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Raspberry Shake Sensor Field Tests for Unstable Rock Monitoring

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Summary

In this work, we evaluate the performance of the Raspberry Shake 3D (RS-3D) seismometer in estimating the resonance frequencies of unstable rock blocks. In this perspective, we compared this low-cost sensor with the Nanometrics Trillium Compact 20s to assess whether RS-3D is suitable for the development of reliable rock monitoring systems. We carried out surveys on eight rock compartments located both in the Northern Italy and in the Maltese archipelago. Ambient noise recordings have been processed by computing the mean amplitude spectra, the ratio between the Raspberry Shake spectra and the Trillium ones, and the Horizontal-to-Vertical Spectral Ratio. The obtained results show that the RS-3D performs according to the vendor specifications, with slight spectral differences with respect to the Nanometrics reference. Our preliminary tests reveal that the Raspberry Shake may be a reliable sensor for estimating the fundamental frequency of unstable rock blocks provided the HV peak occurs within the RS flat frequency response, and, because of its low-cost, may promote the deployment of denser seismic monitoring networks.

Introduction

In last decades, passive seismic methodologies have been increasingly employed in a wide variety of application areas. The initial studies have been mainly focused on the analysis of seismic noise measurements for both assessment and monitoring purposes in civil and mining engineering (e.g., Burjánek et al. 2010). In recent years, passive techniques have become increasingly popular in many other applications and, with the global growth of climate-related disasters, they have also been used to monitor unstable slopes (Larose et al., 2015). To this regard, research activities have demonstrated that, by cross-correlating the ambient noise recorded at two different locations, it is possible to continuously monitor the seismic velocity changes occurring within a slope and correlate them with both the displacements and the water table variations (Mainsant et al., 2012; Voisin et al., 2016). In addition to this technique, the seismometers have also been installed directly on unstable rock compartments with the aim of studying the evolution over time of their fundamental frequency by processing the recordings with the horizontal-to-vertical spectral ratio technique (HVSR) (Burjánek et al., 2012; Taruselli et al., 2019). The success of these passive methodologies in different application fields lies in the fact that the ambient seismic noise can be recorded at any time and in any location since it does not require any specific active source. In order to deploy dense seismic networks, researchers are now extremely interested in newly-developed low-cost seismometers. These solutions may be convenient in terms of both economic savings and limited installation and maintenance efforts (Manconi et al., 2018). Moreover, they can be more suitable for long-term monitoring than classical seismological sensors, since they can be set up to transmit real-time data with affordable costs (Anthony et al., 2019). However, many inexpensive sensors do not generally guarantee ground motion measurements in a broad frequency band. This issue may prevent their use in some application fields, including monitoring of unstable rock blocks, in which the detection of low frequencies is extremely important. A candidate sensor for these scenarios may be the recently-developed all-in-one OSOP RaspberryShake 3D. This sensor provides an interesting cheap plug-and-play solution that combines both the three-component geophone and the digitizer in a single waterproof enclosure, ideal for outdoor studies. Since its application to unstable slopes monitoring has received little scientific attention, in this work we present the analysis of seismic noise recordings collected on eight rock compartments with both the Raspberry Shake and the Nanometrics Trillium seismometers. The main objective of this test is to compare the sensitivity of the two sensors and to evaluate the suitability of the low-cost solution to detect the resonance frequencies of the investigated rock structures.

Methods

At each site we installed the Nanometrics Trillium three-component seismometer, coupled with the Centaur digitizer, and the Raspberry Shake 3D - V5 (RS-3D) one next to the other. The frequency response of the first sensor spans from 0.05 to 100 Hz, whereas the RS-3D includes a 3-component 4.5 Hz Sunfull PS-4.5B geophone with the corner frequency electronically extended down to 2 seconds. More in detail, OSOP estimates a -3dB frequency bandwidth spanning from 0.7 to 39 Hz. Although both seismometers are factory calibrated to the same unit-to-unit sensitivity, for this test we used two sensors from each manufacturer to statistically strengthen the results. Since the sampling rate of the Raspberry Shake is fixed to 100Hz, we oversampled the collected ambient vibration recordings in order to make it comparable with the Trillium data series that was sampled at 200Hz. The obtained time-series were firstly analysed by computing the mean amplitude spectra. Then, to deeply investigate the reliability of the low-cost seismometer recordings, we computed the ratio between the Raspberry Shake spectra and the Trillium ones, considering the latter as a reference. We averaged all the obtained ratios in order to limit the influence of site effects and coupling issues on the final the results. Finally, we checked the suitability of the Raspberry Shake in revealing the fundamental frequency of unstable rock blocks by estimating the ratio between the amplitude spectra of the horizontal and vertical components (Nakamura, 1989).

