ISSN 2303-498X

XIII INTERNATIONAL CONFERENCE ON SOCIAL AND TECHNOLOGICAL DEVELOPMENT

PROCEEDINGS

XIII MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU

ZBORNIK RADOVA

Trebinje, June, 06-09, 2024
Trebinje, 6 - 9. juni 2024. godine

ISSN 2303-498X

XIII INTERNATIONAL CONFERENCE ON SOCIAL AND TECHNOLOGICAL DEVELOPMENT

PROCEEDINGS

XIII MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU

ZBORNIK RADOVA

Trebinje, June, 06-09, 2024
Trebinje, 6 - 9. juni 2024. godine

Co-organizers:

UNIVERSITY of DEBRECEN

Univerza v Mariboru
Fakulteta za logistiko

TECHNICAL UNIVERSITY OF KOŠICE
Faculty of Manufacturing Technologies

AUE FON
AMERICAN UNIVERSITY OF EUROPE

АКАДЕМИЈА СТРУКОВНИХ СТУДИЈА ШАБАЦ

VELEUČILIŠTE VIMAL
University of Applied Sciences

УДРУЖЕЊЕ ИНЖЕЊЕРА ТЕХНОЛОГИЈЕ РЕПУБЛИКЕ СРПСКЕ
УИТРС

EUMMAS

VUB
VISOKA ŠKOLA ZA USLUŽNI BIZNIS

XIII INTERNATIONAL CONFERENCE ON SOCIAL AND TECHNOLOGICAL DEVELOPMENT
XIII MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU
PROCEEDINGS

Publisher:
University PIM, Banja Luka, Republic of Srpska, Bosnia and Herzegovina

For publisher
Dejan Kojić, PhD, General Manager

Editorial board:
Dejan Kojić, PhD, Vice-Rector for Science
Darjana Sredić, PhD.

Design and Computer processing:
Ljubica Janjetović, PhD

Print:
„Vilux“ Banja Luka

Circulation:
25 Cipies

CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

33:005(082)
62(082)

МЕЂУНАРОДНА конференција о друштвеном и технолошком развоју (13 ; 2024 ; Требиње)

Zbornik radova / XIII Međunarodna konferencija o društvenom i tehnološkom razvoju, Trebinje, 6-9. juni 2024. godine = Proceedings / XIII International conference on social and technological development, Trebinje, June, 06-09, 2024 ; [editorial board Dejan Kojić, Darjana Sredić]. - Banja Luka : Univerzitet za poslovni inženjering i menadžment = University PIM, 2024 (Banja Luka : Vilux). - 608 стр. : илустр. ; 25 cm. - (Međunarodna konferencija o društvenom i tehnološkom razvoju = International conference on social and technological development, ISSN 2303-498X)

Радови на срп. и енгл. језику. - На кор: Sted. - Тираж 25. - Напомене и библиографске референце уз текст. - Библиографија уз сваки рад. - Abstracts.

ISBN 978-99955-40-79-1

COBISS.RS-ID 141600769

Trebinje, June, 06-09, 2024. Republic of Srpska, B&H

XIII INTERNATIONAL CONFERENCE ON SOCIAL AND TECHNOLOGICAL DEVELOPMENT
XIII MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU

Trebinje, June, 06-09, 2024. Republic of Srpska, B&H

Zbornik radova sa međunarodne naučne konferencije o društvenom i tehnološkom razvoju – STED, publikuje se uz finansijsku podršku Ministarstva za naučnotehnološki razvoj i visoko obrazovanje u Vladi Republike Srpske.

Proceedings from the International scientific conference on social and technological development - STED, is published with the financial support of the Ministry of Scientific-Technological Development and Higher Education in the Government of the Republic of Srpska.

XIII INTERNATIONAL CONFERENCE ON SOCIAL AND TECHNOLOGICAL DEVELOPMENT
XIII MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU

Trebinje, June, 06-09, 2024. Republic of Srpska, B&H

Organizing and Program Committee:

Dr Dejan Kojić, president, Dr Mladen Ivić, Dr Ljubica Janjetović. Dr Nikola Vojvodić, Dr Predrag Raosavljević, Dr Simonida Vilić, Dr Danijela Jokanović, Dr Darjana Sredić, MSc Nada Dursun, Ba Ognjen Todorović.

