Geosci. Instrum. Method. Data Syst. Discuss.,
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Geoscientific Instrumentation Methods and Data Systems Discussions

Interactive comment on "A geophone-based and low-cost data acquisition and analysis system designed to microtremor measurements" *by* Ozkan Kafadar

Ozkan Kafadar

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Received and published: 8 July 2020

I would like to thank the Editor and the anonymous reviewers for their constructive comments which helped me improve the quality of my work. To address these comments, I have carefully revised the paper. In the following, I provide a point-by-point response to the comments and detail the actions that I have taken to address those issues. For ease of cross referencing, the performed changes are highlighted in red color.

Comment 1: There is a word error in line 4 and line 169.

Reply 1: Thank you very much for your suggestion. The typing errors were

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corrected as follows:

Page 1, line 4: It is also an integrated system developed to interpret the microtremor data using the horizontal-to-vertical spectral ratio (H/V) method without any external software.

Page 11, line 179: The channel consistency, internal noise measurement and comparison tests were performed to demonstrate the accuracy and precision performances of the proposed system.

Comment 2: Lines 12 and 13 should be expressed more meaningfully.

Reply 2: Thank you very much for your suggestion. The sentence was revised as follows:

Page 1, line 12: The channel consistency and internal noise measurement tests were performed to demonstrate the accuracy and precision of the proposed system.

Comment 3: Figures 3a, 3b, 5a, 5b,6 and 8b are not framed.

Reply 3: Thank you very much for your suggestion. All figures were framed.

Comment 4: The author should emphasize the importance of this manuscript, its contribution to science in the summary and introduction sections.

Reply 4: Thank you very much for your suggestion. The abstract and introduction sections were rewritten according to your suggestions. The sentences emphasizing the contribution of the study to science were highlighted red color.

Page 1, line 1-16:

Abstract

The commercial data acquisition instruments designed for three-component microtremor measurements are usually very expensive devices. In this paper, a low-cost, computer-aided and geophone-based system designed to record, monitor and analyze

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the three-component microtremor data, is presented. This proposed system is not a simple data acquisition system. It is also an integrated system developed to interpret the microtremor data using the horizontal-to-vertical spectral ratio (H/V) method without any external software. Therefore, the H/V peak frequency and amplitude can be easily estimated by using this system. The proposed system has several features such as 200 Hz sampling frequency, approximately 72 dB dynamic range, text data format and data analysis tools. This system consists of a graphical user interface developed by using .NET Framework 4.5.2 and an external hardware that includes signal conditioning circuits, voltage converter circuit, external analog-to-digital converter and Arduino Uno board. The proposed system uses the low-cost vertical and horizontal geophones with 4.5 Hz natural frequency to measure three-component microtremor data. The developed software undertakes many tasks such as communication between the external hardware and computer, transferring, monitoring and recording the seismic data to the computer, and interpretation of the recorded data using the Nakamura method. The channel consistency and internal noise measurement tests were performed to demonstrate the accuracy and precision of the proposed system. Besides, the proposed system was compared to a commercial triaxial digital seismograph, and satisfactory results were obtained. The developed system is completely an open-source and open-hardware system, and can be easily used in academic studies conducted by researchers and university students who are interested in seismic ambient noise analysis.

Page 1-2, line 19-44:

Introduction.

The fundamental of the seismic methods is based on the recording of the seismic waves generated by the natural or synthetic sources. There are two type sensors, called velocimeter and accelerometer, with different bandwidths and sensing mechanisms to measure these seismic oscillations. These sensors measure the ground motion as velocity and acceleration, and convert the ground motion into a measurable

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electrical signal. Accelerometers are electromechanical devices, which measure the acceleration, and are generally used for specific purposes such as vibration and inclination measurements. On the other hand, geophones are velocimeter, which are often preferred in local seismic applications because of their excellent reliabilities, highly sensitivities and low costs. Besides, accelerometers are generally less sensitive than velocimeters and are also used in strong ground motion measurements. Broadband velocimeters have a large passband than geophones, and can measure ground motions with frequencies ranging from 0.001 Hz to 500 Hz. Classical short-period velocimeters are constituted by orthogonally mounted three geophones that have natural frequencies of a few hertz. Data acquisition systems are needed to digitize the analog signals detected by these sensors and to store them in a data storage device. Recently, many studies have been performed to design seismic data acquisition systems. In a study by Khan et al. (2012), a software component was developed to digitize the analog seismic signals using the computer sound card. Llorens et al. (2016) designed a simple data acquisition system for recording the seismic data detected by the vertical geophone to an external SD card. In our previous study, we developed a hardware and software for seismic refraction method (Kafadar and Sertcelik, 2016). In another study, a hardware was designed for recording the seismic noise (Llorens et al., 2018).

In this paper, a low-cost, computer-aided and Arduino-based three-component microtremor measurement and analysis system (MicDAC) is presented. In the literature, there are many data acquisition and analysis systems developed with using the Arduino boards for scientific purposes (Llorens et al., 2016; Fisher and Gould, 2012; Huang et al., 2018; Puente et al., 2017). The MicDAC is controlled through a user-friendly graphical interface (MicDAC-GUI) developed by using the Microsoft .NET Framework 4.5.2 platform and C language. The MicDAC is not a simple digitizer. Moreover, it is an analysis tool that it can interpret the recorded ambient noise using the Nakamura method (Nakamura, 1989) and it can calculate the two parameters (H/V peak frequency and amplitude), which are too important to design earthquake-resistant structures. This study is completely different from the literature since the proposed system does not

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require any external software. On the other hand, it can display the calculated Fourier spectra for three-component ambient noise in real-time. This feature provides a pre-information about the frequencies of ambient noise in the survey area before starting the measurement to the user.

Comment 5: The conclusions section should be expanded considering all results of this manuscript.

Reply 5: Many thanks for your valuable suggestion. The conclusions section was rewritten to include the results of this study.

Page 10, line 173: The aim of this study is to develop a low-cost, computer-aided and Arduino-based three-component microtremor data acquisition and analysis system using the basic electronic components, integrated circuits and Microsoft .NET Framework 4.5.2 application development platform. The designed external hardware can be easily assembled by readers and controlled through a developed graphical user interface using C# language. This software allows monitoring and recording the three-component microtremor data, and analyzing the recorded data using the horizontal-to-vertical spectral ratio (H/V) technique. In this way, the peak frequency and amplitude of H/V curve can be estimated. The channel consistency, internal noise measurement and comparison tests were performed to demonstrate the accuracy and precision performances of the proposed system. In the channel consistency test, it was shown that the error percentage of the difference signals were lower than 1%. Besides, it was shown that the H/V is equal to 1 when a single sensor is connected to each channel input at the same time. In the internal noise measurement test, the noise levels for three channels were observed as approximately ± 3 counts. In particular, the H/V curves obtained from data recorded simultaneously with MicDAC and GeoBox and their peak frequencies and amplitudes proved the reliability of the proposed system. Finally, an experimental study was performed to test the performance of MicDAC in field conditions. The obtained H/V peak frequency and amplitude from the experimental study were compared to a previous study, and it was shown a good correlation between them.

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Therefore, it can be concluded that MicDAC is a suitable and inexpensive alternative system for three component microtremor measurements and H/V analysis.

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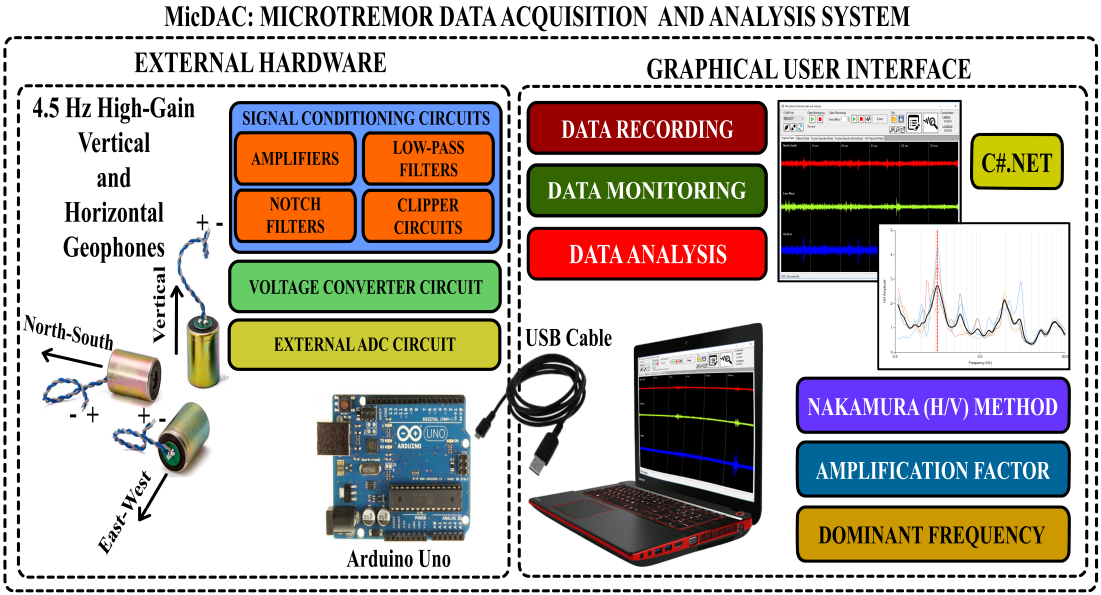

Fig. 1. Graphical abstract of the proposed system for measurement and analysis of three-component microtremor data.