Case studies

We recorded ambient noise on eight different rock compartments which are located both in Northern Italy and in the Maltese archipelago. The Italian survey has been performed in Abbadia Lariana (Italian Prealps) on Torrioni di Rialba (Figure 1), four conglomerate pillars more than 100 m-high, separated from each other by nearly fully-persistent vertical fractures. The stability condition of the study area is strongly affected by the underlying plastic shale layer that promotes a lateral spreading due to the huge weight of the overlying rock towers (Taruselli et al., 2019). This geological setting, coupled with severely excavated and altered areas in the lower section of the most exposed pillar, suggests that the most probable failure mechanism is toppling (Arosio et al., 2019).
The second measurement campaign has been performed along the north-western coast of Malta island in two different sites, namely Il-Qarraba at Ghajn Tuffieha Bay and Il-Prajjet at Anchor Bay (Figure 1). This sites have been selected since they offer a similar geological condition to the above-mentioned site. In fact, the two bays are characterised by the superposition of the Upper Coralline Limestone and the softer Blue Clay formation fostering the development of lateral spreading phenomena (Soldati et al., 2018). The deformation occurring within the clay layer causes the propagation of persistent cracks on the overlying limestone plateau with the following formation of unstable rock blocks that may either slide or topple (Devoto et al., 2013).

Figure 1 *A) Torrioni di Rialba; B) Il-Qarraba at Ghajn Tuffieha Bay; C) Il-Prajjet at Anchor Bay.*

Results and discussion

The comparison between the above-mentioned high-cost and low-cost seismometers seems to suggest that the Raspberry Shake is a reliable sensor for measuring ground motion velocity. As expected, the main difference between the two sensors occurs outside the frequency bandwidth of the RS-3D. More in details, we observed that the mean amplitude spectra of the two sensors almost perfectly match within the flat frequency response of the Raspberry Shake for most of the collected time series. The only noticeable difference in the 0.7-39Hz range is a very slight overestimation of the amplitude spectra for the RS recordings. On the contrary, when comparing the mean spectra outside the bandwidth of the Raspberry Shake, it is clear that the low-cost seismometer underestimates the amplitude ground motion with respect to the reference, broadband Trillium sensor. To deeply evaluate the sensitivity of the low-cost sensor, we can examine the result obtained by computing the ratio between the RS and the Trillium amplitude spectra (Figure 2). We can observe that there are slight differences among the three components. In particular, along the vertical direction only, the spectral ratio within RS flat response is always slightly higher than one, meaning that the retrieved seismic noise is overestimated compared to the reference one. Regarding the horizontal components, we observe that the spectra ratio curves within the RS frequency bandwidth can be subdivided into two distinct areas: a first one in which the geophones overestimate the reference ground motion (~ 0.9-15Hz), and a second one in the frequency range between 15-39Hz where we observe the opposite behaviour. In order to investigate this aspect and to more precisely assess the Raspberry Shake sensitivity, a laboratory test on a vertical shake table is ongoing for both the RS and Trillium seismometers. This test will be also used to interpret the monochromatic high frequency peaks, which mostly occur at the same frequency along the three components.
Finally, with respect to the computed HVSR curves, we observed that the Raspberry Shake is able to correctly estimate the resonance frequency of unstable rock blocks, provided the HV peak occurs within

the RS flat frequency response. Figure 2 shows an interesting result obtained for a tower at the Torrioni di Rialba site, which has a fundamental frequency of 1.84Hz, lower than the geophone resonant frequency. Thanks to the electronically extended corner frequency, the Raspberry Shake gives the same frequency peak measured by the Trillium sensor.