***Students:** Dajana Bašić, Sofija Pačariz, Sanja Miljanović, Nataša Belović, Slaviša Marković*

Scientific and Program Committee:

***Dr Mladen Ivić,** president, University PIM, Banja Luka, **B&H; Dr Darina Dupláková,** Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Prešov, Institute of Advanced Technologies, Prešov, **Slovakia; Dr Maja Fošner,** Faculty of Logistics, University of Maribor, Celje, **Slovenija; Dr Savo Ashtalkoski,** American University of Europe, Skopje, **North Macedonia; Dr Milena Marinović-Cincović,** University of Belgrade, Vinča Institute of nuclear Sciences, Belgrade, **Serbia; Dr Jelena Pavličević,** University of Novi Sad, Faculty of Technology, Novi Sad, **Serbia; Dr Ayse Aroguz,** Istanbul University-Cerrahpasa, Engineering Faculty, Istanbul, **Turkey; Dr Irena Petrušić,** Faculty of Management, Herceg Novi, **Montenegro; Dr Svetlana Karić,** Academy of vocational studies in Šabac, **Serbia; Dr Tigran Petrosyan,** Yerevan Haybusak University, Yerevan, **Armenia; Dr Tibor Gonda,** Faculty of Business and Economics of the University of Pécs, **Hungary; Dr Zoltán Raffay,** Faculty of Business and Economics of the University of Pécs, **Hungary; Dr Dragan Brenjo,** Food safety agency of Bosnia and Herzegovina, **B&H; Dr Boris Dorbić,** scientific- expert association "FUTURA", Šibenik, **Croatia; Dr Ilija Džombić,** University PIM, Faculty of Economics, Banja Luka, **B&H; Dr Mile Vasić**, European Marketing and Management Association, **B&H; Dr Ognjen Bakmaz,** The College of Service Business, Sokolac, **B&H; Dr Osman Khan,** Institute of Customer Management, **United Kingdom; Dr Perica Bošković**, Faculty of Science, Split, **Croatia; Dr Yajnya Dutta Nayak,** P.G. Dept. of Commerce, Khallikote Auto. College, Berhampur, Odisha, **India; Dr Martin G. Abrahamyan,** Yerevan Haybusak University, Yerevan, **Armenia; Dr Svetlana Radchenko,** Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Prešov, Institute of Advanced Technologies, Prešov, **Slovakia; Dr Lucia Knapčíková,** Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Prešov, Institute of Advanced Technologies, Prešov, **Slovakia; Dr Bojan Rosi,** Faculty of Logistics, University of Maribor, Celje, **Slovenija; Dr Tomaž Kramberger,** Faculty of Logistics, University of Maribor, Celje, **Slovenija; Dr Isaac Lera,** University of the Balearic Islands, Dept. of Mathematics and Computer Science, Balearic Islands, **Spain; Dr Benea Marius Calin,** Politehnica University Timisoara, Faculty of Engineering Hunedoara, **Romania; Dr Milena Špírková,** Institute of Macromolecular Chemistry, Prague, **Czech Republic; Dr Yaroslav Kusyi,** National University "Lviv Polytechnic", Lviv, **Ukraine; Dr Irena Ashtalkoska**, American University of Europe, Skopje, **North Macedonia; Dr Bojana Ikonić,** University of Novi Sad,* *Faculty of Technology, Novi Sad,* **Serbia; Dr Mirjana Jovičić,** *University of Novi Sad, Faculty of Technology, Novi Sad,* **Serbia; Dr Nikša Grgurević,** *Faculty of Management, Herceg Novi,* **Montenegro; Dr Oskar Bera,** *University of Novi Sad, Faculty of Technology, Novi Sad,* **Serbia; Dr Nataša Lukić,** *University of Novi Sad, Faculty of Technology, Novi Sad,* **Serbia; Dr Vesna Teofilović,** *University of Novi Sad, Faculty of Technology, Novi Sad,* **Serbia; Dr Azemina Mašović,** *American University of Europe,* **North Macedonia; Dr Hafiz Imtiaz Ahmad,** *Faculty of Business, Higher Colleges of Technology, Ali Alin, Abu Dhabi,* **UAE; Dr Milenko Košutić,** *Institute of Food Technology, Novi Sad,* **Serbia; Dr Jovana Kojić,** *Institute of Food Technology,* **Serbia; Dr Jelena Krulj,** *Institute of food Technology,* **Serbia; Dr Nevena Vukić,** *University of Kragujevac, Faculty of Techinc, Čačak,* **Serbia; Dr Tamara Erceg,** *University of Novi Sad, Faculty of Technology,* **Novi Sad, Serbia; Dr Predrag Kojić**, *University of Novi Sad, Faculty of Technology,* **Novi Sad, Serbia; Dr Snežana Papović,** *University of Novi Sad, Faculty of Sciences,* **Novi Sad, Serbia; Dr Jovana Panić,** *University of Novi Sad, Faculty of Sciences,* **Novi Sad, Serbia; Dr Enes Sukić,** *Faculty of Information technology and engineering, Belgrade,* **Serbia; Dr Ljiljana Tanasić,** *Academy of vocational studies in Šabac,* **Serbia; Dr Bojan Damnjanović,** *Academy of vocational studies in Šabac,* **Serbia; M.Sc. Emilija Friganović,** *scientific-expert association "FUTURA", Šibenik,* **Croatia; Dr Božana Odžaković,** *University of Banja Luka, Faculty of technology, Banja Luka,* **B&H**; **Dr Željko Grublješić,** *University PIM, Banja Luka,* **B&H**; **Dr Branko Latinović,** *Panevropski univerzitet „APEIRON", Banja Luka,* **B&H**; **Dr Saša Salapura,** *University PIM, Banja Luka,* **B&H**; **Dr Marijana Žiravac-Mladenović,** *University PIM, Banja Luka,* **B&H**; **Dr Nikola Vojvodić,** *University PIM, Banja Luka,* **B&H**; **Dr Predrag Raosavljević,** *University PIM, Banja Luka,* **B&H**; **Dr Snežana Samardžić,** *University PIM, Banja Luka,* **B&H**; **Dr Velimir Dedić,** *University PIM, Banja Luka,* **B&H; Dr Svetlana Anđelić,** *University PIM, Banja Luka,* **B&H; Dr Ljubica Janjetović,** *University PIM, Banja Luka,* **B&H; Dr Danijela Jokanović,** *University PIM, Banja Luka,* **B&H; Dr Darjana Sredić,** *University PIM, Banja Luka,* **B&H; Dr Dejan Kojić,** *University PIM, Banja Luka,* **B&H.**