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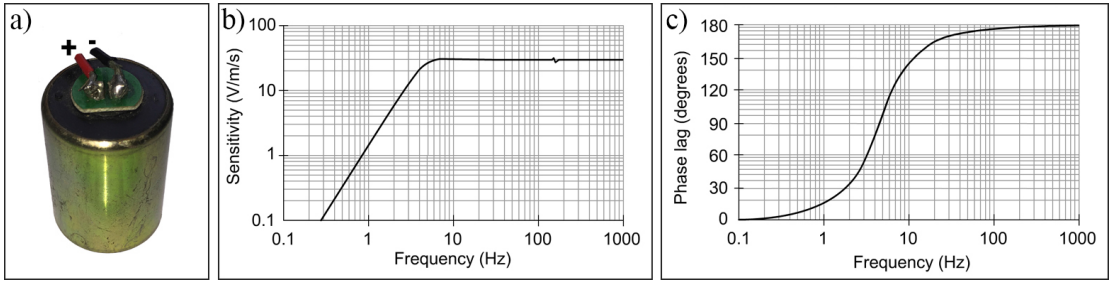

Fig. 2. For the geophones with 4.5 Hz natural frequency a) External view b) Amplitude response c) Phase response.

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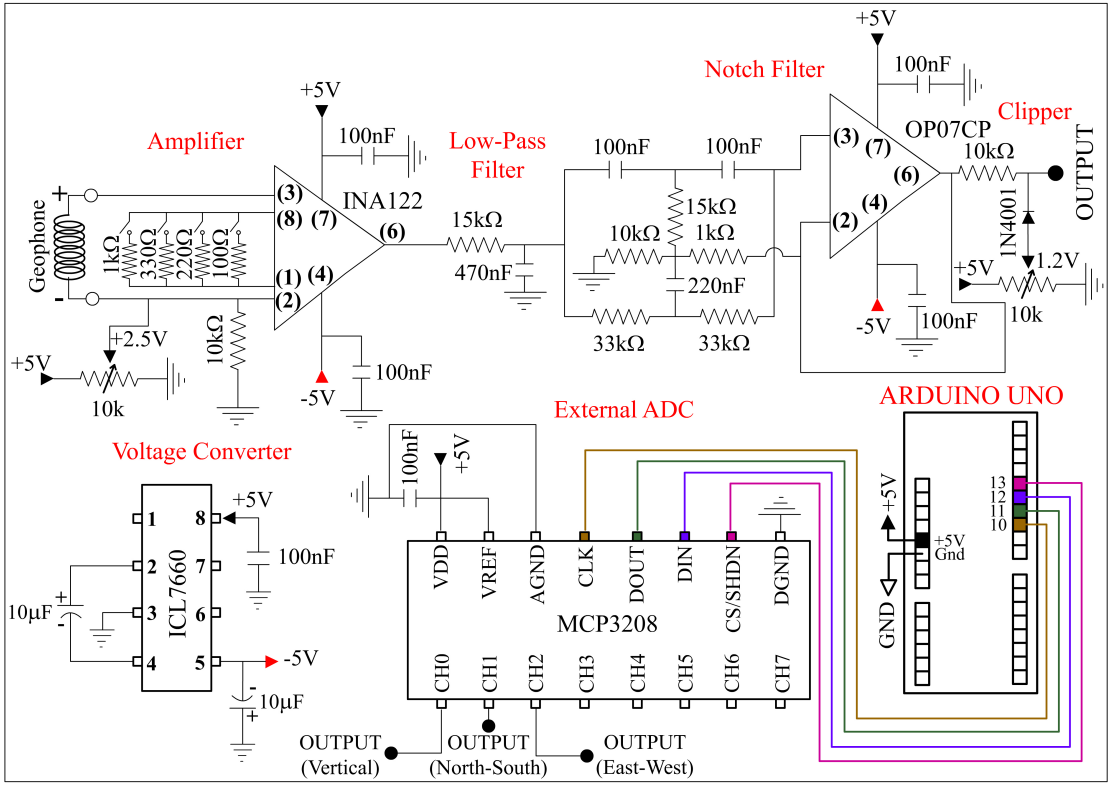

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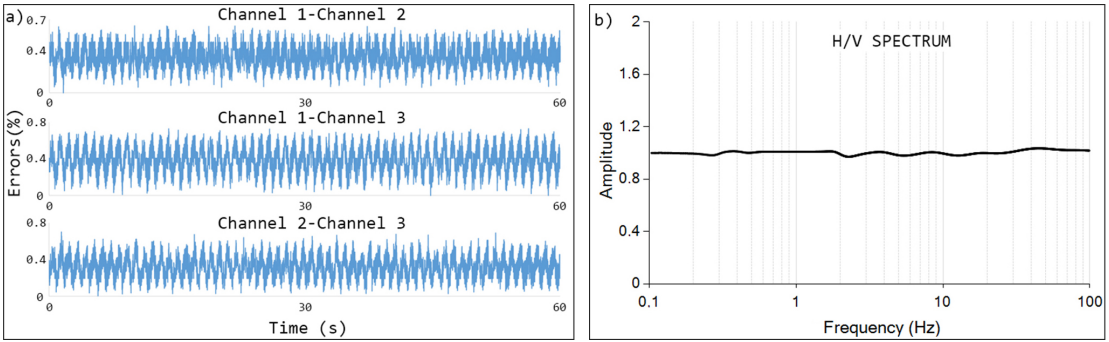

Fig. 4. a) Error percentage of difference signal estimated during the first channel consistency test b) H/V spectral ratio.

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Fig. 5. Screenshot of MicDAC-GUI and detected signals using a 4.5 Hz vertical geophone connected to each channel inputs.

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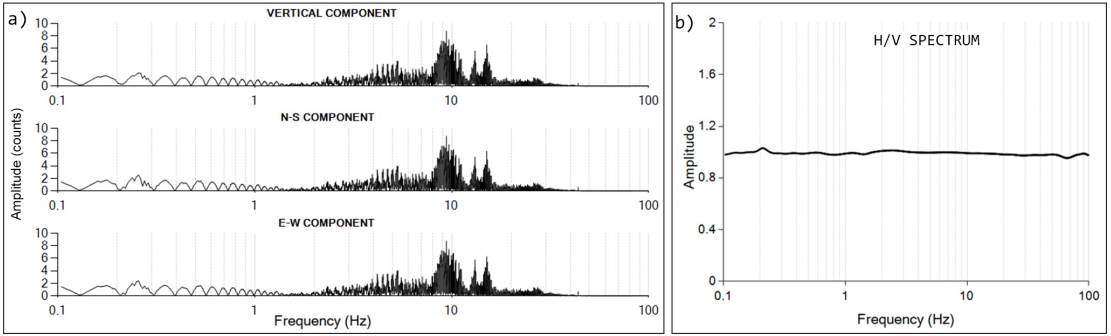

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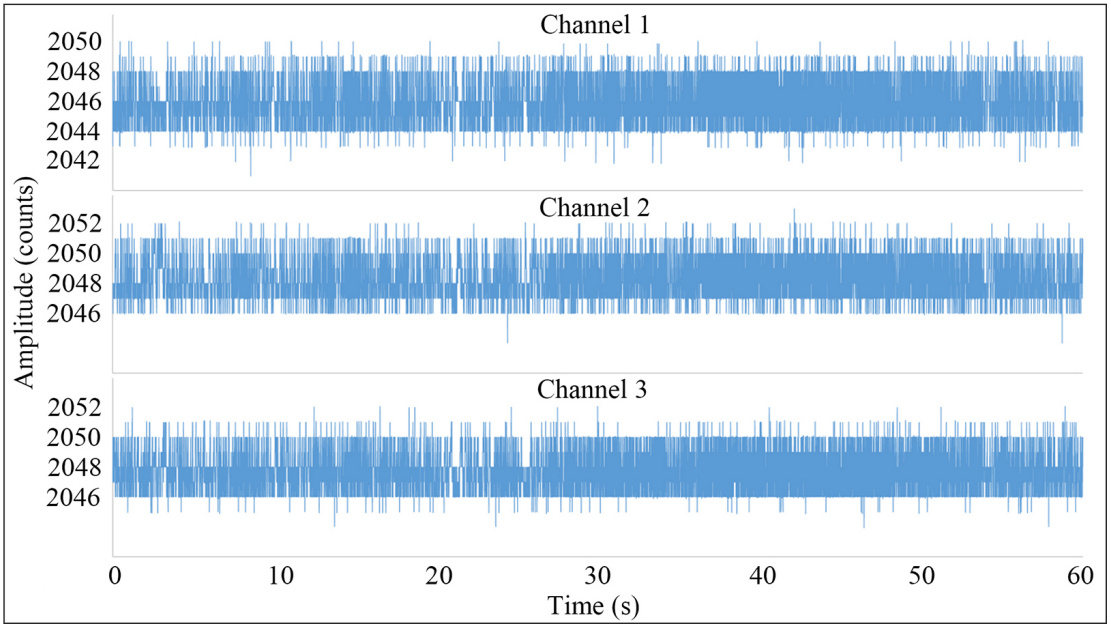

Fig. 7. Internal noise measurements for each channel.

