DESCRIPTIVE STATISTICAL CALIBRATION METHOD OF TRIAXIAL DIGITAL ACCELEROMETER ADXL345 AS EARTHQUAKES SENSOR

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ABSTRACT: *Seismic monitoring networks are the crucial elements in strong motion seismology for effective risk reduction. Low scale lateral variation of high intensity ground movement caused by earthquakes will be detected more effectively with densely located networks. However, the limitations of developing such project are rooted in expensive costs associated with the construction and installation in addition to bulky size of the conventional seismic observation system. Recently, micro-electromechanical system (MEMS) has being recognized in the applications of seismological and earthquake engineering due to the high precision obtained in these micron size semiconductor instruments and cheaper alternative for traditional seismic detector. ADXL345 is a type of digital triaxial MEMS accelerometer that is ideal for measurement of low-frequency vibrations and static accelerations of gravity, which makes it suitable for ground motion detection. Thus, this study aims at calibrating ADXL345 sensor that is required as sensing component in an affordable earthquake monitoring system with the Earthquake Benchmarking System (Penanda Aras Gempa Bumi, PAG) available in the inventory of Department of Mineral and Geoscience Malaysia, Sabah. Soil vibrations in EW (east-west or x-axis), NS (north-south or y-axis), and UD (up-down or z-axis) directions during random forces hit on the surface are recorded by both accelerometers. Acceleration magnitudes recorded by PAG and ADXL345 are extracted and data exploration is performed. Predominantly, ADXL345 measurements in horizontal and vertical ground movements are on a higher scale than the reference device. Subsequently, evaluation by using descriptive statistical analysis is chosen to produce numerical equations for data correction operations. İmplementation of the mathematical functions in ADXL345 for observing land movements in EW, NS, and UD directions resulted in decreasing the range values of output readings. Higher approximation of magnitudes of ground motion with the PAG system is achieved.*

KEYWORDS. affordable, ground motion, calibration, descriptive analysis

INTRODUCTION

Propagation of seismic waves is due to the formation of earthquakes that result from the fault movement between tectonic plates (Jena and Pradhan, 2018). Gravitational and inertial forces from the quake generate ground movements causing lateral displacement of large shallow blocks of soils. Consequently, destructive effects are experienced in the faulted areas and increase the risk (Khoiry *et al.*, 2018) of life loss in the aftermath of demolition of buildings as well infrastructures (Khoiry *et al.*, 2018).

In a situation of a ravaging earthquake strikes an area, emergency rescue operations are facing crucial situations to save lives. The possibility of saving victims trapped or injured in a collapsed structure decreases exponentially as a function of time and eventually vanishes after hours (D'alessandro *et al.*, 2018). With massive seismic monitoring networks, low intensity lateral variation of land motion due to tremors will be measured effectively. This increases preparedness time prior to earthquake occurrence in a community and improve the efficiency of emergency management. However, the growth of seismic observation weakens as such projects can cost millions of dollars (Strauss and Allen, 2019) and usually heavy and bulky (Scudero *et al.*, 2018) with complex maintenance procedures. For instance, a complete seismic monitoring system for the West Coast of the United States would cost 16.1 million dollars per year and cost to increase number of stations as well to upgrade the system is 38 million dollars (Strauss and Allen, 2019).