NOTE:

The authors have full responsibility for the originality and content of their own papers

CONTENT
SADRŽAJ

DOI 10.7251/STEDZ2401349P

ORIGINALAN NAUČNI RAD – ORIGINAL SCIENTIFIC PAPER

APPLICATION OF AUDIO RECORDERS FOR REGISTERING SEISMIC SIGNALS FROM INDUCED SEISMICITY PRODUCED BY BLASTING IN OPEN PIT MINES

Zoran Panov[1], Dushan Bikov[2]

[1] Goce Delcev University, Faculty of Natural and Technical Sciences, Krste Misirkov 10-A, 2000 Stip, Macedonia, zoran.panov@ugd.edu.mk
[2] Goce Delcev University, Faculty of Computer Science, Krste Misirkov 10-A, 2000 Stip, Macedonia, dusan.bikov@ugd.edu.mk

ABSTRACT

Seismic events induced by blasting operations in open pit mines pose significant challenges for monitoring and mitigation. This paper presents an innovative approach utilizing audio field recorders to capture seismic signals from both vertical and horizontal geophones deployed in mining environments. Field experiments were conducted at a mining site, where a network of geophones coupled with audio recorders was strategically deployed to comprehensively monitor induced seismicity. The integration of audio field recorders with geophone arrays enabled the accurate detection and analysis of seismic activity, providing valuable insights into the spatial distribution and characteristics of induced seismic events. Our findings underscore the efficacy of audio field recorders in recording high-fidelity seismic data, showcasing their versatility as essential tools for seismic monitoring in challenging mining environments. Furthermore, this research contributes to enhancing safety protocols and risk management strategies in the mining industry by leveraging innovative technologies for improved seismic monitoring and mitigation efforts.

Keywords: Seismic Signals, Blasting, Open Pit Mines, Audio Recorders, Geophone.

INTRODUCTION

Surface mining of mineral raw materials is one of the most effective methods for extracting valuable minerals, metals, and non-metals from the earth's surface. One of the phases in surface exploitation is the application of drilling and blasting techniques. During this process, rock is fragmented to facilitate subsequent operations such as loading, transportation, crushing, grinding, concentration, and extraction.

Surface mine blasting, which typically involves mass blasting methods, generates significant seismic activity that can affect surrounding structures and pose safety risks. Traditionally, seismometers and accelerometers have been used to monitor these seismic effects. While these instruments provide valuable information about the blasting events themselves, they often offer limited data on the potential risks of dynamic seismic waves generated by the blasts. Additionally, the use of these classic methods (Stein, & Wysession, 1990) can be costly and may require substantial investment for proper maintenance.