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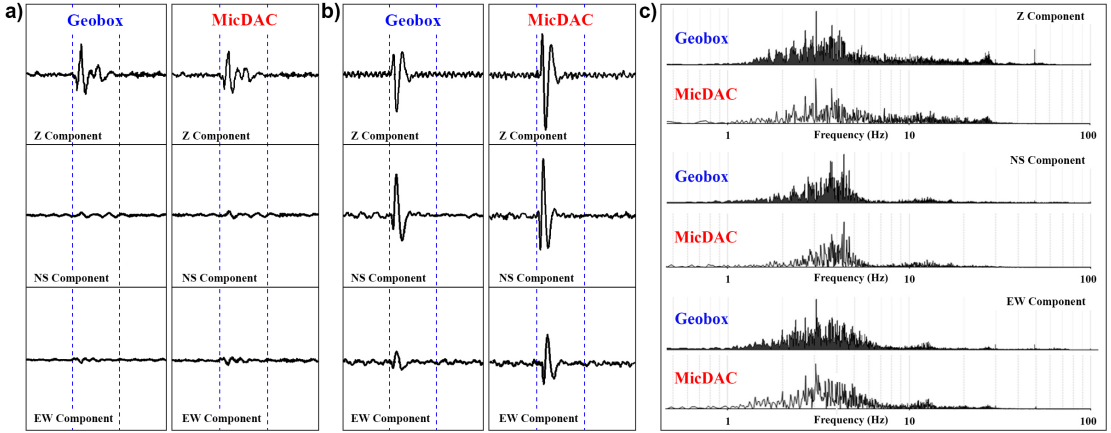

Fig. 8. Three-component seismic data recorded simultaneously using both devices a) MicDAC with 46 dB gain b) MicDAC with 60 dB gain c) Comparison of Fourier spectra of recorded three-component microtremor ...

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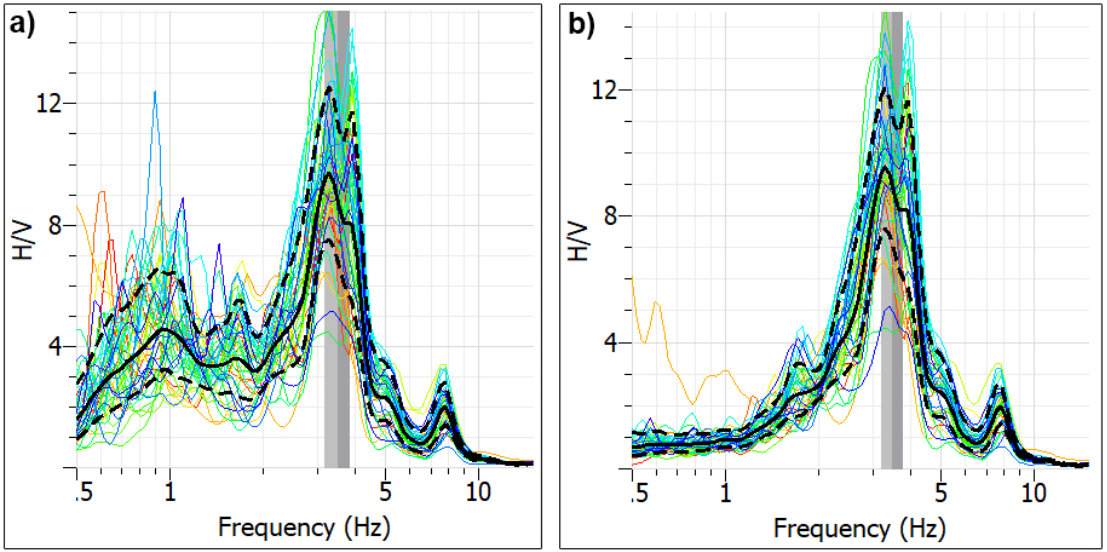

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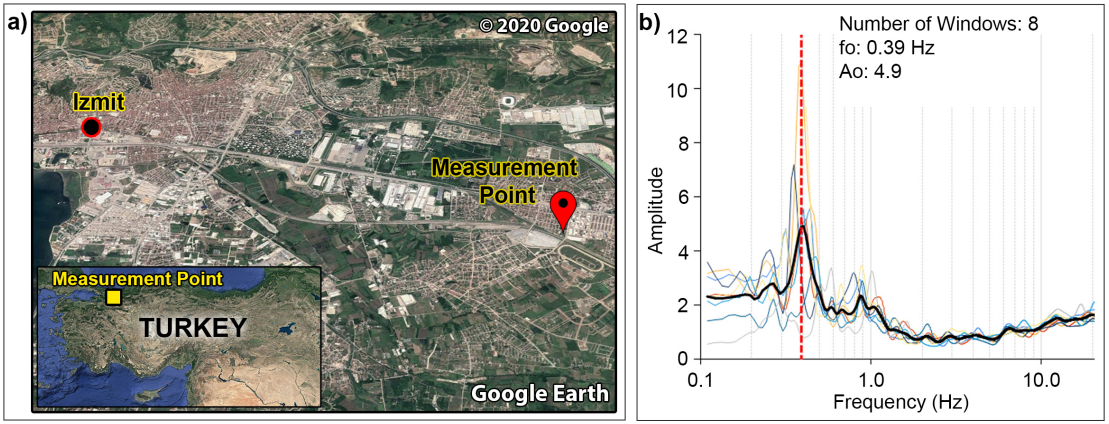

Fig. 10. a) Location of test measurement point on Google Earth© view b) H/V spectral ratio.

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Comment 1: Page 1, line 18: seismometers, geophones and accelerometers do not differ only for their natural frequencies and bandwidth but also for the physical observable that they are able to measure (ground motion velocity for seismometers and

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geophones; ground motion acceleration for accelerometers); furthermore, accelerometers are less sensitive than geophones and seismometers but, on the other hand, they are preferred for strong ground motion measurements. Therefore, I suggest to better describe here the different kind of seismic sensors.

Reply 1: Many thanks for your valuable suggestion. The first paragraph of the introduction section was rewritten to include a brief information about the two type seismic sensors such as velocimeters and accelerometers.

Page 1, line 19: The fundamental of the seismic methods is based on the recording of the seismic waves generated by the natural or synthetic sources. There are two type sensors, called velocimeter and accelerometer, with different bandwidths and sensing mechanisms to measure these seismic oscillations. These sensors measure the ground motion as velocity and acceleration, and convert the ground motion into a measurable electrical signal. Accelerometers are electromechanical devices, which measure the acceleration, and are generally used for specific purposes such as vibration and inclination measurements. On the other hand, geophones are velocimeter, which are often preferred in local seismic applications because of their excellent reliabilities, highly sensitivities and low costs. Besides, accelerometers are generally less sensitive than velocimeters and are also used in strong ground motion measurements. Broadband velocimeters have a large passband than geophones, and can measure ground motions with frequencies ranging from 0.001 Hz to 500 Hz. Classical short-period velocimeters are constituted by orthogonally mounted three geophones that have natural frequencies of a few hertz. Data acquisition systems are needed to digitize the analog signals detected by these sensors and to store them in a data storage device. Recently, many studies have been performed to design seismic data acquisition systems. In a study by Khan et al. (2012), a software component was developed to digitize the analog seismic signals using the computer sound card. Llorens et al. (2016) designed a simple data acquisition system for recording the seismic data detected by the vertical geophone to an external SD card. In our previous study, we developed a hardware and

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software for seismic refraction method (Kafadar and Sertcelik, 2016). In another study, a hardware was designed for recording the seismic noise (Llorens et al., 2018).

Comment 2: Page 3, line 70: you should better justify why the usable band of the sensor is 0.2- 240 Hz; probably, a figure showing the amplitude and phase response of the sensor would be a good addition.

Reply 2: Thank you very much for your suggestion. This sentence was rewritten to avoid confusion by contacting the manufacturer, and Figure 2 was added including the 4.5 Hz sensor's external view, amplitude and phase responses.

