Reference Materials

V&N App Installation and User Guide

(for Measurement of Vibration and Noise)

Disclaimer: The function given in the App is solely the responsibility of the Project Team at the PolyU. The CIC would encourage users to seek appropriate independent advice from professional advisors in using the App where possible and users should not treat or rely on this App as a substitute for such professional advice for taking any relevant actions.

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Preface

With the rapid development of smartphones incorporating built-in accurate sensors in recent years, monitoring of vibration and noise using smartphones now becomes possible.

The Department of Civil and Environmental Engineering of the Hong Kong Polytechnic University (PolyU) has developed a smartphone-based monitoring App for measuring construction-induced vibration and noise. The smartphone can be used to collect the vibration and noise data, and the App (viz. the V&N App) can then convert the collected data into useful parameters for use by construction industry stakeholders. The research and development work is documented in a report accessible from the CIC website (ZHU S, 2021).

The following models of smartphones have been checked and verified by the PolyU Project Team as acceptable for use with the V&N App:

|			
iPhone 12 Pro Max		iPhone 12 Pro	
iPhone 12	iPhone 12 mini	iPhone 11 Pro Max	iPhone 11 Pro
iPhone 11	iPhone SE (2nd gen.)		iPhone XS Max
iPhone XS	iPhone XR	iPhone X	iPhone 8 Plus
iPhone 8			

1. Introduction

The V&N App is the first smartphone App for real-time monitoring and assessment of construction-induced vibration and noise impact using sensitive receivers, providing useful indices commonly used in Hong Kong and introducing a practical tool for the local construction industry. This App also enables online data storage, sharing, and report generation, which are not commonly provided by traditional portable seismographs/geophones. The appealing characteristics, such as low price, excellent mobility, flexible range, multiplex functions, convenient operation, friendly interface, and cloud-based autonomous saving, statistical analysis, and report generation render the smartphone-based monitoring device a very promising option for monitoring vibration and noise impact on sensitive receivers caused by construction activities.

The sampling rate of the V&N App is 100 samples/sec. Therefore, it enables the measurement of construction-induced vibrations in the frequency range of 1 to 50 Hz. According to the laboratory calibration, the V&N App is suitable for measuring vibration levels with a peak particle velocity (PPV) greater than 0.5 mm/s, or with a root-mean-square (RMS) velocity greater than 0.1 mm/s.

2.   Setting-up for Smartphone and Measurements
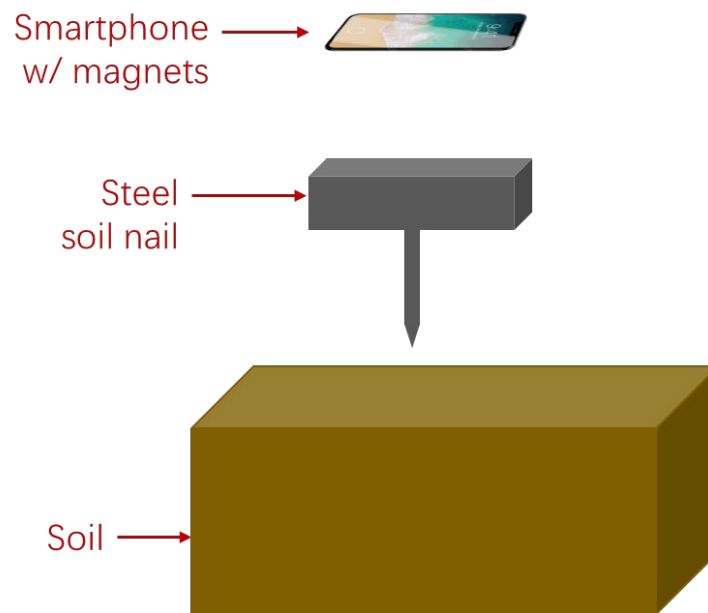
The installation guidance for smartphone devices is given as follows.