Recently, there has been growing interest in researching alternative technologies for seismic monitoring (Lellouch et. al., 2020). One such technology is the use of audio recorders (Skibicki et. al., 2024). While audio recorders are primarily designed for capturing sound, there is potential for them to register seismic signals due to their high sensitivity to vibrations (Igel et al., 2016), even at low frequencies. Human hearing typically ranges from 20 Hz to 20 kHz, but sensitive audio recorders can capture frequencies below 20 Hz—within the range of seismic waves caused by blasting as well as natural earthquakes with frequencies below 1 Hz.

This paper explores the potential of using audio recorders to monitor seismic activity resulting from blasting in surface mines. By analyzing data recorded from seismic events captured by audio recorders, this study aims to improve seismic monitoring practices, enhance safety protocols, and optimize operational costs in mining activities.

For the research, five 32-bit, 6-channel ZOOM F6 audio recorders and vertical and horizontal geophones (4.5 Hz) were used. For comparison, recordings were made with seismograph. Additionally, short-period field seismometers, paired with same geophones, were employed. The recordings were processed using software tools developed in Python, utilizing the libraries NumPy (NumPy Developers, 2023), pandas (Pandas Development Team, 2023), ObsPy (Python framework for seismology, 2023), SciPy (SciPy Community, 2024), Librosa (McFee et al., 2023) and Pyrocko (Pyrocko Team, 2023), Framework documentation site (SeisIO site, 2024), Seislib (Niemeyer et. al, 2023) etc.

METHODOLOGY

The research aims to evaluate the effectiveness of audio recorders for monitoring seismic signals in comparison with traditional seismic monitoring methods. The study employs a quantitative approach for analyzing seismic data and includes qualitative assessments of the usability and practicality of audio recorders. To achieve this, audio recorders have been tested alongside conventional seismometers under both controlled and field conditions to assess their performance.

The analysis was conducted using recorded data from blasting operations in two open-pit mines in Macedonia. Specifically, several randomly selected blasting events were chosen to ensure a representative dataset, resulting in a total of ten recorded events. The signal recording system used in the study comprised a ZOOM F6 audio recorder, one vertical geophone, and two horizontal geophones (4.5 Hz). Second way is to connect only one vertical geophone. It is done on several experiments in open pit mines (fig. 1 and 2).


a b

Figure 1. ZOOM F6 audio recorder.
a – 5 ZOOM F6 audio recorders, b – connected 3 geophones to XLR inputs (1, 2 and 3) on ZOOM F6

The geophones were connected to the ZOOM F6 audio recorder (fig. 1) via shielded 3-pin XLR cables. The ZOOM F6 was configured to record on three channels (connected to channels 1, 2, and 3, fig. 1b) with a minimum sampling rate of 44.1 kHz. Multiple recording setups were employed to capture multi-channel WAV files at both 24-bit and 32-bit depths, allowing for a comparison with 24-bit and 32-bit analog-to-digital converters.

A significant challenge when using multiple audio recorders is time synchronization. Each ZOOM F6 recorder employs a time sync system using audio cables, where the primary ZOOM sends an audio signal via cable to neighboring ZOOM F6 devices. In theory, this signal can be cascaded to subsequent ZOOMs, but signal quality and synchronization feasibility decrease with greater distances. Based on our experience, we successfully synchronized ZOOMs over distances up to 65 meters. This implies that if the primary audio recorder is centrally located in the cable string, it can synchronize seismic profiles extending up to approximately 125-130 meters in length.

An alternative synchronization method is simpler but involves more coordination: multiple individuals are needed to position the audio recorders. This method involves setting the time on one ZOOM unit first, then simultaneously activating the remaining ZOOMs. Activation is triggered by a "test" hammer strike near the placed ZOOMs. All ZOOMs are triggered simultaneously by the same impact, allowing for straightforward post-processing synchronization unless they are manually powered off. The ZOOM devices remain idle at the intended measurement points until specific dynamic events are recorded.

Figure 2. ZOOM F6 connected with one vertical geophone.