Page 3, line 76: The vertical and horizontal geophones manufactured by EGL Company were used to measure three-component microtremor data. They have some characteristic features such as natural frequency of 4.5±10% Hz, typical spurious frequency greater than 150 Hz, damping of 0.6±5% and open circuit sensitivity of 28.8±5% V/m/s. The external view, amplitude response and phase response of these geophones are shown in Fig. 2.

Comment 3: Page 3, line 73: please provide some numbers when you say "low-cost hardware software device"; e.g., less than one hundred euros or hundreds of euros or less than one thousand euros, etc. It is important for the reader to understand if your device is effectively a low-cost device.

Reply 3: Thank you very much for your suggestion. The total cost of the proposed system was explained briefly. Besides, the used electronic components and their estimated costs were given in Table 1 in detailed.

Page 3, line 82: Estimated costs of electronic components of the designed external hardware in this study are presented in Table 1. The total cost of the hardware, including the sensors, is approximately 255€

Comment 4: Page 7, lines 142-145: I think that you should compare the amplitudes directly in physical units by applying the appropriate transduction constant for each

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Table 1. List of the electronic components.

Components	Source	Total	Cost (€)
4.5 Hz vertical geophone	Sentez System	x1	65.0
4.5 Hz horizontal geophone	Sentez System	x2	70.0
Arduino UNO + USB cable	Int-el Electronic	x1	21.0
ICL7660 DC-DC converter	Int-el Electronic	x1	1.0
INA122 instrumentation amplifier	Int-el Electronic	x3	5.5
OP07CP operational amplifier	Int-el Electronic	x3	0.3
MCP3208 12-bit ADC	Int-el Electronic	x1	3.0
Resistor, capacitor, diode, potentiometer, DIP switch, connector	Int-el Electronic		4.0
Breadboard	Int-el Electronic	x3	1.1

Table 2. H/V peak frequencies and amplitudes calculated from the data recorded simultaneously by GeoBox and MicDAC.

	GeoBox	MicDAC
H/V peak frequency (Hz)	3.5034	3.4919
H/V peak amplitude	8.8663	8.9264

device. In this way, you demonstrate that the signals are perfectly comparable also in terms of their amplitudes. Alternatively, another solution would be a comparison of their H/V functions; indeed, both the horizontal and vertical components should differ only for a constant value among the different devices.

Reply 4: Thank you very much for your suggestion. The H/V spectrum ratios of simultaneously recorded data by GeoBox and MicDAC were presented in the manuscript to demonstrate the correlation of horizontal-to-vertical component ratio (Fig. 9). Besides, the obtained H/V peak frequencies and amplitudes for each device were compared in Table 2.

Page 8, line 145: Finally, the MicDAC was compared with a triaxial digital seismograph

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called as GeoBox manufactured by SARA Electronic Instruments. The GeoBox is an instrument designed especially for recording ambient seismic noise, and its different versions with sensors of 0.5, 1, 2 and 4.5 Hz are available in the market. In this study, the SR04HS model with 4.5 Hz sensors of GeoBox was used to make a comparison with MicDAC. The signals recorded simultaneously by MicDAC and GeoBox are shown in Fig. 8a and Fig. 8b. Log-MT software was used to monitor and to record the signals with GeoBox. Two different gain levels, 46 dB and 60 dB, were used in the signals recorded using MicDAC. As a result of this comparison in the time domain, a good correlation between the recorded signals using GeoBox and MicDAC was observed. This similarity was also observed in their frequency spectra (Fig. 8c). In addition to the comparisons in the time and frequency domains, their H/V spectral ratios were also obtained using the Geopsy software (Fig. 9a and 9b). The obtained H/V peak frequencies and amplitudes were given in Table 2. A good correlation was observed between the calculated H/V peak frequencies and amplitudes.

Comment 5: Page 2, line 36: substitute "that the proposed" with "since the proposed".

Reply 5: Thank you very much for your suggestion.

Page 2, line 42: This study is completely different from the literature since the proposed system does not require any external software.

Comment 6: Page 2, line 49: substitute "developed for analysis of" with "developed for the analysis of".

Reply 6: Thank you very much for your suggestion.

Page 2, line 55: The horizontal-to-vertical spectral ratio (H/V) technique proposed by Nakamura (1989) is one of the most popular methods developed for the analysis of the microtremor data.

Comment 7: Page 2, line 54: substitute "each selected time windows" with "each selected time window".

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Reply 7: Thank you very much for your suggestion.

Page 3, line 60: Then the tapering and Fast Fourier Transform operations are applied to each selected time window.

Comment 8: Caption of Figure 1: substitute "abstract of proposed system" with "abstract of the proposed system".

Reply 8: Thank you very much for your suggestion. The caption of the Figure 1 was revised as follows:

Figure 1. Graphical abstract of the proposed system for measurement and analysis of three-component microtremor data.

Comment 9: Page 5, line 97: please remove "(Fig. 4)" because you mention here Fig. 4 before Fig.3 and because Fig. 4 is principally useful to show the waveforms recorded by using a real sensor.

Reply 9: Thank you very much for your suggestion. The Fig. 4 reference was removed in the sentence.

Page 6, line 105: The second program (MicDAC-GUI), developed by using .NET Framework 4.5.2 in C language, is a user-friendly and Windows operating system-based software.

Comment 10: Page 5, line 110: substitute "The duration of the analyze process" with "The time duration of the analysis process".

Reply 10: Thank you very much for your suggestion.

Page 6, line 119: The time duration of the analysis process increases or decreases depending on the number of enabled time windows and data length.

Comment 11: Caption of Figure 3: please refer in the figure to the first channel consistency test. For example, you could write as follows: "Error percentage of difference

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signal estimated during the first channel consistency test."

Reply 11: Thank you very much for your suggestion. The caption of Figure 4 (Figure 3 before revision) was revised.

Figure 4. a) Error percentage of difference signal estimated during the first channel consistency test b) H/V spectral ratio.

Comment 12: Caption of Figure 5: as already suggested for the caption of Figure 3, here you should refer to the second channel consistency test.

Reply 12: Thank you very much for your suggestion. The caption of Figure 6 (Figure 5 before revision) was revised.

Figure 6. a) Fourier spectra for the recorded three-component data during the second channel consistency test b) H/V spectral ratio.

Comment 13: Figure 7a: waveforms are not well visible. I suggest to substitute the background color from black to white and to increase the width of lines.

Reply 13: Thank you very much for your suggestion. Figure 8a and 8b (Figure 7a and 7b before revision) were revised according the referee's comments.

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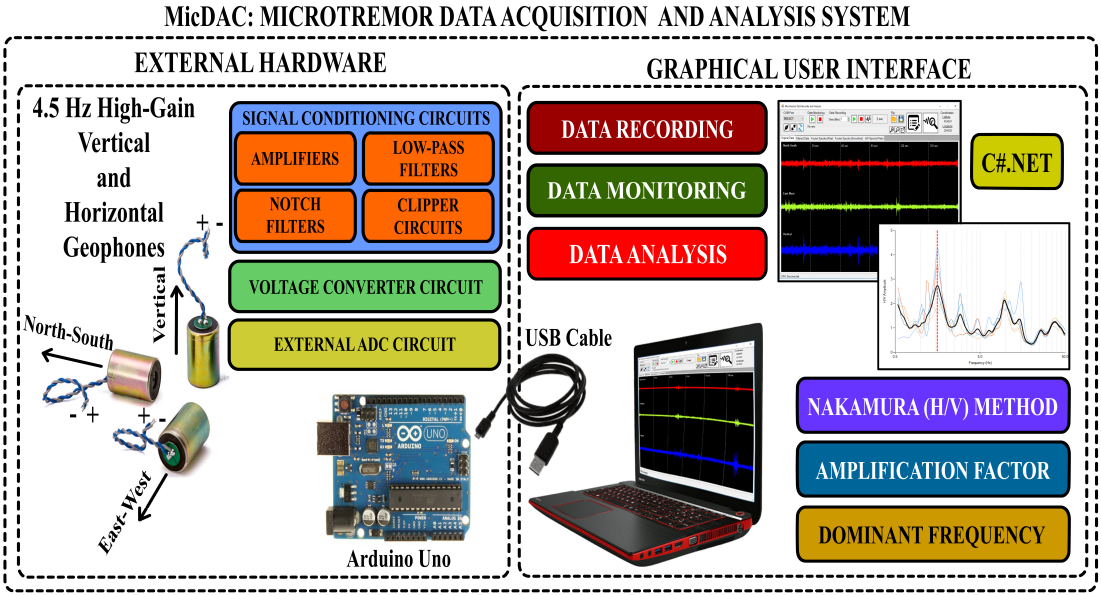