Great advancements in seismological and earthquake engineering have been attained in the last decades following the technical modernization of the instrumentation. The quake monitoring application substantially developed in the 1990s in view of the introduction of MEMS (micro-electromechanical system) technology (Scudero *et al.*, 2018). MEMS device own its recognition as an affordable alternative of conventional earthquake detector, it is a high-precision system (Tanırcan *et al.*, 2017) with sensitivity and dynamic range that allows the measurement of earthquake obtained from a dimension on the order of microns (D'Alessandro *et al.*, 2014). Moreover, frequency response of a MEMS accelerometer can easily be improved by equalization (Sigcha *et al.*, 2018).
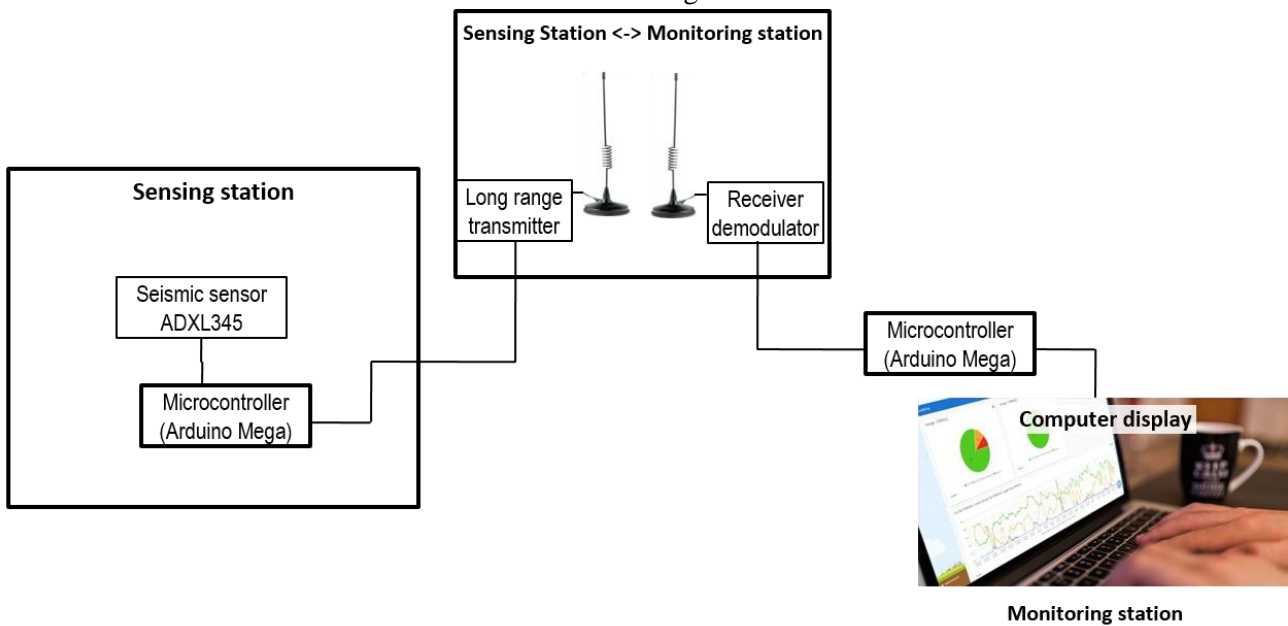
Triaxial Digital Accelerometer ADXL345 (ADXL345) is a type of MEMS accelerometer that is well suited for mobile device application. The measurement range of ADXL345 is ±2g to ±16g. The accelerometer sensor module able to record static acceleration of gravity in tilt-sensing application also dynamic acceleration from motion or shock. High resolution of ADXL345 scale range capable of detecting changes of inclination less than 1.0° (Description and Diagram, 2009). Physical properties of ADXL345 make it as ideal transducer module in the construction of seismic monitoring network. Hence, this research aims at calibrating ADXL345 accelerometer sensor that is required as sensing component in an affordable earthquake monitoring system with the Earthquake Benchmarking System (Penanda Aras Gempa Bumi, PAG) available in the inventory of Department of Mineral and Geoscience Malaysia, Sabah.

MATERIALS AND METHODS

In the process of calibrating ADXL345 with PAG as reference instrument, there are two major steps that are included which is the measurements of gravity acceleration in the field and the descriptive statistical calibration that is performed on the data obtained. ADXL345 device (in Figure 1) used for seismic data acquisition was built by integrating the accelerometer sensor module with processing unit which is the Arduino Mega 2560 microcontroller.
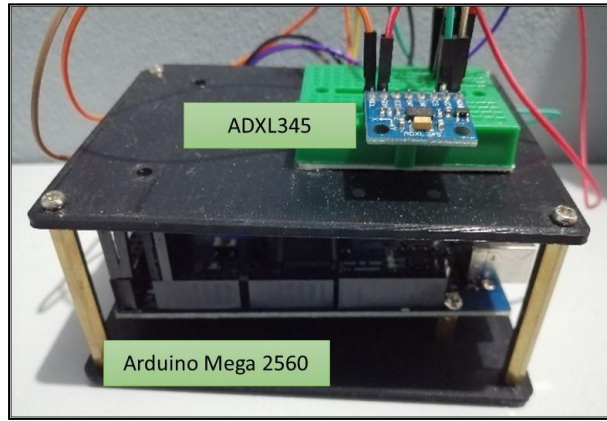
a. Photo of the sensing instruments

b. Complete block diagram of the earthquake measurement system using ADXL345

Figure 1: ADXL345 earthquake sensor consists of ADXL345 triaxial digital accelerometer, and Arduino Mega 2560 microcontroller as the processing unit