2.1.   Smartphone

Magnets adhered to the back of smartphone by 3M tapes
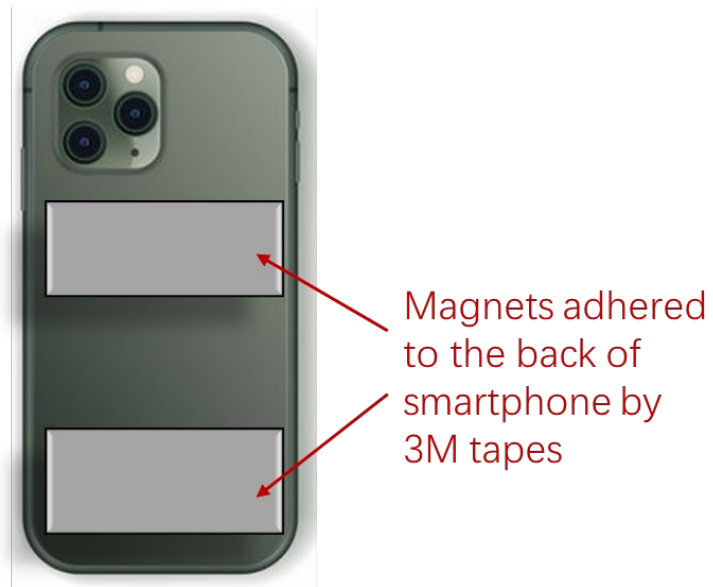
Adhere two or more strong magnets to the back of the smartphone by using strong tapes.

2.2.   On soil surface

Smartphone
w/ magnets

Steel
soil nail

Soil

If the measurement is conducted on the soil surface, a soil nail made of a ferromagnetic material (e.g. steel) is suggested to be used during measurement. The top area of the soil nail should be bigger than the smartphone. The specific operations are as follows:

1) Insert the soil nail into the soil.

2) Mount the smartphone with strong magnets on the top surface of the soil nail before the measurement.

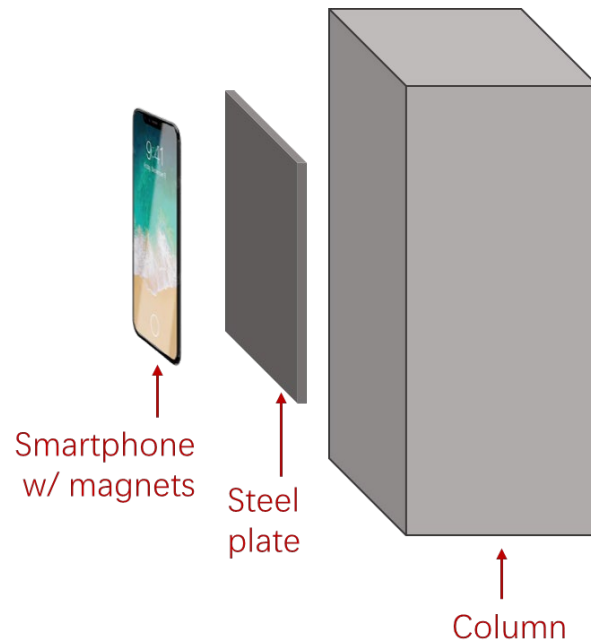3) Remove the smartphone after the measurement.

2.3. On rock or ground surface
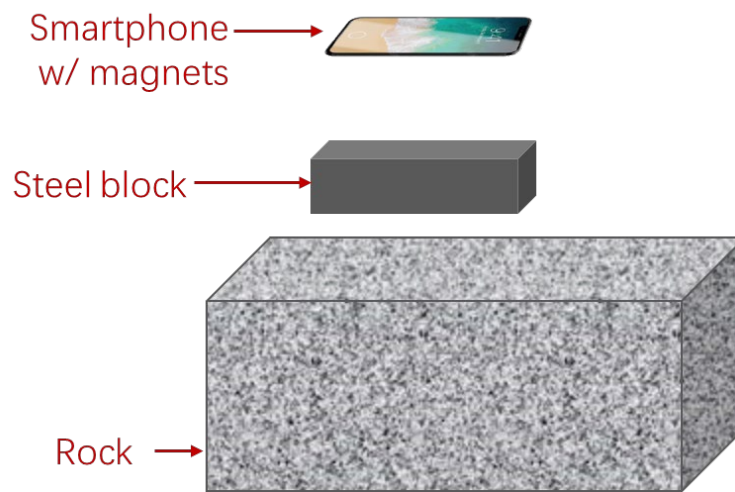
If the measurement is conducted on ground or rock, a block made of a ferromagnetic material (e.g. steel) is suggested to be used on the rock or ground surface. The top area of the block should be bigger than the smartphone. The specific operations are as follows:

1) Fix the steel block on flat ground or rock surface.