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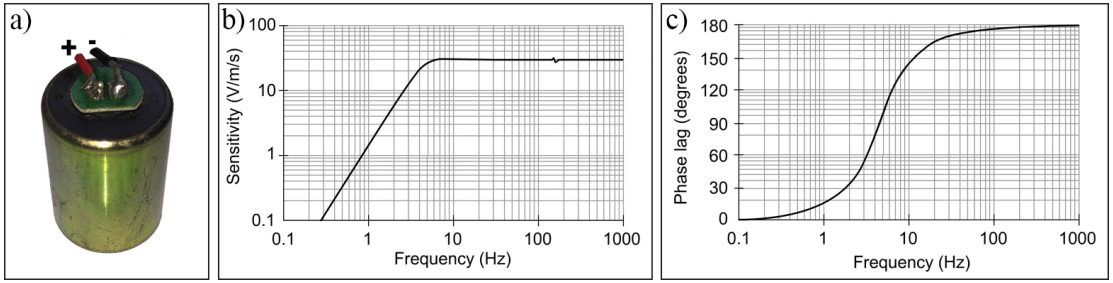

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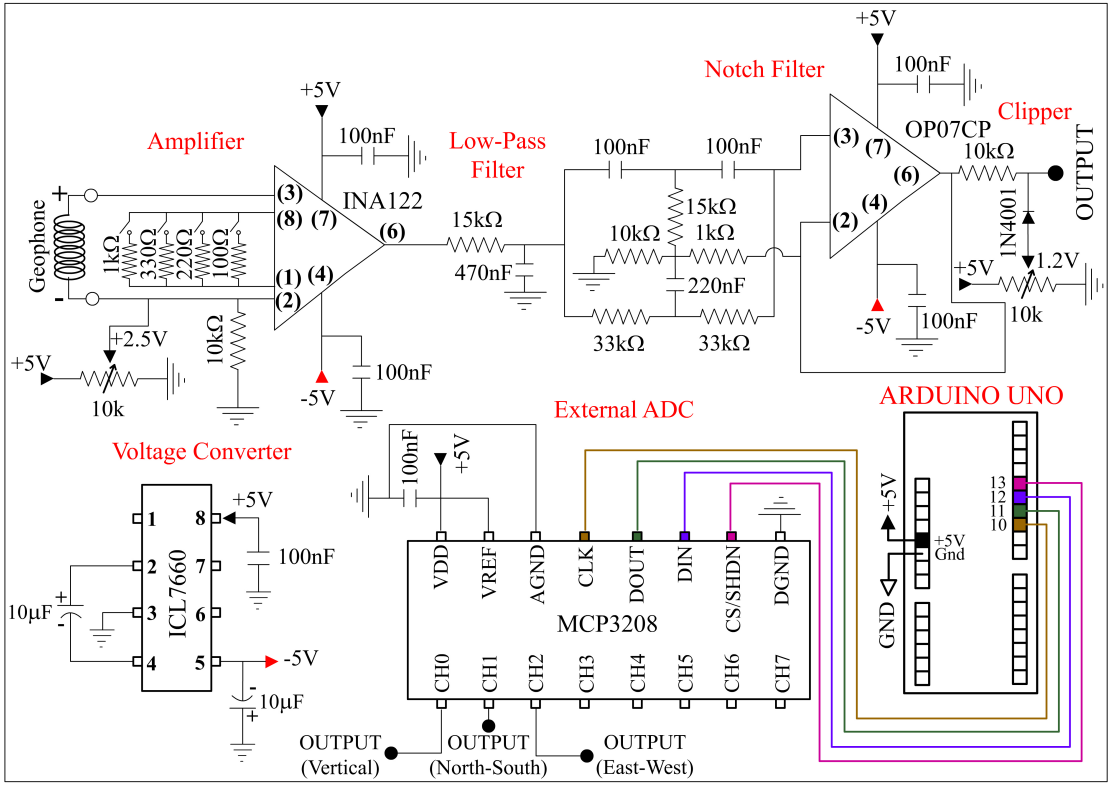

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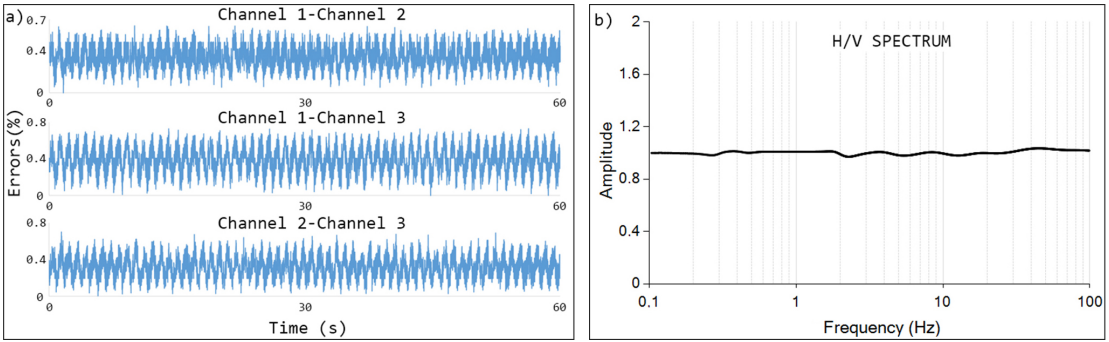

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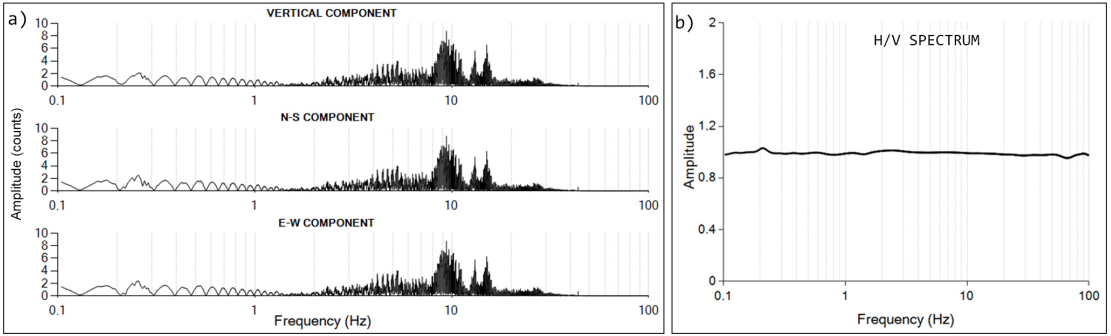

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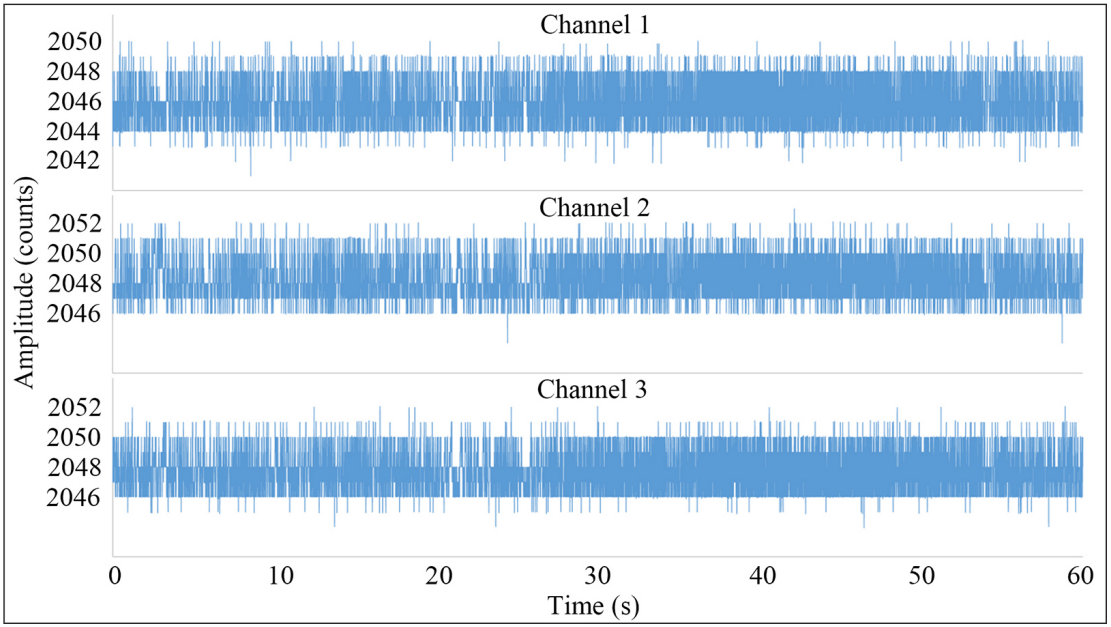