Field tests are conducted by creating a simulation of an earthquake condition in an outdoor area. ADXL345 device and PAG is placed 1.0 m from each other as shown in Figure 2. Hit forces randomly given to the ground surface using a hammer at a distance of 3.0 m from both systems to mimic the propagation of seismic waves. Ground acceleration in the direction of EW (east-west or also known as x-axis), NS (north-south or y-axis), and UD (up-down or z-axis) is recorded simultaneously by ADXL345 and PAG. Then, acceleration magnitudes are extracted to perform data exploration. Next, linear regression analysis is performed using SPSS (Statistical Package for the Social Sciences) to obtain the correlation coefficient (R) of recorded data by both devices. By using descriptive statistical calibration method, numeral equations are formed for data correction operation.

Figure 2: Placement of PAG and ADXL345 is in distance 1.0m and force is given from 3.0m away of both devices.

RESULTS AND DISCUSSION

Measurements of ground acceleration obtained from PAG and ADXL345 system in the directions of EW, NS, and UD due to impact force on surface of the ground plotted in line graphs as presented in Figure 3. It can be seen there is huge difference between the two recorded data. Linear regression analysis of raw data of ADXL345 and the reference instrument (in Figure 4) in the direction of EW, NS, and UD resulted in R values of 0.364, 0.562, and 0.306, respectively. The correlation coefficient indicates a low positive correlation (Mukaka, 2012) between the MEMS accelerometer sensor and the reference instrument.
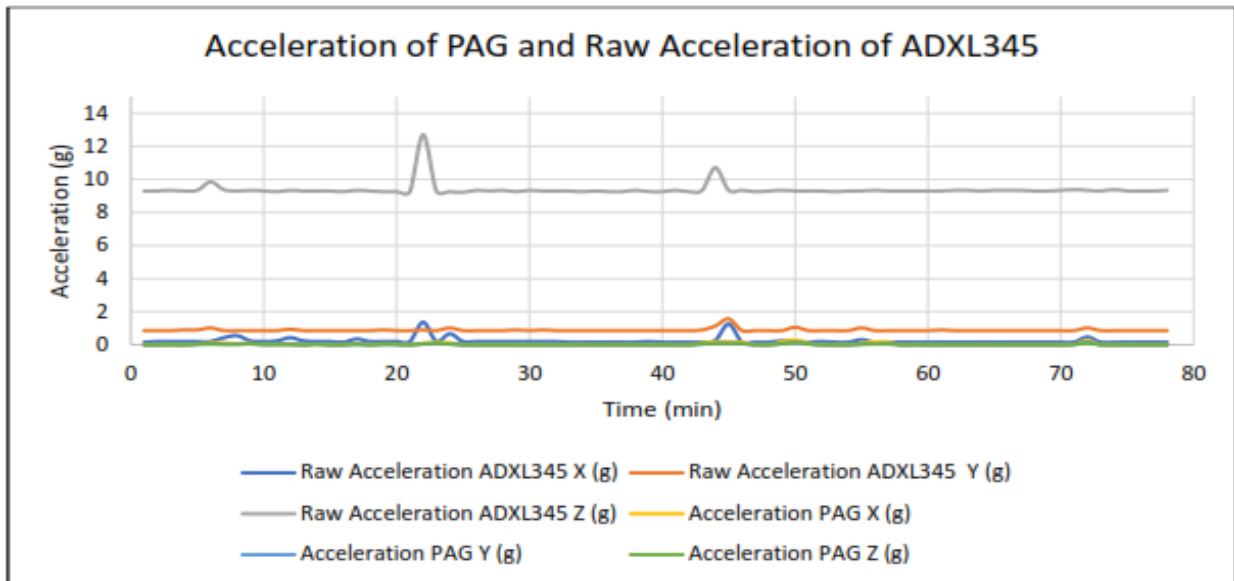