2) Mount the steel block on the surface using glue.

3) Mount the smartphone with strong magnets on the top surface of the block before the measurement.

4) Remove the smartphone after the measurement.

2.4. On structural vertical surface

Smartphone w/ magnets · Steel plate · Column

If the measurement is conducted on a structural vertical surface (e.g., column), a plate made of a ferromagnetic material (e.g. steel) is suggested to be used. The surface area of the plate should be bigger than the smartphone. The specific operations are as follows:

1) Fix the steel plate on a flat vertical surface.

2) Adhere the steel plate to the surface using glue.

3) Mount the smartphone with strong magnets on the surface of the plate before the measurement.

4) Remove the smartphone after the measurement.

3. Data Processing Using V&N App

3.1. Methodology

3.1.1. Vibration Measurement

General Guidance

i. Install the smartphone and other devices (e.g.. soil nail, steel block, or steel plate) as specified in Section 2.

ii. Avoid tapping the smartphone or walking around the smartphone to prevent disturbance to the measurements.

iii. Fix the tabs in the main menu screen during the measurement process. The chart view can only be changed when the measurement is stopped.

The directions of the x, y, and z axes are fixed and determined as below. Changing the orientation of the smartphone will not influence the direction of the three axes.
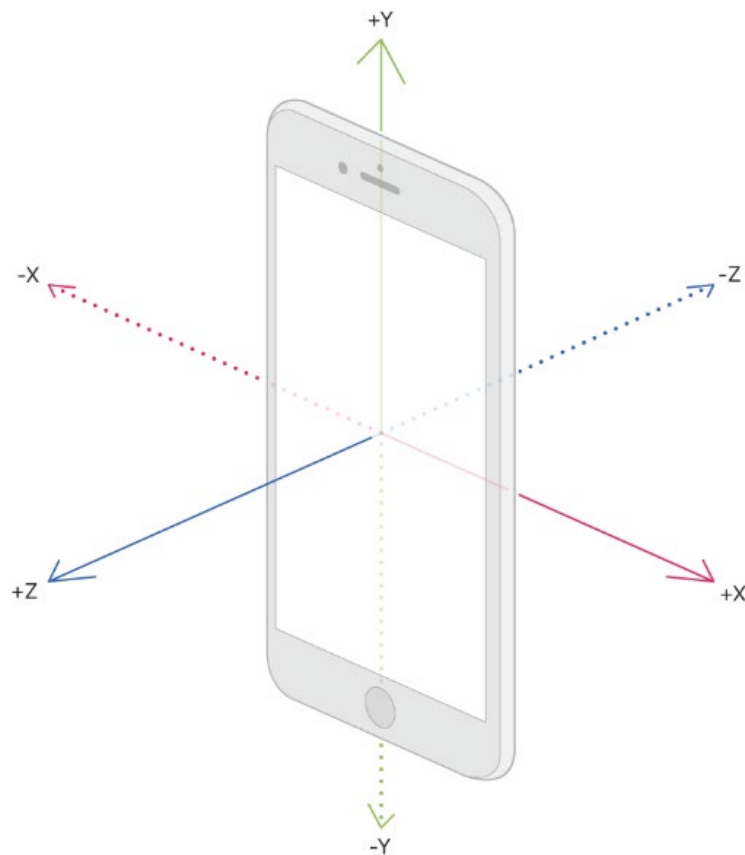
3.1.2. Noise Measurement

General Guidance

i. Hold the smartphone at about 25 to 30 cm from your 'hearing zone' (sphere around your head).

ii. Point the smartphone directly at the source of noise, preferably at 30 to 45 degree from the horizontal.

iii. If the noise source is constant, take the measurement for 30 seconds to 1 minute. If the noise source is varying, take the measurement for longer periods to capture all the variations.

iv. Do not tap or rub the smartphone to prevent inclusion of artefacts in the measurements.

v. Avoid measuring within 1 meter of large noise emitting or reflecting surface.

Noise Measurement Manual Adjustment

This process is used for adjusting the reading of the App, which might not be accurate due to differences among microphones and smartphone models. Another calibrated sound level meter could be used as a reference. The readings of the App should be adjusted until it matches the reference. The iPhone and the reference sound meter should measure the same position on the sound surface.