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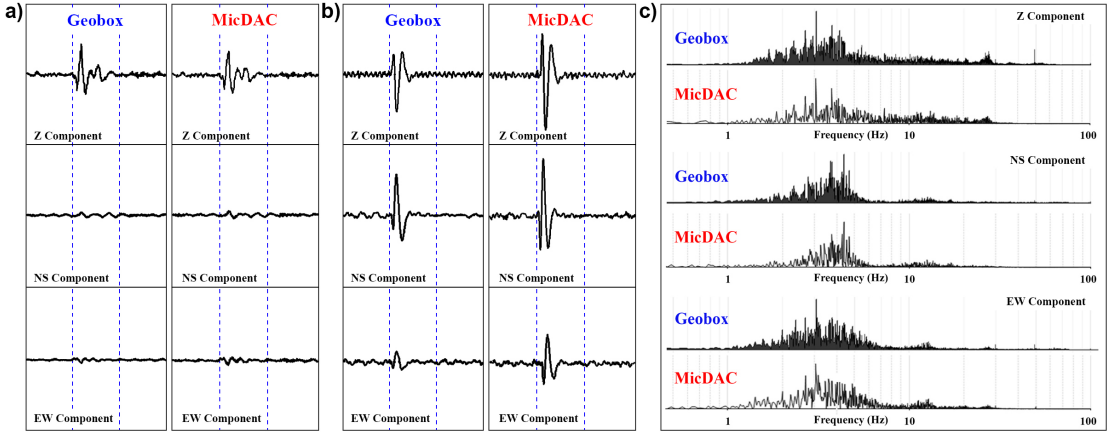

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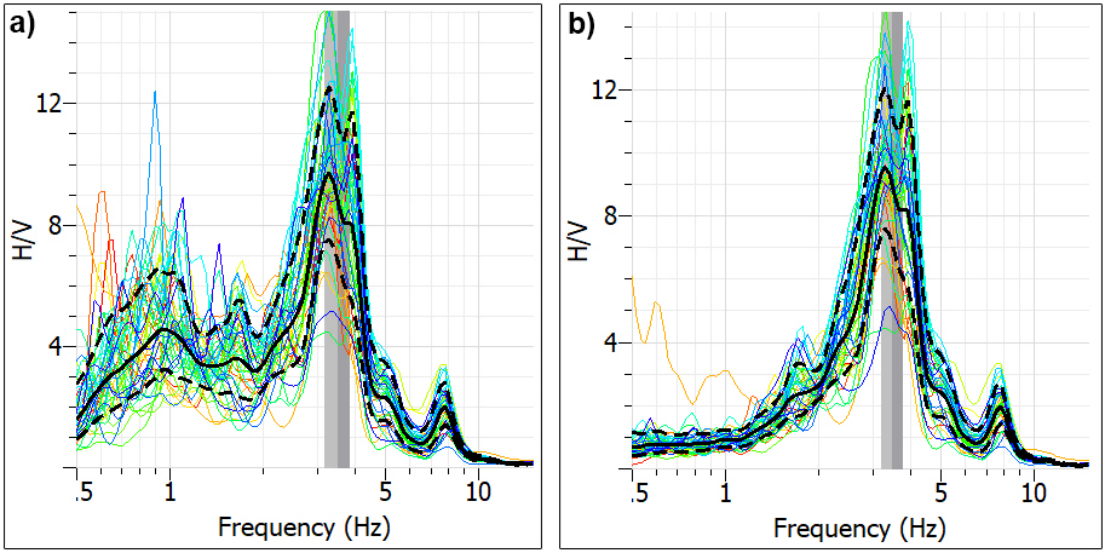

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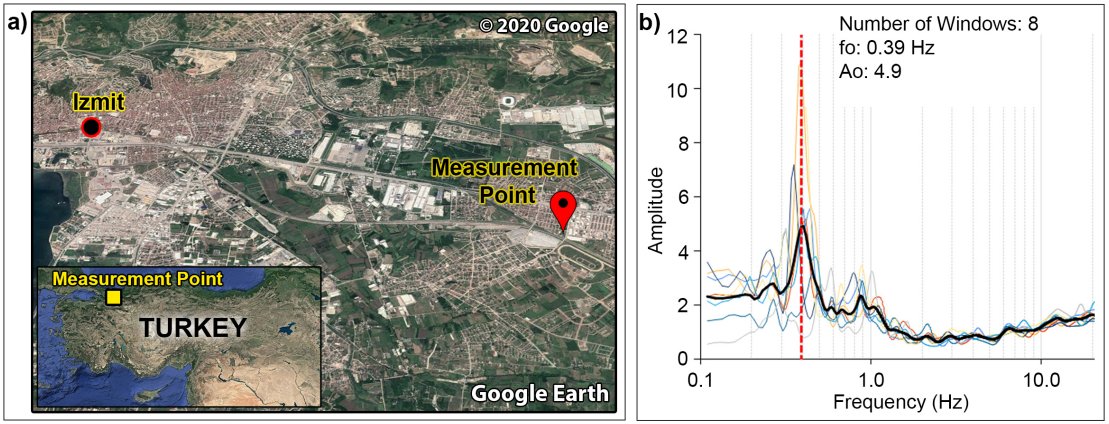

Fig. 10. a) Location of test measurement point on Google Earth© view b) H/V spectral ratio.

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I would like to thank the Editor and the anonymous reviewer for their constructive comments which helped me improve the quality of my work. To address these comments, I have carefully revised the paper. In the following, I provide a point-by-point response to the comments and detail the actions that I have taken to address those issues. For ease of cross referencing, the performed changes in this revised manuscript are highlighted in red color.

Comment 1: In your reply to my first comment you added several sentences in the first paragraph of the introduction section. All the sentences better describe the different

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kind of seismic sensors. Anyway I do not completely agree with the final part of the sentence "On the other hand, geophones are velocimeter, which are often preferred in local seismic applications because of their excellent reliabilities, highly sensitivities and low costs." I suggest to remove "low costs" because this is not true. Therefore, substitute "because of their excellent reliabilities, highly sensitivities and low costs" with "because of their excellent reliabilities and highly sensitivities".

Reply 1: Thank you very much for your suggestion. I removed the "low costs" term. Page 1-2, line 23-25: On the other hand, geophones are velocimeter, which are often preferred in local seismic applications because of their excellent reliabilities and highly sensitivities.

Comment 2: Figure 9: substitute "H/V spectrum ratios" with "H/V spectral ratios".

Reply 2: Thank you very much for your suggestion. I used the "spectral" term instead of the "spectrum".

Figure 9. The obtained H/V spectral ratios of recorded data by a) GeoBox b) MicDAC.

Comment 3: Figure 9: there is a perfect match between H/V spectral ratios obtained from data recorded by GeoBox and MicDAC above 2 Hz. On the other hand, below 2 Hz the H/V functions significantly differ each other. Could you explain why? Is this difference due to the different quality of sensors for frequencies below 2 Hz? Please, justify this possibly with the help of an additional figure if necessary.

Reply 3: Thank you very much for your suggestion. The reason of the difference at frequencies below 2 Hz is that the GeoBox uses an electronic circuit board to obtain a flat band wider than the natural band of the geophone and moves the eigen-frequency to lower value. In this way, it can obtain better sensitiviy at lower frequencies. I briefly explained the reason of amplitude difference of H/V curves at frequencies below 2 Hz in the last paragraph of Section 3.3

Page 8, line 145: Finally, the MicDAC was compared with a triaxial digital seismograph

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called as GeoBox manufactured by SARA Electronic Instruments. The GeoBox is an instrument designed especially for recording ambient seismic noise, and its different versions with sensors of 2 and 4.5 Hz are available in the market. In this study, the SR04HS model with 4.5 Hz sensors of GeoBox was used to make a comparison with MicDAC. The signals recorded simultaneously by MicDAC and GeoBox are shown in Fig. 8a and Fig. 8b. Log-MT software was used to monitor and to record the signals with GeoBox. Two different gain levels, 46 dB and 60 dB, were used in the signals recorded using MicDAC. As a result of this comparison in the time domain, a good correlation between the recorded signals using GeoBox and MicDAC was observed. This similarity was also observed in their frequency spectra (Fig. 8c). In addition to the comparisons in the time and frequency domains, their H/V spectral ratios were also obtained using the Geopsy software (Fig. 9a and 9b). The obtained H/V peak frequencies and amplitudes were given in Table 2. A good correlation was observed between the calculated H/V peak frequencies and amplitudes. The main reason for the differences in the amplitudes of the H/V curves at frequencies below 2 Hz is related to the electronic design of the GeoBox. Since GeoBox has an electronic architecture that can obtain a flat band wider than the natural band of the geophone embedded in the instrument. Therefore, it obtains better sensitivity at low frequencies.

Interactive comment on Geosci. Instrum. Method. Data Syst. Discuss., https://doi.org/10.5194/gi-2020-11, 2020.