Figure 3: Line graph plots of the ground acceleration obtained using ADXL345 and PAG in directions of EW (x), NS (y), and UD (z)
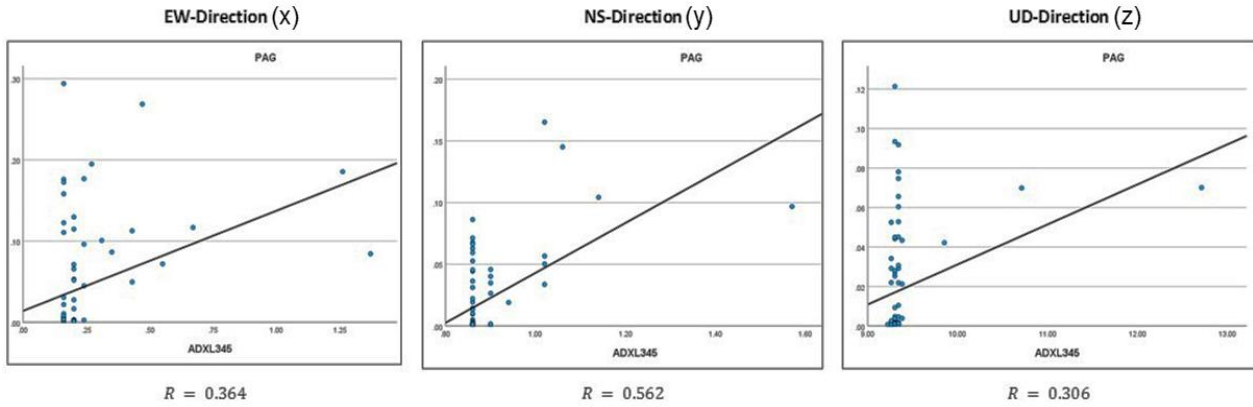
Figure 4: Linear regression of raw acceleration readings from ADXL345 and PAG for each orientation of motion.

Detail examination shows that ADXL345 recorded higher value of soil motion in horizontal (EW and NS) and vertical (UD) axis compared to readings from PAG (Figure 3). The overall recorded data are in the range of 0.00 g to 0.29 g for PAG and 0.16 g to 12.67 g for ADXL345. Therefore, a correction to the observed data should be carried out and is described in the following.

The descriptive statistical calibration method is performed by observing the mean of acceleration on sensitive axis of ADXL345 within the scale range measured in the relative axis by PAG. Sensitive axis of ADXL345 by mean is the axis that succeeded to respond and measured corresponding either increase or decrease pattern on motion of relative axis recorded by PAG. Calculation of correction factor is performed for the average data from sensitive axis on ADXL345 with readings on the similar axis of PAG. Correction factor for the other axis is calculated from the average calibrated data of sensitive axis of ADXL345 with mean of relative data on the remaining axis of PAG. Subsequently, numeral equations are formed by including the correction factors for correcting the data of the MEMS device. Mathematical functions for producing data in ranges of 0.00 g to 0.29 g on ADXL345 are listed in Table 1. In those equations, x, y, and z, is the average raw data and X, Y, and Z is the mean calibrated data of axis EW, NS, and UD respectively.

Table 1: Numeral Equations Formed to Calibrate Data Obtained From ADXL345.

Range	Sensitive Axis on ADXL345	Equation
0.00g – 0.09g	UD or Z-Axis	$Z = z \div 233.4$
		$X = Z \times 2.72$
		$Y = Z \times 1.34$
0.10g – 0.19g	NS or Y-Axis	$Y = y \div 7.31$
		$X = Y \times 2.03$
		$Z = Y \div 1.20$
0.20g – 0.29g	EW or X-Axis	$X = x \div 1.75$
		$Y = X \div 1.63$
		$Z = X \div 2.93$

Implementation of the numeral functions in ADXL345 described in Table 1 has lowered its measurement range values close to that of PAG. The linear regression analysis made for the calibrated data ADXL345 with PAG in Figure 5 shows that the R values are 0.732, 0.805, and 0.728 for direction of motion