3.2. Installation of V&N App

To find and install the V&N app for iOS:
1) On your iPhone, open App Store.
2) Tap the Search icon.
3) Enter "Vibration and Noise" in the search field.
4) Select "Vibration and Noise" in the search results to go to the app page.
5) Follow the standard installation procedure.

https://apps.apple.com/hk/app/vibration-noise/id1497998044

3.3. Before Getting Started

For the first time you open the V&N App, you will be requested for authorisation for access of the location and microphone. Please allow the authorisation as needed, otherwise may influence some functions of the V&N App.
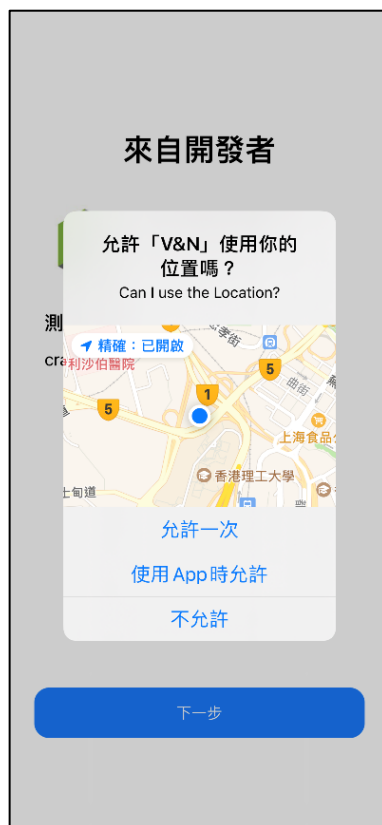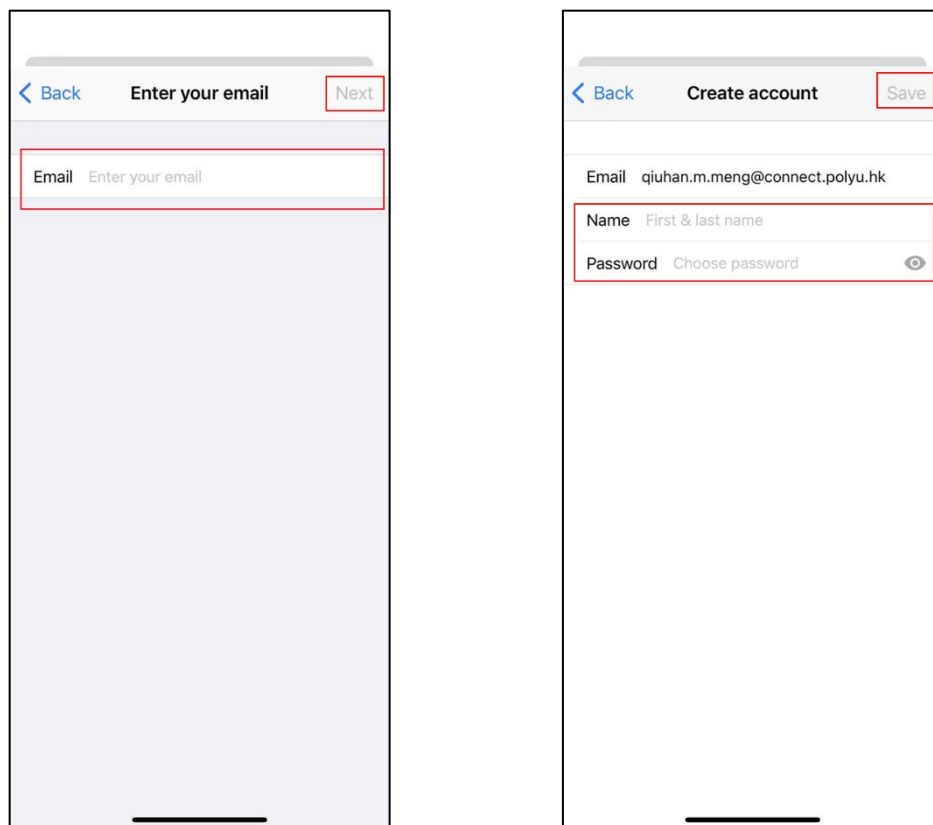
3.4.   Signing In