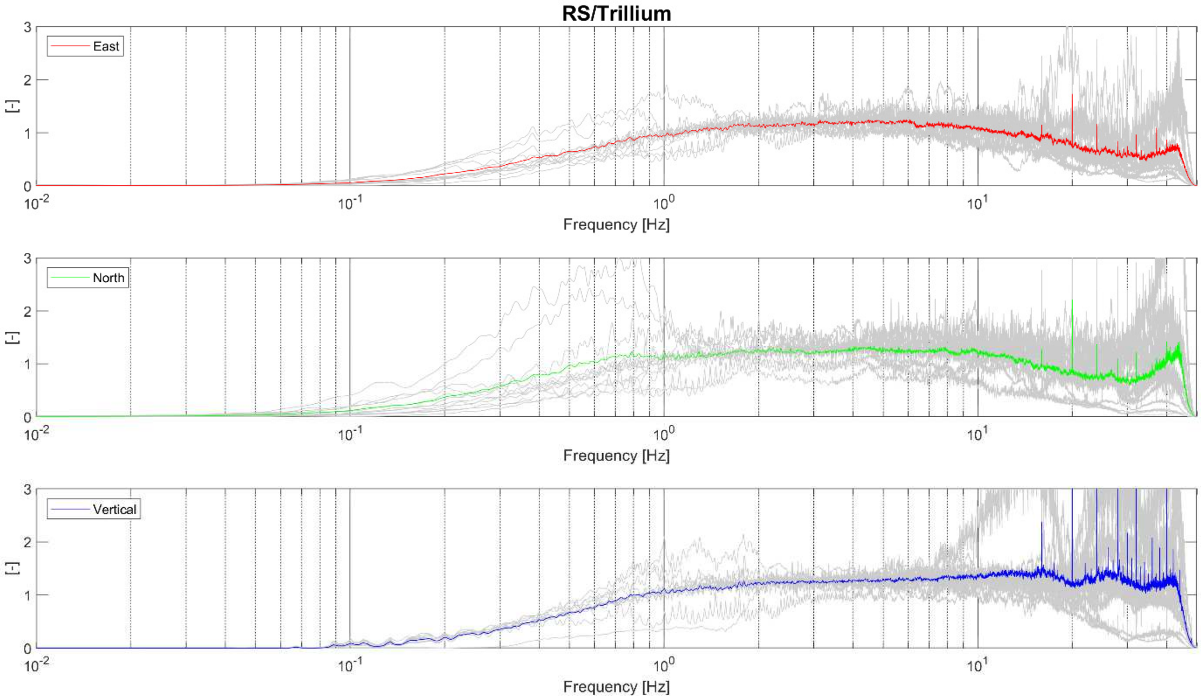

***Figure 2** Ratio between the Raspberry Shake and the Trillium amplitude spectra computed for the three components.*

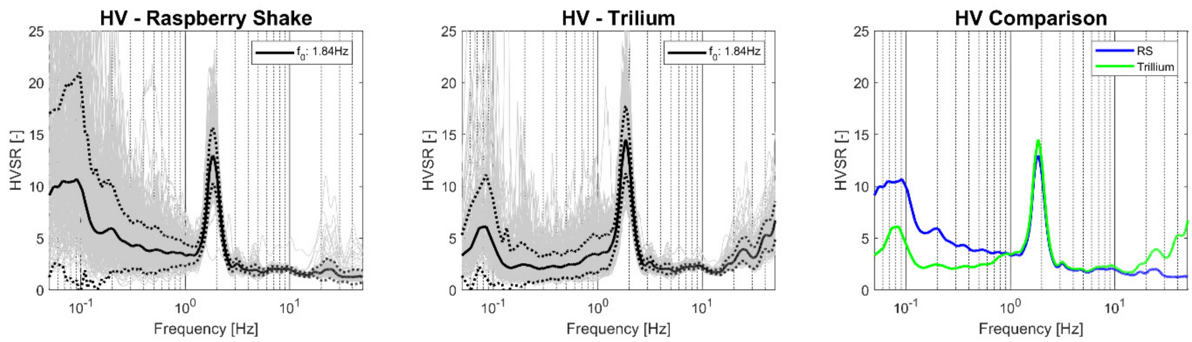

***Figure 3** Comparison between the HV curves computed for the data collected at Torrioni di Rialba site.*

Conclusions

In this work, we compared the Raspberry Shake 3D and the Nanometrics Trillium seismometers with the objective of assessing whether a low-cost seismic sensor can be used to continuously monitor unstable rock compartments. The preliminary results demonstrate that the RS-3D performs according to the vendor specifications with slight overestimations and underestimations of the amplitude spectra with respect to the Trillium reference ones. Since this issue may be due to the coupling of the sensors to the ground, lab testing on a shaker is underway. This test may be also helpful to interpret both the detected monochromatic peaks at higher frequencies and the different sensitivities observed for the three components.
The computed Horizontal-to-Vertical spectral ratios reveal that the Raspberry Shake may be a valuable tool to monitor the fundamental frequency variations of the unstable rock blocks provided the HV peak

occurs within the RS flat frequency response. Thus, it is important to always keep in mind the frequency bandwidth of this sensor as it may lead to a wrong interpretation of the observed HV peaks.
To conclude, RS seems to be an ideal candidate for rock fall monitoring purposes since it is low-cost and also guarantees limited installation and maintenance efforts, and the possibility to transmit real-time data. Furthermore, considering the Raspberry Shake is about eight times cheaper than the Nanometrics seismometer station, the deployment of more sensors on the same unstable rock block may be practicable, and could be helpful to investigate the shape of the block vibration modes.

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