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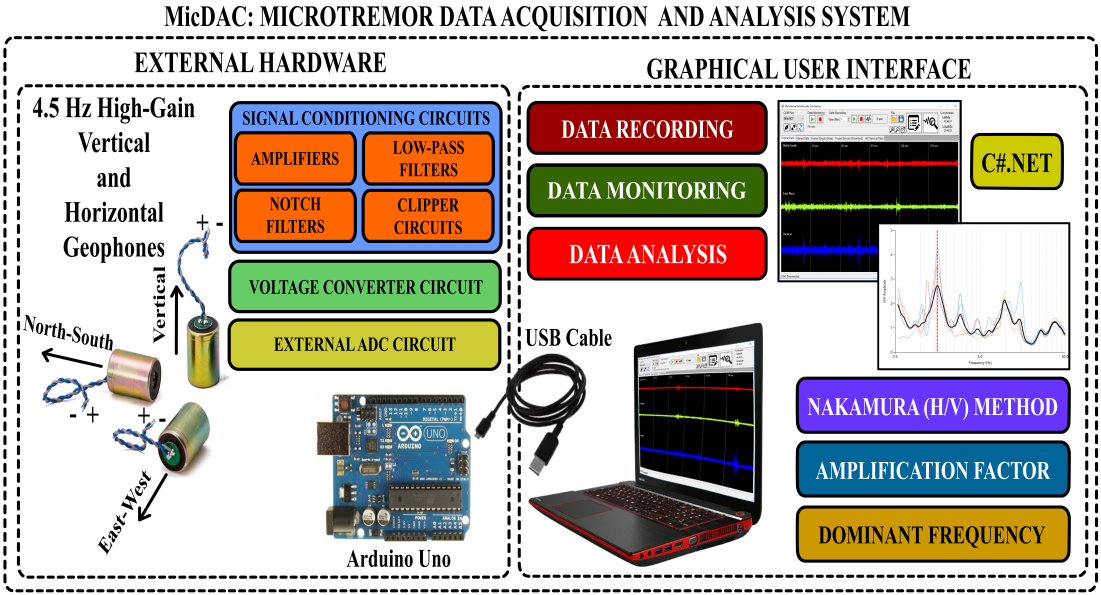

Fig. 1. Graphical abstract of the proposed system for measurement and analysis of three-component microtremor data.

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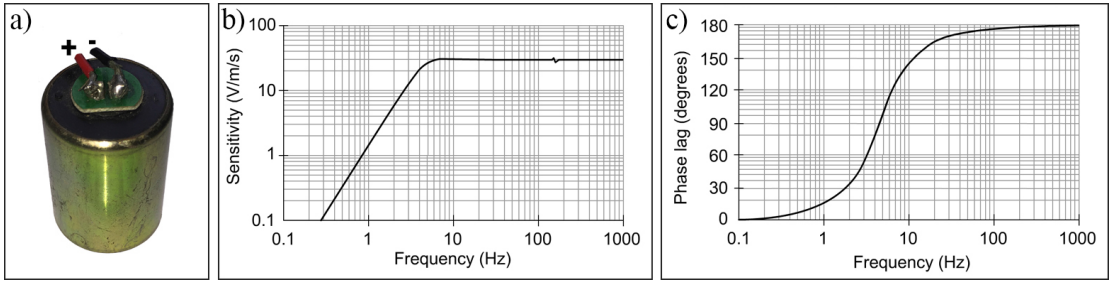

Fig. 2. For the geophones with 4.5 Hz natural frequency a) External view b) Amplitude response c) Phase response.

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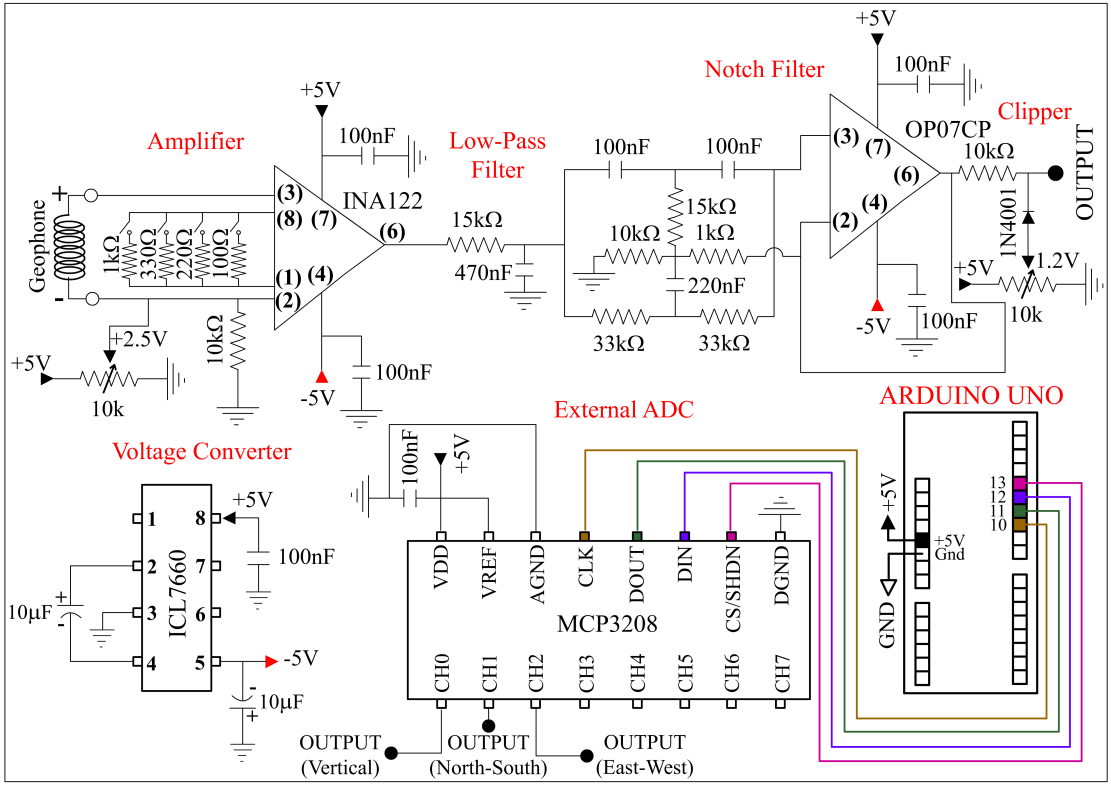

Fig. 3. Schematics of external hardware and pin connections.

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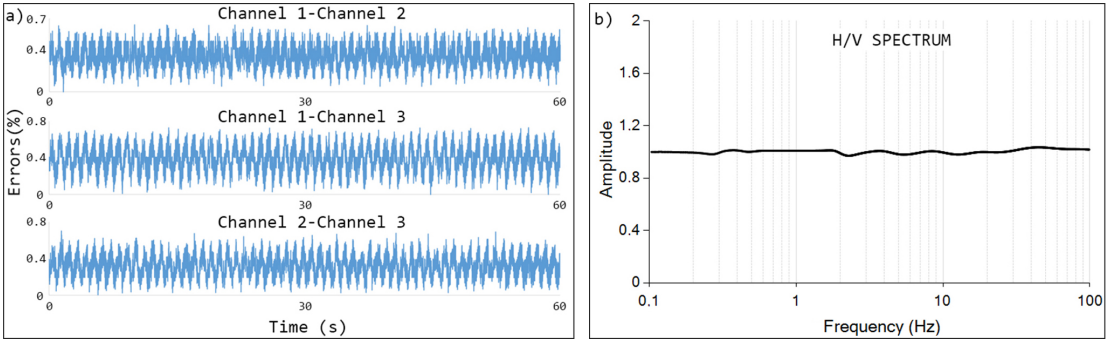

Fig. 4. a) Error percentage of difference signal estimated during the first channel consistency test b) H/V spectral ratio.

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Fig. 5. Screenshot of MicDAC-GUI and detected signals using a 4.5 Hz vertical geophone connected to each channel inputs.

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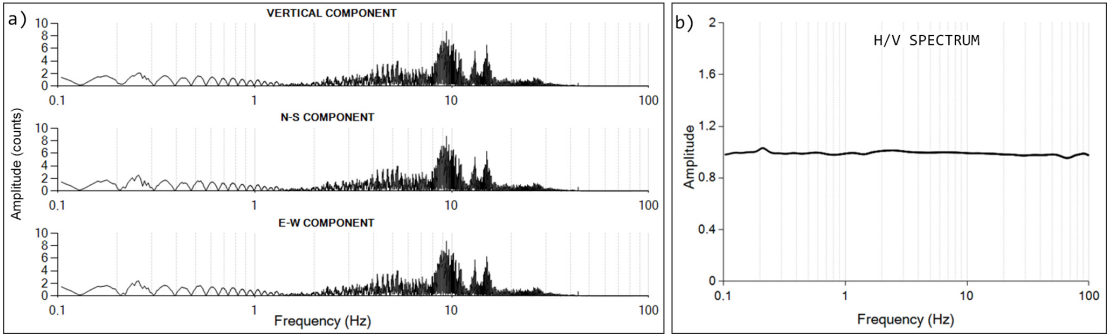

Fig. 6. a) Fourier spectra for the recorded three-component data during the second channel consistency test b) H/V spectral ratio.