Three login methods are provided, which are *Sign in with email*, *Sign in with Google*, and *Sign in with phone number*.
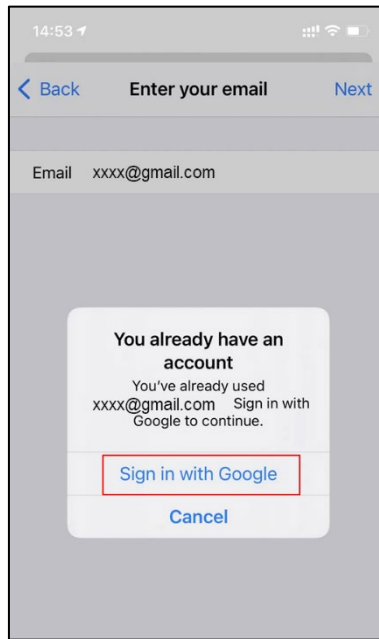
3.4.1.   Sign in with email

1) Tap *Sign in with email* and enter your email address, then tap the *Next* button;

2) Enter username and password, and tap the *Save* button.

The V&N App will create the account and log in automatically.

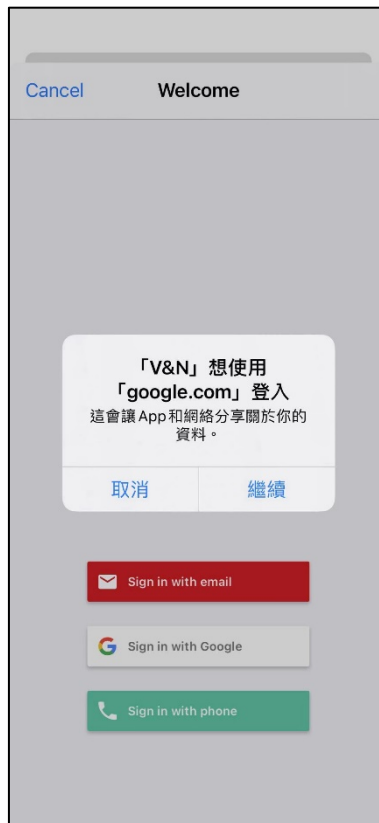If the email address you entered is the same as your Google account, the V&N App will continue with *Sign in with Google*.

3.4.2. Sign in with Google

1) Tap *Sign in with Google* and enter your Google email address, tap the *Continue* button

3.4.3. Sign in with phone

1) Tap *Sign in with Phone* and enter your phone number, then tap the *Verify* button;

2) The V&N App will send you a six-digit verification code. Enter the six-digit code you received and tap the *Next* button;

3) If you don't receive the verification code, tap *Resend code* after 15 seconds.
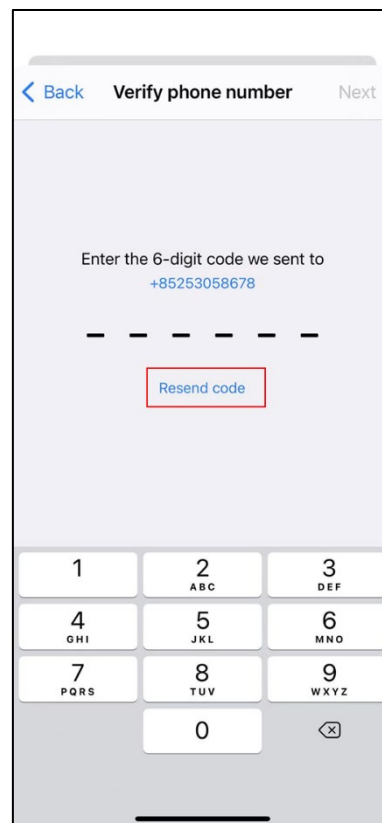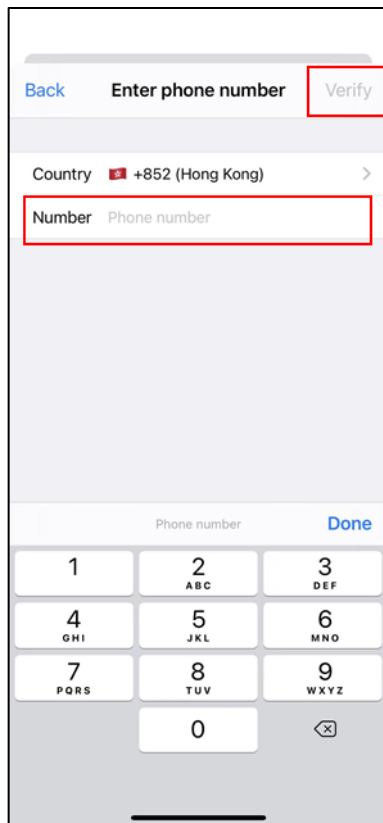
3.5.   Main Menu

The V&N App contains three tabs: **Vibration and Noise Meter**, **Data List**, and **User Info**.