EW, NS, and UD, respectively. These values are much higher compared to the correlation in the original data shown in Figure 4. This indicates that the data of ADXL345 now has a high positive correlation (Mukaka, 2012) and better represents the observed data from ADXL345 in comparison with the reference measurement using PAG. This is shown in Figure 6 where there is huge improvement between the data acquired using numerically calibrated ADXL345 and from PAG, in comparison before the calibration shown in Figure 3.
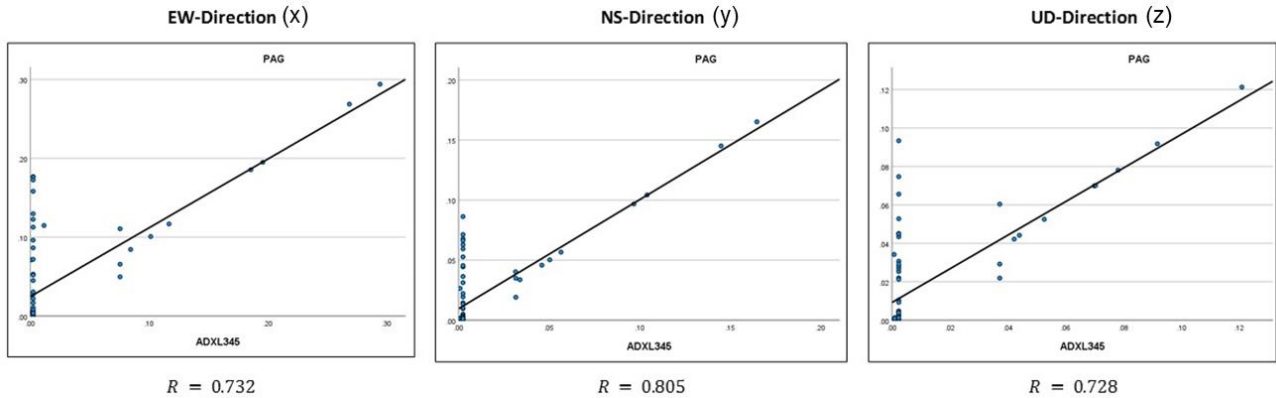

Figure 5: Linear regression analysis of calibrated data ADXL345 and PAG for each direction of motion EW, NS, and UD
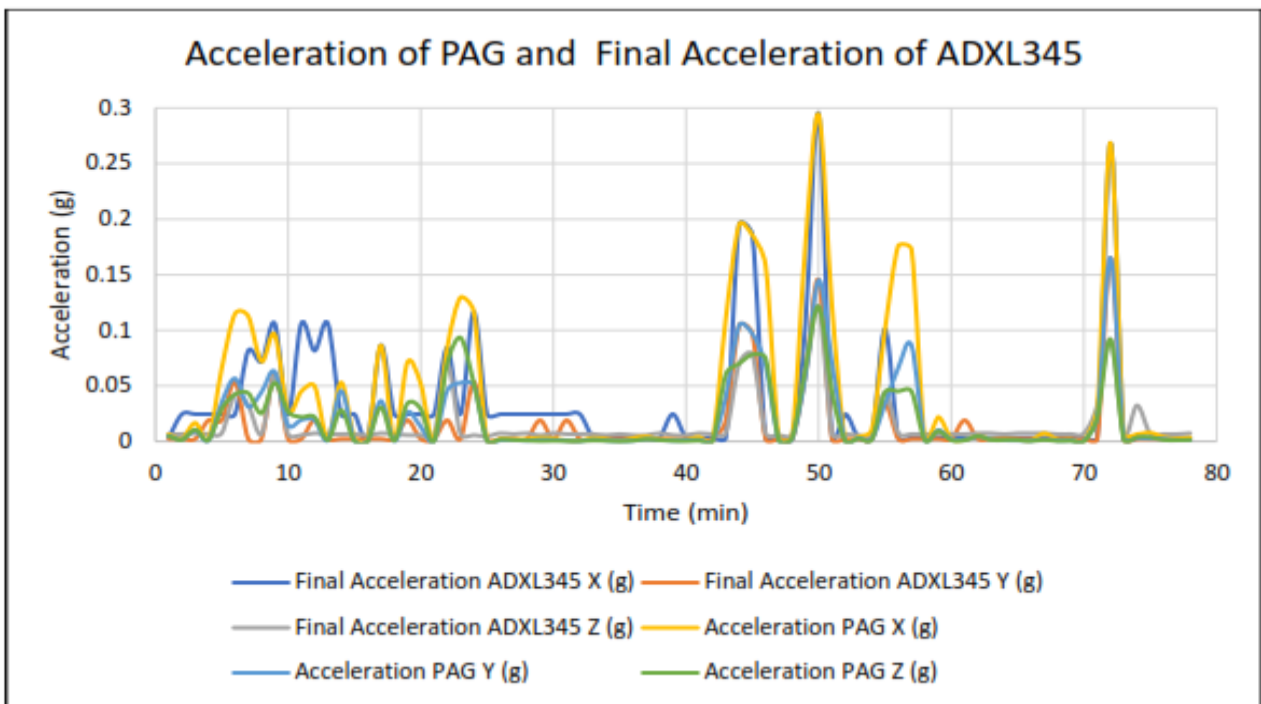

