



PRELIMINARY ASSESSMENT OF ADIS16470AMLZ SENSOR FOR MONITORING OF SEISMIC ACTIVITY IN MINING AREA

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Abstract

Seismic activity monitoring in the mining exploitation area is an important factor, that has an effect on safety and infrastructure management. The introduction sections presents the outline of mining interference into rock mass structure and selected parameters and methods of observation related to its effects. Further in the article an alternative to currently seismic measurement devices was proposed, and an preliminary research of its metrological quality was carried out based on experimental data. Assessment was based on short time Fourier transform (STFT) and Pearson cross-correlation coefficient.

Keywords: mining damage, peak ground acceleration, STFT, Pearson correlation coefficient

1. INTRODUCTION

Mining is an integral element in development of industry and economy. Cost-effectiveness of mineral exploitation depends heavily on the continuity of mining operations. It is affected, among other things, by numerous natural and human-caused hazards, which can lead to downtime in extraction of ores and minerals. Moreover, natural hazards negatively affect safety of miners, and have an impact on the surface of the ground above it.

Mining exploitation is a process of extracting raw minerals. Due to the nature of mining operations the impact on environment is significant. Violation of balance within rock mass is inseparably related to mineral exploitation. This violation of balance propagates its effects to the natural environment in the region of exploitation. Mining activities induce paraseismic phenomena, which can lead to deformation of the terrain surface in the area of exploitation.

With regard to underground mining an important factor that has an impact on environment is the process of creation of post-exploitation voids in rock mass. Under the effect of gravity floor strata of excavation zone can shift. In regard to open-pit mining – the displacements of terrain are related with the displacements of rock masses, related to formation of internal or external heaps.

Terrain surface deformation in mining areas, where underground mining activities are being led,

is undesirable. Due to displacement of the ground related to mining activities ground infrastructure (buildings and structures) [7] as well as infrastructure located underground (underground utility networks, pipelines) can be damaged.

Terrain displacement may cause damage to ground infrastructure, municipal infrastructure, cause groundwater pollution or tap water contamination. Due to dangers and expenses related to mining related terrain deformation the need for continuous monitoring of terrain deformation exists. Such a monitoring is needed the most in the areas where underground or open-pit mining takes place.

Continuous monitoring of rock masses movement may allow to find correlations between operations, that are a part of mining process, and displacement of terrains surface. Therefore it may allow to monitor and predict the extent of environmental interference, damage to buildings, infrastructure, and so on. Established relationships can serve as foundation for implementation of plan for securing infrastructure or environment. Collected data may serve as a basis for determining the level of correlation between mining operations and damage caused, which can serve as evidence in lawsuits regarding issuance of compensation related to mining damage.

Impact of mining operations on terrain surface deformation is currently being monitored using specialized geodetic networks (observation lines, height matrices, levelling networks etc.), GNSS

observations [11] and satellite interferometric synthetic aperture radar (InSAR) [10]. Dynamic impact is monitored using surface seismic networks, consisting of distributed sensors (seismographs or accelerographs). An example of network using a distributed system of sensor devices is the Quake-Catcher Network [3] used in sensing of seismic events.

Ground surface monitoring with a single measurement node, or small amount of measurement nodes can make obtaining useful information from acquired data difficult. The solution is to monitor ground surface using multiple measurement nodes, forming a grid of measurement nodes. Each node is bound to a specific ground surface point. Each device being part of the grid acquires acceleration data, that can be analysed. That is why distributed sensoric systems, such as Distributed Acoustic Sensing (DAS) can be used to take seismic measurements [14].

Commonly used accelerographs are devices that are not optimal in terms of building a grid of sensors. Due to high cost of single device, building a node grid with multiple devices is largely financially burdening. Because of that, common accelerographs used in such manner can probe non profitable.

MEMS accelerometers are an alternative to commonly used accelerographs, because of coherence comparable with professional accelerometers [1]. They allow to measure accelerations in three orthogonal axes, while, at the same time, coming in at lower price. In this regard they are more optimal as a single node in distributed measurement device network.

Peak Ground Acceleration (PGA) is a measure of ground movement acceleration. It is used to describe the intensity of phenomena related to ground displacement during seismic events. PGA describes the largest absolute value of acceleration during a seismic event [4].

During seismic tremors the acceleration is logged in three orthogonal directions: vertical (V), and horizontal (XY).