3.5.1.   Vibration and Noise Meter

The **Vibration and Noise Meter** tab contains the three main modules: **Vibration**, **Noise Level**, and **Other Info**.

Vibration

The **Vibration** module includes *Time Series*, *Frequency Domain*, *Axis x/y/z*, *Response Vel/Acc/RMS Vel*, *Fold*, *Start/Stop/Reset*, *Save*, *Email*, and *Time select*.
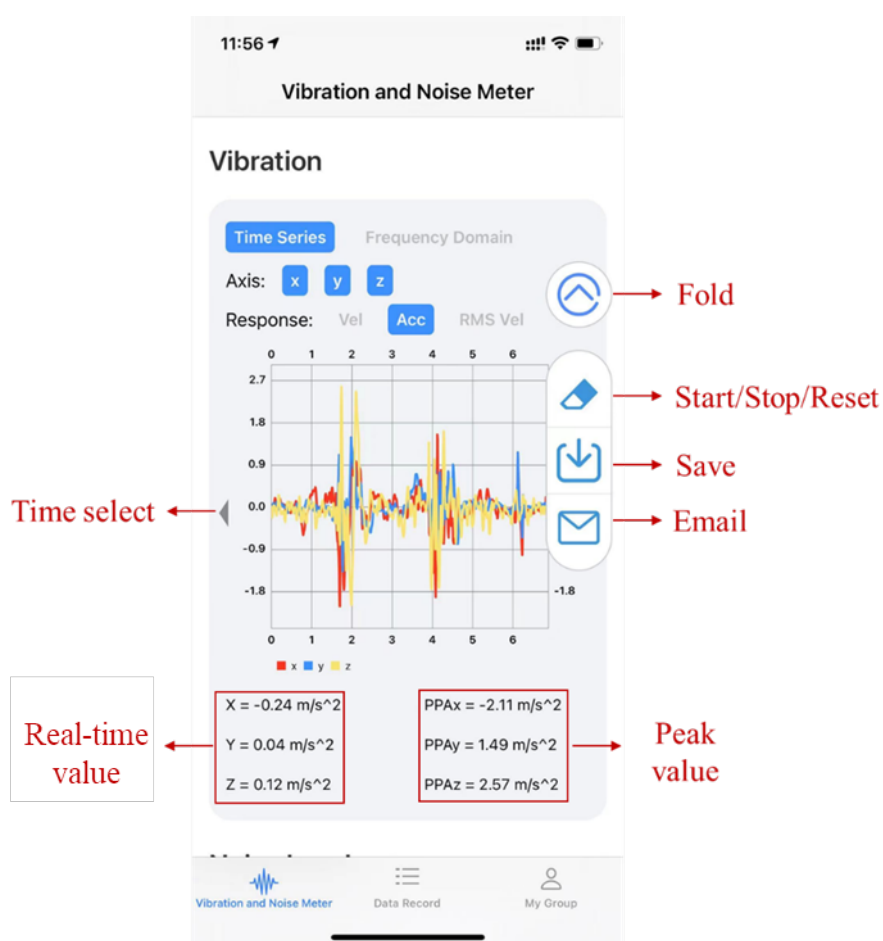
i.   *Time Series*: Show vibration in the time domain.

ii.   *Frequency Domain*: Show vibration in the frequency domain.

iii.   *Axis x/y/z*: Show vibrtion in X/Y/Z direction.

iv.   *Response Vel/Acc/RMS Vel:* Show response in terms of velocity/acceleration/RMS velocity in 1/3 octave band.

v.   *Fold*: Fold or expand the options, including Start/Stop/Reset, Save, and Email.

vi.   *Start/Stop/Reset*: Start, stop, or reset the monitoring process. When the *Start* button is clicked, it will be replaced by the *Stop* button; and when the *Stop* button is clicked, it will be replaced by the *Reset* button.

vii.   *Save*: Save the current monitoring file locally.

viii.   *Email*: Email the current monitoring file.

ix.   *Time select*: Select to show the data in the last or next minute.