First Model

The previous system is the first model to use the ZOOM F6 recorder as a three-channel seismometer. The recording is done on these three channels using three 4.5 Hz geophones (one vertical and two horizontal). The ZOOM F6 saves the recorded data on an internal SD card as a 24/32-bit multi-channel WAV file. This file is then analyzed and processed using software for audio editing or converted directly with custom-developed Python software utilizing libraries such as librosa, scipy, and base64. To conduct a comparative analysis of the results, both the audio editing software and the developed Python application were used. The procedure for converting (Aki, & Richards, 2002) the recorded audio track from induced seismicity (Fan et. al., 2020) involves the following steps:

1. Splitting the three-channel WAV file into three separate mono WAV files, each representing an individual channel from the recordings of the vertical and two horizontal geophones.
2. Resampling the three independent mono WAV files to the sampling frequency required for the specific analysis. The ZOOM F6 samples at a minimum of 44.1 kHz, which is often too high for certain analyses. Therefore, the files need to be resampled to 100, 200, 500, 1000, or 4000 Hz, depending on whether the analysis involves refraction, reflection, or MASW seismic methods.
3. Combining the three mono files into a single digital file, typically in CSV format. This involves creating a CSV file with four columns: the first column represents the sample number, and the second, third, and fourth columns contain the voltages (in mV) recorded by the vertical geophone and the two horizontal geophones, respectively. This step is necessary when utilizing off-the-shelf software tools for sound editing, such as Audacity (Audacity Team, 2024). However, it may be omitted when employing an audio signal converter from a multi-channel WAV file. Below is a Python code snippet demonstrating the use of the Librosa library for converting audio to digital format.

```
import librosa
import pandas as pd
wav_file_path = 'fq1000.wav'
csv_output_path = 'fq1000_data.csv'
audio, sr = librosa.load(wav_file_path, sr=None, mono=False)
duration = librosa.get_duration(y=audio[0], sr=sr)
num_samples = len(audio[0])
time_values = librosa.times_like(audio[0], sr=sr)
df = pd.DataFrame({
    'Time': time_values,
```

```
    'Geoph_z': audio[0],
    'Geoph_x': audio[1],
    'Geoph_y': audio[2]
})
df.to_csv(csv_output_path, index=False)
```

4. Creating a new file with converted amplitude values of the recorded data. This step involves using the recorded voltage values (in mV) and the calibration constants for each geophone (both horizontal and vertical) to compute the amplitudes of the recorded oscillations. The resulting file is also a CSV format with four columns: the first column is the same as before, and the remaining three columns contain the converted amplitude values. Converting the recorded voltage from an audio recorder to the amplitude of a seismic signal involves a few steps. It is need to use the geophone's sensitivity to convert the recorded voltage into ground motion measurements. Here's a general approach:

a. Geophone Sensitivity

The geophone's sensitivity is a critical factor in this conversion. It is typically given in terms of volts per unit of ground motion, such as mV/(mm/s) or mV/(g), where:

- *mV* stands for millivolts.
- *mm/s* stands for millimeters per second, representing the velocity of recorded seismic wave.
- *g* stands for gravitational acceleration (9.81 m/s²), representing acceleration.

b. Sensitivity Value

For a 4.5 Hz geophone, the sensitivity might be provided in the manufacturer's specifications. Generally, in this case is 50 mV/(mm/s). This means that for every millimeter per second of ground motion, the geophone outputs 50 millivolts – recorded by ZOOM F6.

c. Conversion to Velocity

To convert the recorded voltage (in mV) to velocity, is used for:

$$V = \frac{U}{S} \text{ [mm/s]}$$

Where are:
U – voltage recorded by audio recorder, [mV]
S – sensitivity (Constance) of geophone, [mV/(mm/s)]

d. Converting Velocity to Acceleration

To convert the calculated velocity (in mm/s) to acceleration (mm/s^2):

$$V = \frac{V_{i+1} - V_i}{\Delta t} \text{ [mm/s}^2\text{]}$$

Where are:
V_i, V_{i+1} – velocity of seismic wave in first and second measurement, [mm/s]
Δt – time interval between measurements, [s]

Second Model

The second application model for using audio recorders to capture tremors from induced seismicity involves a setup with five ZOOM F6 recorders, each equipped with six recording channels (fig. 2). This configuration allows for the creation of a seismic array with a total of 30 inputs by forming a string of vertical geophones. Each recorder is connected to a series of six independent 3-pin cables, each cable linked to a separate geophone, resulting in a total array of 24 geophones distributed across the five audio recorders.

This model is suitable for various seismic survey methods, including MASW (Multichannel Analysis of Surface Waves), refraction, and reflection techniques. In this setup, the geophones are spaced 5 meters apart, yielding a maximum array length of 115 meters, which represents the length of the seismic profile.