The acceleration is logged, and its highest value is used to calculate the PGA parameter of a specific event. Calculating PGA can be based upon searching for the highest value of acceleration in any of three given axes directly, or on calculating average value, sum or vector sum of values from two or three axes. Calculating PGA can also be based upon statistical methods [9].

Classic methods of measuring ground acceleration are carried out using accelerometers. Current trends in accelerometer development is aiming towards MEMS based technology in the structure of the device [8]. Piezoelectric accelerometers are not advised for seismological use, due to relatively large attenuation and phase shift in low frequencies [12]. Under those circumstances using MEMS capacitive accelerometers is advantageous.

Simultaneously to methods of measuring acceleration with accelerometers, methods utilizing high-rate GNSS positioning systems are currently under heavy development [6].

Observations of rock mass movement with use of GNSS positioning systems provide the possibility to monitor seismic events of medium to large magnitude [2] through monitoring the positions of measurement nodes. Due to relatively lower accuracy of position tracking in vertical direction (roughly 1cm) than in horizontal directions (roughly 1mm). HR-GNSS is performing better when taking measurements of horizontal ground acceleration [13].

Rock mass displacement measurements made using GNSS and seismographic equipment can complement each other. GNSS can be used to log large-amplitude and low-frequency displacement data. Seismographs can be used simultaneously, to extend measurement bandwidth to higher frequencies. Data from both measurement systems can be merged using Kalman filter [15].

An example of a device used to log ground acceleration data, in the context of calculating PGA parameter, is MS2011+ sensor that interfaces with MR3003C system.

MR3003C is a compact microprocessor acceleration and displacement data logging system. The device allows to log acceleration or velocity using built-in sensors in specific models. It also allows to use a separate sensor compatible with system as the data source. Chosen MR3003C parameters, derived from manufacturers specification have been presented in Table 1.

Table 1. MR3003C parameters

Parameter	Value
Resolution [bit]	24
Rate [sps]	250 to 4000
Channels	3
Dynamic range [dB@sps]	130@250sps 124db@1000sps

MR3003C system can cooperate with MS2011+ sensor device containing triaxial force balance accelerometer (FBA). Chosen MS2011+ parameters have been presented in Table 2.

Table 2. MS2011+ parameters

Parameter	Value
Linearity [%FS]	<0.1
Frequency response	DC to 130Hz (-3dB)
Measuring range [G]	±4
Sensitivity [V/G]	2.5
Cross axis reject. [dB]	>40
Dynamic range [dB]	>135 (1 to 100[Hz])

MR3003C based ground acceleration logging system is relatively expensive, which proves it is not cost-effective in terms of using it as a single node in distributed array of measurement nodes.

Because of it, in presented field of usage, attempts at using different, low-cost sensors, that retain required metrological parameters are being made. The purpose of the work presented further in the article is a preliminary assessment of properties of MEMS sensor alternative to MR3003C system.

2. METHODS

In order to expand the measurement node grid, while taking final system cost into account, using an alternative to MR3003C/MS2011+ was considered. For this task ADIS16470AMLZ was selected as an alternative.

ADIS16470AMLZ is a miniature integrated inertial measurement unit (IMU). Its sensors are based on MEMS technology. The unit contains triaxial gyroscope, and triaxial accelerometer. The device allows to measure acceleration in three orthogonal axes, as well as measuring angular velocity in three orthogonal axes. Each sensor onboard was calibrated during manufacturing process, to accurate measurements. Selected ADIS16470AMLZ parameters derived from manufacturers specification sheet have been presented in Table 3.

To determine the suitability of ADIS16470AMLZ device as an alternative to MR3003C based system a comparison study has been carried out. The study includes comparing both devices in term of accuracy of acceleration measurements, which are the basis for determination of PGA parameter.

Table 3. ADIS16470AMLZ parameters

Parameter	Value
Resolution [bit]	16 (23)
Dynamic range [G]	±40
Nonlinearity [%FS]	10G: 0.02 40G: 1.5
Bandwidth [Hz@-3dB]	600
Sensitivity [LSB/G]	16b format:800 32b: 52, 428, 800

2.1. Experiment

Classic approach to comparison of vibration sensors in metrological terms consists of a series of tests conducted using shake table. Such a traditional approach allows to assess usefulness of sensor with respect to specific application requirements. However, such an approach requires conducting a series of measurements under laboratory conditions. This justifies preliminary assessment of proposed sensor.

A simplified method of testing sensors' accuracy is proposed in this article. The method covers the comparison of both sensors (traditional MR3003C, and proposed ADIS16470) in terms of accuracy within frequency range of 0-10Hz, which is specified by relevant regulations referring to mining hazards monitoring.