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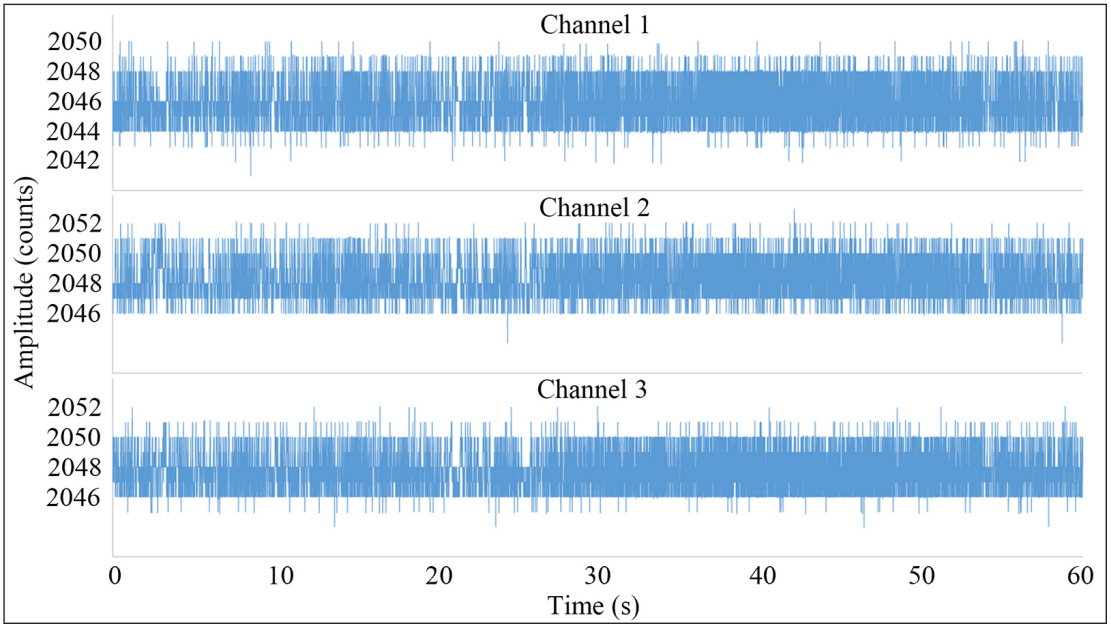

Fig. 7. Internal noise measurements for each channel.

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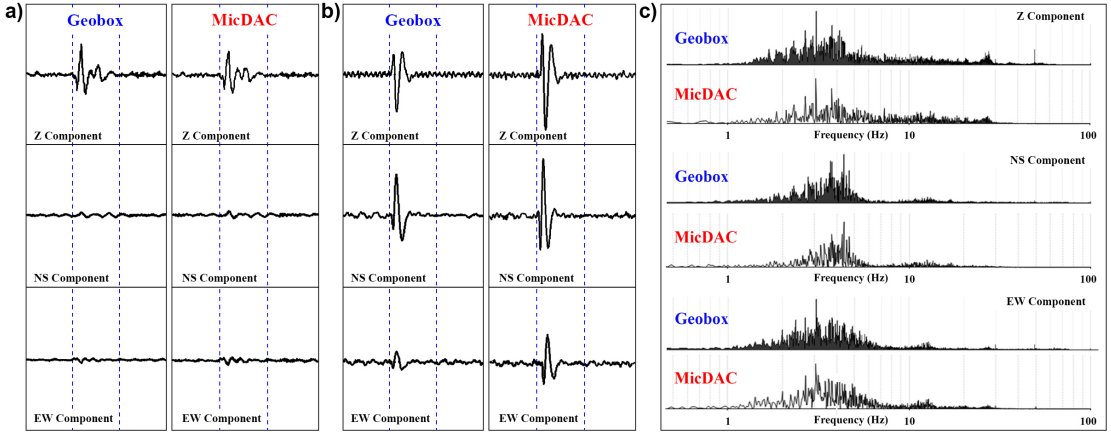

Fig. 8. Three-component seismic data recorded simultaneously using both devices a) MicDAC with 46 dB gain b) MicDAC with 60 dB gain c) Comparison of Fourier spectra of recorded three-component microtremor ...

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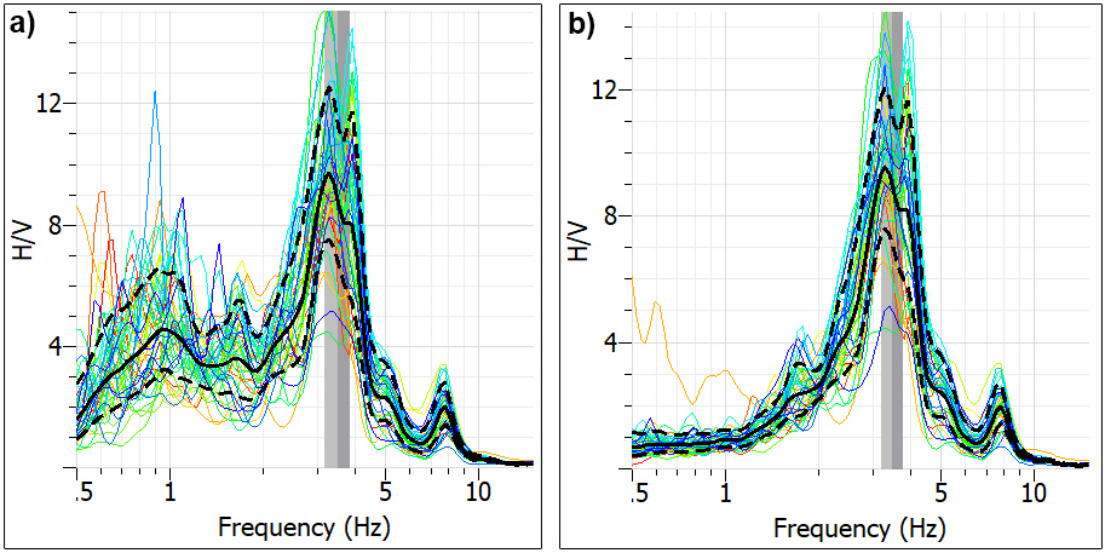

Fig. 9. The obtained H/V spectral ratios of recorded data by a) GeoBox b) MicDAC.

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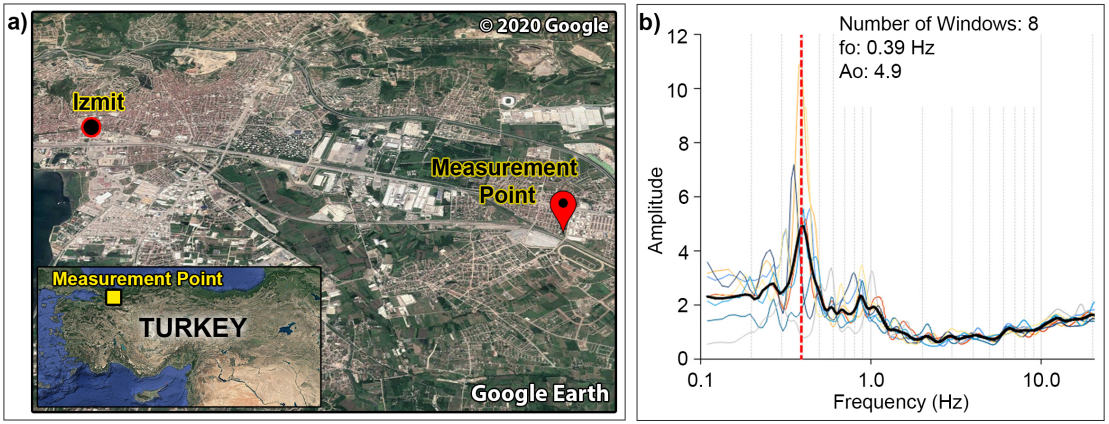

Fig. 10. a) Location of test measurement point on Google Earth© view b) H/V spectral ratio.

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Geoscientific Instrumentation Methods and Data Systems Discussions

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Interactive comment on "A geophone-based and low-cost data acquisition and analysis system designed to microtremor measurements" *by* Ozkan Kafadar

Ozkan Kafadar

ozkankafadar@gmail.com

Received and published: 22 July 2020

REVIEWER REPORT

All proposed corrections were made by the author. It is suitable to be published

Dear Ayhan Keskinsezer,

I would like to thank your constructive comments which helped me improve the quality of my work.

Best regards.

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Dr. Özkan Kafadar

Interactive comment on Geosci. Instrum. Method. Data Syst. Discuss., https://doi.org/10.5194/gi-2020-11, 2020.

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