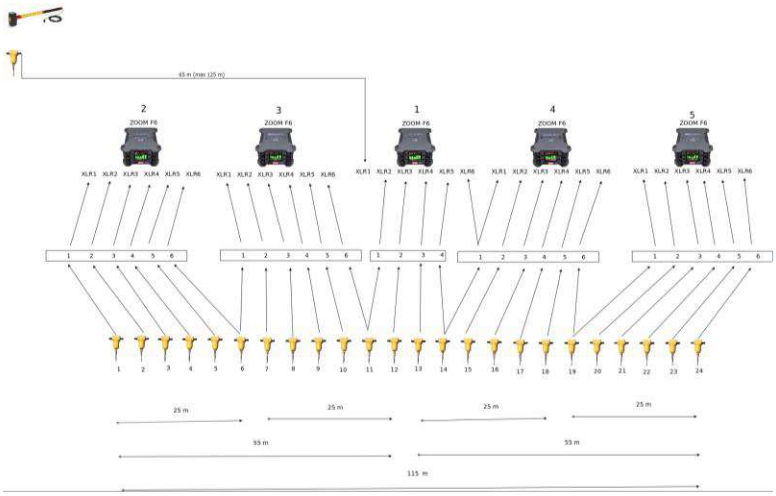


Figure 3. Schemes of string of 24 geophones connected to 5 ZOOM F6.

A total of 24 out of 30 available inputs were utilized to connect 24 vertical geophones for the experiment (fig. 3). Six of these inputs were allocated for synchronizing audio recorders. Specifically, every sixth and first input of the side geophones (inputs 2 and 3, and 4 and 5) were configured to simultaneously record signals from adjacent geophones (2 and 3, and 4 and 5). The central ZOOM recorder (No. 1) played a pivotal role in signal synchronization: its sixth channel was linked to channel 6 of ZOOM No. 2, while its first channel synchronized with the first channel of ZOOM No. 4. The initiation of recording on the central ZOOM (No. 1) was triggered by the first geophone's channel 1 signal.

By utilizing the trigger channel and synchronized channels, all multi-waveform files were aligned temporally and merged into a single 24-channel multi-waveform file, from which 24 mono-waveform files were subsequently derived. This configuration necessitated the use of six 3-pin cables, each 25 meters in length (fig. 4). Additionally, a trigger cable spanning 65 meters was required, ideally extending to 125 meters for accommodating various equipment arrangements.

Apart from this complex setup, simpler configurations using only 1, 2, 3, or 4 ZOOM recorders in combination were also feasible.

Figure 4. Application of multistring system of geophones connected to ZOOM's (induced seismic from seismic hammer).

RESULTS AND DISCUSSION

Below are the seismograms (fig. 5) derived from recordings of induced seismicity sequences triggered by a hammer, comparing the performance of the ZOOM F6 audio recorder when analyzing a single selected channel connected to a 4.5 Hz vertical geophone. This comparison is conducted against a 24-channel seismograph typically used for seismic reflection and refraction analyses. The analysis specifically focuses on the data from the 4.5 Hz geophone, which is positioned relatively close, approximately 20-70 cm away.

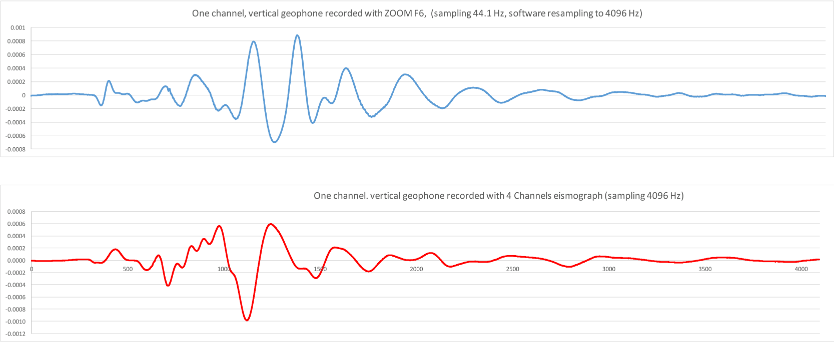
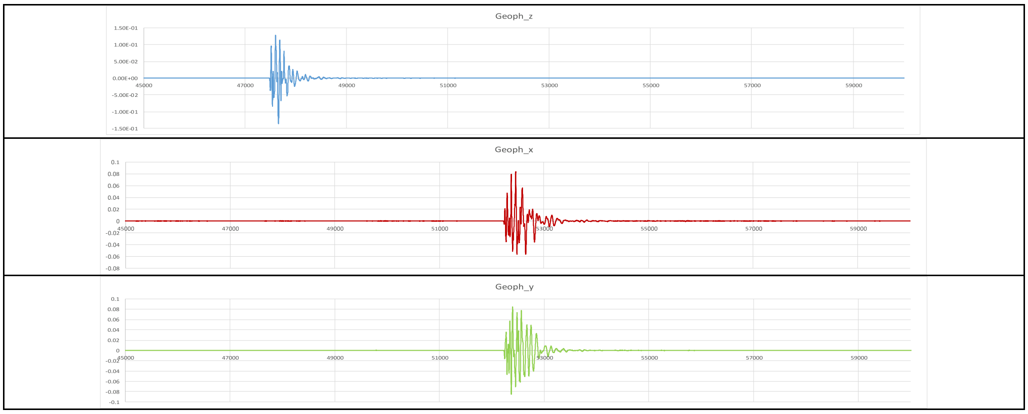