2.2. Test bed and course of the experiment

Acquisition of acceleration data from both devices was carried out according to scheme shown in Figure 1.

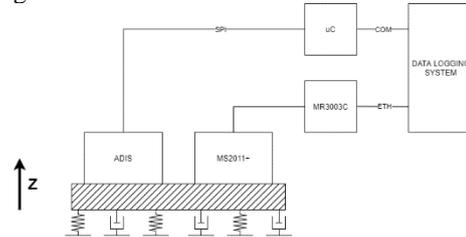


Fig. 1. Test bed diagram

For the practical implementation of the experiment both sensors were fixed to a stiff metal plate base. Set of devices prepared this way was fixed in a car moving along the route with various surface.

Map with the route marked is presented in Fig. 2. Stochastic acceleration signal origins from interaction of vehicle suspension with road surface.



Fig. 2. Route of the car with test bed onboard

3. RESULTS

Acceleration waveform recorded with the use of MR3003C/MS2011+ system and ADIS16470AMLZ sensor, depicted in Fig. 3 and 4, are the result of vibrations coming from the cars suspension, as well as from the working drive train.

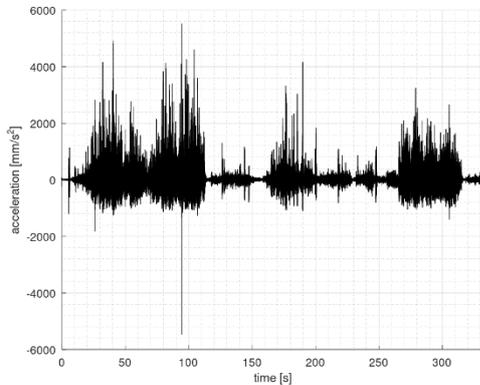


Fig. 3. Acceleration along Z axis of ADIS16470AMLZ device

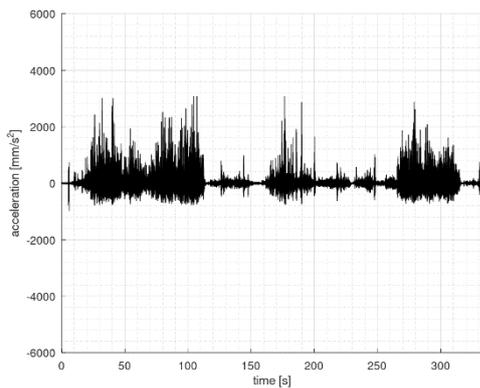


Fig. 4. Acceleration along Z axis of MR3003C/MS2011+ system

As expected, direct comparison of waveforms logged using MS2011+ and ADIS16470AMLZ, determined as the difference between subsequent samples does not provide clear and unambiguous information about the degree of linear dependence between both waveforms. This is caused by the application of filtering algorithms, which limit the frequency bandwidth according to the specific field of MR3003C application, such as earthquake engineering or civil engineering.

The degree of linear dependency of waveforms, registered along the entire route for all the corresponding samples from MR3003C/MS2011+ system and ADIS16470AMLZ device, expressed as Pearson coefficient value equals 0.2978.

To compare the impact of external filtration mechanisms implemented in both sensors a time-frequency analysis of both logged waveforms was carried out. The analysis was performed using short time Fourier transform (STFT) using 500-sample-wide Hanning window and 10-sample step.

Calculated frequency spectra of logged waveforms for subsequent time windows are shown in Fig. 5 for spectrum related to ADIS16470AMLZ and 6 for spectrum related to MR3003C/MS2011+ system.

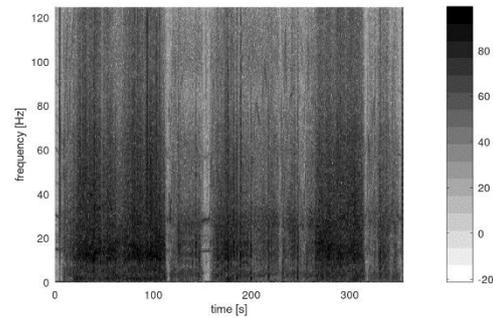


Fig. 5. Spectrogram of Z-axis acceleration waveform obtained from ADIS16470AMLZ

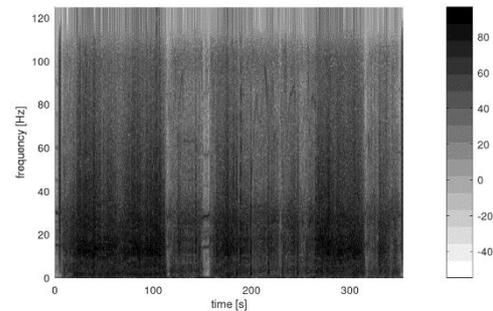


Fig. 6. Spectrogram of Z-axis acceleration waveform obtained from MR3003C/MS2011+ system