Figure 6: Graphical comparison of the readings from ADXL345 and PAG with simulated ground acceleration (refer Figure 2 for simulating ground acceleration using a hammer).

CONCLUSION

Calibration of ADXL345 earthquake sensor with the reference instrument PAG was conducted using descriptive statistical calibration method. Mathematical equalizations are produced by calculating multiplication factors on average range data on sensitive axis of ADXL345 relative to the mean of average of respond data on PAG. Corrected data after the implementation of numeral equations for each range and axis

has decreased the range scale of measured data on ADXL345 and consequently increased the correlation coefficient between the accelerometer sensor and PAG. This has highly improved the accuracy of displayed data from ADXL345 and is ready to be integrated in a construction of actual seismic monitoring networks.

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REFERENCES

D'alessandro, A., D'anna, R., Greco, L., Passafiume, G., Scudero, S., Speciale, S., & Vitale, G. (2018). Monitoring Earthquake through MEMS Sensors (MEMS project) in the town of Acireale (Italy). *5th IEEE International Symposium on Inertial Sensors and Systems, INERTIAL 2018 - Proceedings*, 1–4. https://doi.org/10.1109/ISISS.2018.8358143.

D'Alessandro, A., Luzio, D. & D'Anna, G. (2014). Urban MEMS based seismic network for post-earthquakes rapid disaster assessment. *Advances in Geosciences*, **40**, 1–9. https://doi.org/10.5194/adgeo-40-1-2014.

Analog Devices. (2009). *Digital Accelerometer: Data Sheet ADXL345*. https://www.analog.com/media/en/technical-documentation/data-sheets/ADXL345-EP.pdf.

Jena, R., & Pradhan, B. (2018). A novel model for comparing Peak Ground Acceleration derived from three attenuation laws using an integrated GIS technique in Sabah area, Malaysia. *International Journal of Scientific and Research Publications*, **8**(9), 191–200. https://doi.org/10.29322/IJSRP.8.9.2018.p8127.

Khoiry, M. A., Hamzah, N., Osman, S. A., Mutalib, A. A. & Hamid, R. (2018). Physical Damages Effect on Residential Houses Caused by the Earthquake at Ranau, Sabah Malaysia. *International Journal of Engineering and Technology*, **10**(5), 414 - 418. https://doi.org/10.7763/IJET.2018.V10.1094.

Mukaka, M. M. (2012). Statistics Corner : A guide to appropriate use of Correlation coefficient in medical research. *Malawi Medical Journal*, **24**(3), 69–71.

Scudero, S., D'Alessandro, A., Greco, L. & Vitale, G. (2018). MEMS technology in seismology: A short review. *2018 IEEE International Conference on Environmental Engineering, EE 2018 - Proceedings*, 1–5. https://doi.org/10.1109/EE1.2018.8385252.

Sigcha, L., Pavón, I., Arezes, P., Costa, N., De Arcas, G. & López, J. M. (2018). Occupational risk prevention through smartwatches: Precision and uncertainty effects of the built-in accelerometer. *Sensors (Switzerland)*, **18**(11): 1–20. https://doi.org/10.3390/s18113805.

Strauss, J. A. & Allen, R. M. (2019). Benefits and Costs of Earthquake Early Warning. *Seismological Research Letters*, **87**(3): 765–772. https://doi.org/10.1785/0220150149.

Tanırcan, G., Alçık, H. & Beyen, K. (2017). Reliability of MEMS accelerometers for instrumental intensity mapping of earthquakes. *Annals of Geophysics*, **60**(6): SE673. https://doi.org/10.4401/ag-7501.