Figure 5. Seismograms of comparative analysis.

The seismograph samples at a rate of 4096 samples per second, while the ZOOM F6 records at 44.1 kHz with 32-bit quality settings. Figure 5 illustrates both seismograms. Despite the relatively short analysis window of approximately 1 second (equivalent to about 4096 samples), the seismograms exhibit noticeable similarity. This „relativity" similarity suggests the feasibility of employing audio recorder systems to capture induced seismicity events, such as those generated by blasting activities in surface mining operations.

Based on recordings of tremors induced by surface mining blasts (Boore et al., 1975) using the ZOOM F6 audio recorder (Model 1) with connected vertical and two horizontal geophones, seismograms were obtained (Fig. 6). Analysis of these seismograms indicates relatively satisfactory results, encouraging further examination and processing.

The seismic tremors were recorded during induced seismicity from surface mining drilling. The three geophones were positioned approximately 150 meters from the center of the minefield.

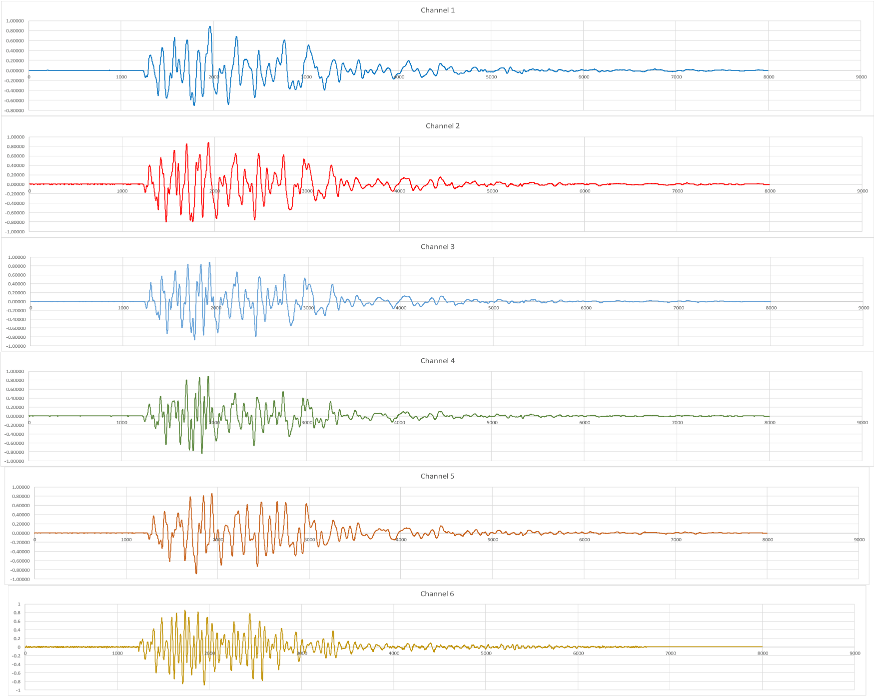

Geoph_z

Geoph_x

Geoph_y

Figure 6. Seismograms from blasting (three components).

The following results (Model 2) depict recordings obtained using a single ZOOM F6 recorder connected to a 25-meter string comprising 6 vertical geophones (4.5 Hz). These measurements were taken during a surface mining blast, with the geophone string positioned radially towards the blast site at a horizontal distance of approximately 510 meters from the last geophone (channel 6). The first geophone is located 25 meters further (channel 1). Figure 7 displays the seismograms recorded during this blasting event (resampled from original 44.1 kHz to 1000 Hz).