Taking into account the discrepant frequency spectra of acceleration waveforms from both sensors a Pearson cross-correlation of spectral magnitude values between corresponding frequencies was calculated for integer frequencies in range between 0Hz and 120Hz

Calculated values of Pearson cross-correlation coefficient in given frequency range are shown in Figure 7.

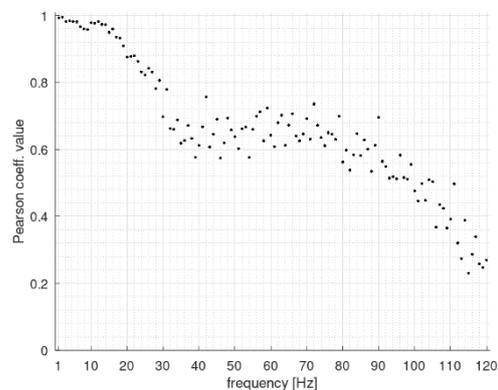


Fig. 7. Pearson cross-correlation coefficient values for frequencies between 0Hz and 120Hz

Comparison of Z-axis acceleration spectra from ADIS16470AMLZ and MR3003C/MS2011+ shows significant differences between them.

Pearson cross-correlation coefficient for distinctive frequency bands are summarized in table 4.

Table 4. Pearson coefficient values for given ranges of frequencies

Frequency band [Hz]	Pearson coeff. MIN	Pearson coeff. MAX
0-15	0.9495	0.9957
15-30	0.6967	0.9594
30-80	0.5625	0.7790
80-120	0.2312	0.6951

In 0Hz to 15Hz frequency band Pearson cross-correlation coefficient value is very high, which indicates strong linear dependency of both acceleration signals within this band.

Further down the chart, a significant decrease in Pearson coefficient value is observed. Coefficient values in 0Hz to 20Hz frequency band are shown in Fig. 9.

Frequencies considered in seismic intensity determines the bandwidth at which vibrations of the ground propagate into building foundations. Frequencies relevant in this regard are within 0 Hz to 10Hz band [5]. Acceleration values that are contained within this band are used as basis for calculating PGA coefficient presented in section 1 of this article.

Due to the measurement bandwidth that is significant for seismic measurements a comparison of Pearson cross-correlation coefficients was carried out.

Line A, in Figure 8, marks the end of 1-10 Hz band, in which the value of Pearson cross-correlation coefficient is between 0.96 and 1.00.

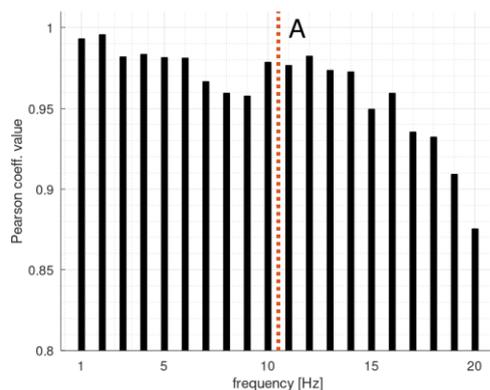


Fig. 8. Pearson cross-correlation coefficient values for frequencies between 0Hz and 20Hz

4. CONCLUSIONS

The results of comparison of MR3003C/MS2011+ system and ADIS16470AMLZ, achieved as a part of conducted

experiment, show strict linear dependency between them in the assumed range of frequencies.

Values of Pearson cross-correlation coefficients calculated for components of the signal between 1 Hz and 15 Hz exceed 0.96. This proves the point of further, more in-depth calibration operations of ADIS sensor to bring it up to specification required for determination of PGA coefficient.

Practically accepted usefulness of MR3003C/MS2011+ system is related to implementation of filtering algorithms narrowing the effective bandwidth of the device by suppressing higher frequencies. This confirms significant decrease in cross-correlation coefficient values related to frequencies above 15 Hz.

In order to eliminate the effect of random external interference on the PGA parameter monitoring using ADIS16470AMLZ sensor the measurement path should include DSP elements that reduce its effective measurement bandwidth.

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