invaluable. All these components are seamlessly integrated and deployed as interactive web applications with the assistance of the Dash framework.

Currently, results are stored in two formats: comma-separated values (CSV) text files and MiniSEED (MSEED) data format, conforming to the Standard for the Exchange of Earthquake Data (SEED). Furthermore, the next section will delve into seismic data, data visualization, and experimental seismic measurements.

RESULT MEASUREMENTS AND DISCUSSION

To assess the performance and capabilities of the seismic DAQ prototype system, an experimental testing phase was initiated, focusing on the analysis of system components, notably the ADC device. Tests conducted encompassed evaluations of system noise, dynamic range performance, field performance, frequency distortion, and click time test.

When the system input is shorted, the size of the collected data represents the level of system noise. In the system noise test, noise data are collected at the shorted input at various sampling frequencies. The results of the noise testing on the data acquisition system over time are shown in Figure 3, with the maximum amplitude of the device noise signal ±1.8μV.

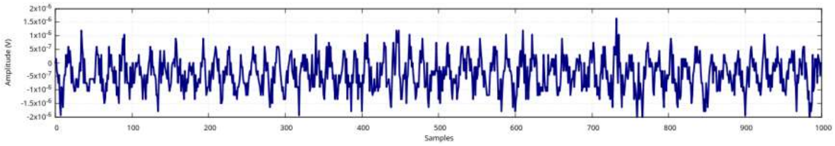

Figure 3. System noise test, 10 seconds (100Hz sampling rate).

The dynamic range of the instrument is the ratio of the maximum to the minimum signal values that the system can accurately detect, with the acquisition system's PGA set to receive signals within ±*1.25V*. The minimum detectable signal is determined by the system noise level, which serves as the reference. System noise test results indicate that the sampling rate does not significantly affect the noise value, allowing flexibility in choosing the sampling frequency.

The Click Time Test validates the system's sampling rate by identifying any deviations in recorded time duration, which indicate lost or oversampled data during acquisition. Factors such as heavy processing interruptions can cause these deviations. Although the tests did not use high-accuracy or calibrated equipment, they yielded consistent results, demonstrating the reliability and quality of the data acquisition device. For our requirements, a sampling rate of *100 Hz* was tested and showed a margin of error of *0.0001%*, confirming the system's precision.

An online interface has been developed to stream real-time seismic data from our DAQ system, accessible at https://geotehnologija.ugd.edu.mk/. The main page (Fig. 4) displays real-time data, with anchor links for better content organization. Users can download stored data in CSV or MSEED format, view daily plot, access tools for data analysis, view worldwide earthquakes with a magnitude greater than *4*, and find information about the *SeisComP6* server.

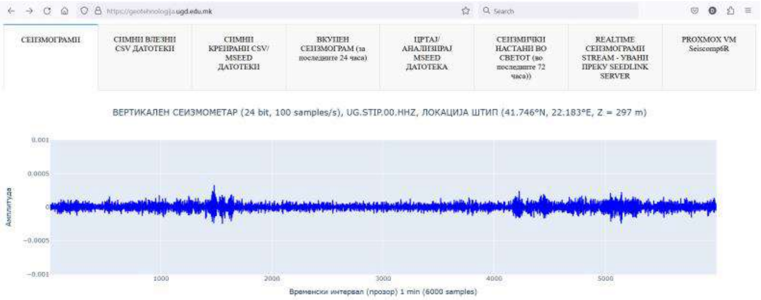

Figure 4. Online page www.geotehnologija.ugd.edu.mk.

We established an isolated area within the university campus for continuous seismic data acquisition using a single-channel vertical seismometer at coordinates 41.746°N, 22.183°E, Z=297. During this period, the device detected several significant earthquakes in neighboring countries (Fig. 5), demonstrating the system's effectiveness in collecting seismic activity. Future tests will involve shallow earthquake environments and controlled seismic activity from artificial hammering for more precise field validation.

Figure 5. Day plot from the vertical seismometer.

This initial phase of seismic DAQ system development branches into two paths: sustainable stationary stations and mobile standalone stations for fieldwork. Hardware updates, such as adding GSM, UPS and GPS, will be crucial for the mobile units. Software enhancements will include implementing databases for scalable data handling and real-time data acquisition protocols like SeedLink (GFZ Potsdam and IRIS DMC, 2024), enabling data transmission. Mobile stations will monitor and analyze artificial seismic waves from human activities like industrial, mining, and transportation operations.

CONCLUSIONS

We introduce a prototype seismic DAQ system designed for precise data collection, with potential for hardware upgrades and software scalability. Our roadmap includes developing both stationary and mobile stations, focusing on hardware improvements and real-time data transmission, to create a comprehensive seismic monitoring system for geophysical research, structural health monitoring, and disaster preparedness, ultimately enhancing safety measures and understanding of seismic activity.

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LITERATURE

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