Channel 1

Channel 2

Channel 3

Channel 4

Channel 5

Channel 6

Figure 7. Registration of 6 channels string of vertical geophones aligned radial from center of blasting.

CONCLUSIONS

The study demonstrates the feasibility of using audio recorders, such as the ZOOM F6, as effective tools for recording seismic signals resulting from blasting activities. Vertical and horizontal geophones were integrated to enhance data quality, enabling detailed analysis of ground movement characteristics during blasting events. This approach suggests that audio recorder systems could potentially serve as cost-effective alternatives to traditional seismographs, offering reduced operational costs without compromising data accuracy significantly.

Moving forward, it is recommended to focus on advancing signal processing algorithms tailored for extracting and analyzing seismic signals from audio recordings. This includes developing techniques to mitigate tremors and noise, as well as optimizing waveform analysis algorithms specifically for seismic data obtained from surface mine blasting.

Moreover, comprehensive studies are needed to evaluate the reliability and durability of audio recorder systems for continuous monitoring of induced seismicity over extended periods.

A crucial next step involves conducting comparative studies between audio recorder systems and traditional seismographs under various operational conditions. These studies would validate findings and optimize deployment strategies.

This study serves as a preliminary exploration into the application of audio recorders in seismic monitoring. Further research and intensified efforts are necessary to advance seismic monitoring practices, enhance safety and efficiency in mining operations, and foster greater engagement among mining engineering professionals in addressing these challenges.

LITERATURE

Aki, K., & Richards, P. G. (2002). *Quantitative Seismology (2nd ed.).* University Science Books.

Audacity Team. (2024). Audacity(R): Free Audio Editor and Recorder [Computer program]. Version 3.5.1 Retrieved April 20, 2024 from http://audacity.sourceforge.net/ [1].

Boore, D. M., McEvilly, T. V., & Lindh, A. G. (1975). Quarry blast sources and earthquake prediction: the Parkfield, California, earthquake of June 28, 1966. *Pure and Applied Geophysics 113*, 293-296. (200 Kb)

Fan, Y., Cui, X., Leng, Z., Zhou, Y., Zheng, J., & Wang, F. (2020). Development of a model to predict vibrations induced by blasting excavation of deep rock masses under high in situ stress. *Shock and Vibration*, *2020*(1), 8817631.https://doi.org/10.1155/2020/8817631

Igel, H. (2016). *Comuptational Seismology. A Practical Introduction.* Deoartmnent of Environmental Sicences, Ludwig – Maximilians-Universitat Munichen, Germany. Oxford University Press.

McFee, B., Raffel, C., Liang, D., & others. (2023). "Librosa" (Version 0.10.0) [Computer software]. Retrieved April 20, 2024 from https://librosa.org

Niemeyer, J., & Pausch, M. (2023). Seislib (Version 0.7.0) [Computer software]. Retrieved April 20, 2024 from https://github.com/seislib/seislib

NumPy Developers. (2023). „NumPy" (Version 1.24.2) [Computer software]. Retrieved April 20, 2024 from https://numpy.org

ObsPy. (2024). Python framework for seismology. Retrieved April 13, 2024, from https://docs.obspy.org/

Pandas Development Team. (2023). „Pandas" (Version 2.0.3) [Computer software]. Retrieved April 20, 2024 from https://pandas.pydata.org

Pyrocko Team. (2023). „Pyrocko" (Version 2023.1) [Computer software]. Retrieved April 20, 2024 from https://pyrocko.org

SeisIO. (2024). Framework documentation site. Retrieved April 13, 2024, from https://seisio.readthedocs.io/en/latest/index.html

Seismological Society of America. (n.d.). „Seismic Data Analysis and Processing". Retrieved April 20, 2024 from https://www.seismosoc.org

SciPy Community. (2024). „SciPy" (Version 1.11.2) [Computer software]. Retrieved April 20, 2024 from https://www.scipy.org

Skibicki, J. D., Licow, R., Karosińska-Brzozowska, N., Daliga, K., Chrostowski, P., Wilk, A., ... & Omilianowicz, J. (2023). Analysis of the Usefulness of Cheap Audio Recorders for Spectral Measurement of Environmental Noise. *Metrology*, *3*(4), 381-388. https://doi.org/10.3390/metrology3040024

Stein, S., & Wysession, M. (1990). An *Introduction to Seismology, Earthquakes, and Earth Structure.* Willey - Blackwell.