During the monitoring process, the line chart in the middle will show the real-time raw acceleration time histories, where x, y and z axes are in red, blue, and yellow colors, respectively. The values of X, Y and Z on the left present the current acceleration values, and the PPAx, PPAy, and PPAz on the right side illustrate the peak acceleration values during the monitoring period.
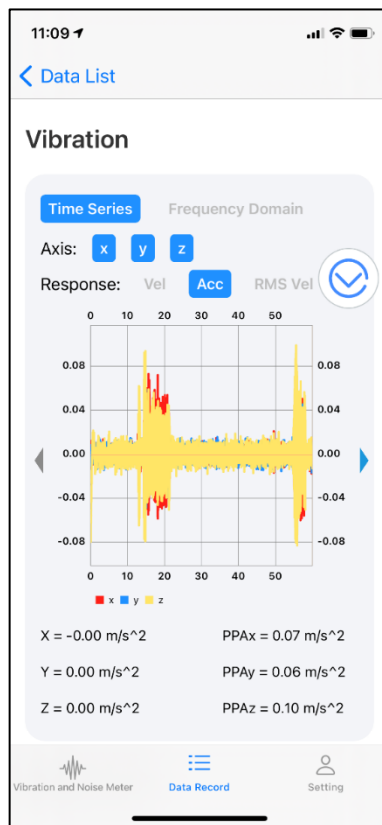
Considering that the size of the iPhone screen is not suitable to display a long-time response, the V&N App is designed to display one-minute time history data only, and two *Time select* buttons are added to allow users to select the response display one minute before or after.

Noise Level

The **Noise level** module shows sound pressure levels in instantaneous level, LAeq, Lmax, and Lmin. In addition, a *Correlation (dB)* slide button is used to adjusting the sound level by adding or reducing the sound level. The adjusting noise level ranges from -10 dB to +10 dB.
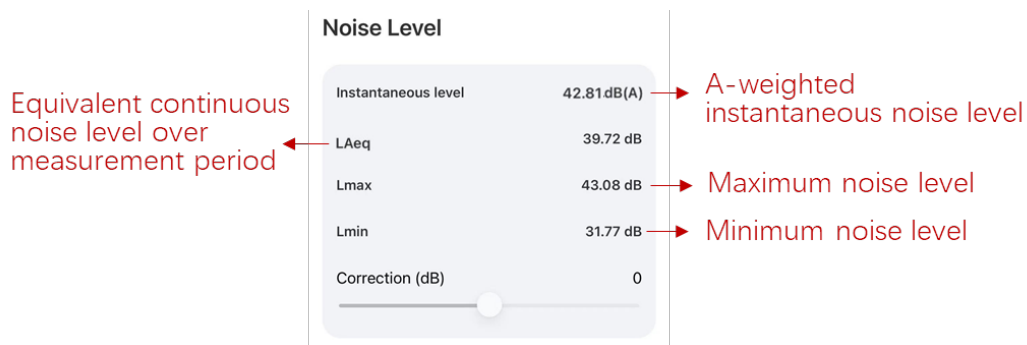
Other Info

The **Other Info** module contains the photo, coordinate, and remark textbox. Tap the *photo* icon can take a photo or upload a photo from the phone album.
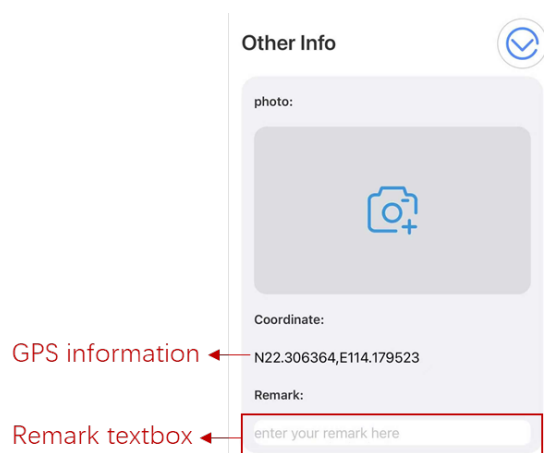
3.6. Data Record

All data sets stored locally would be checked through **Data Record** tab. Tap one date to check the data. The data record will be presented in the same way as in the **Vibration and Noise Meter** tab.
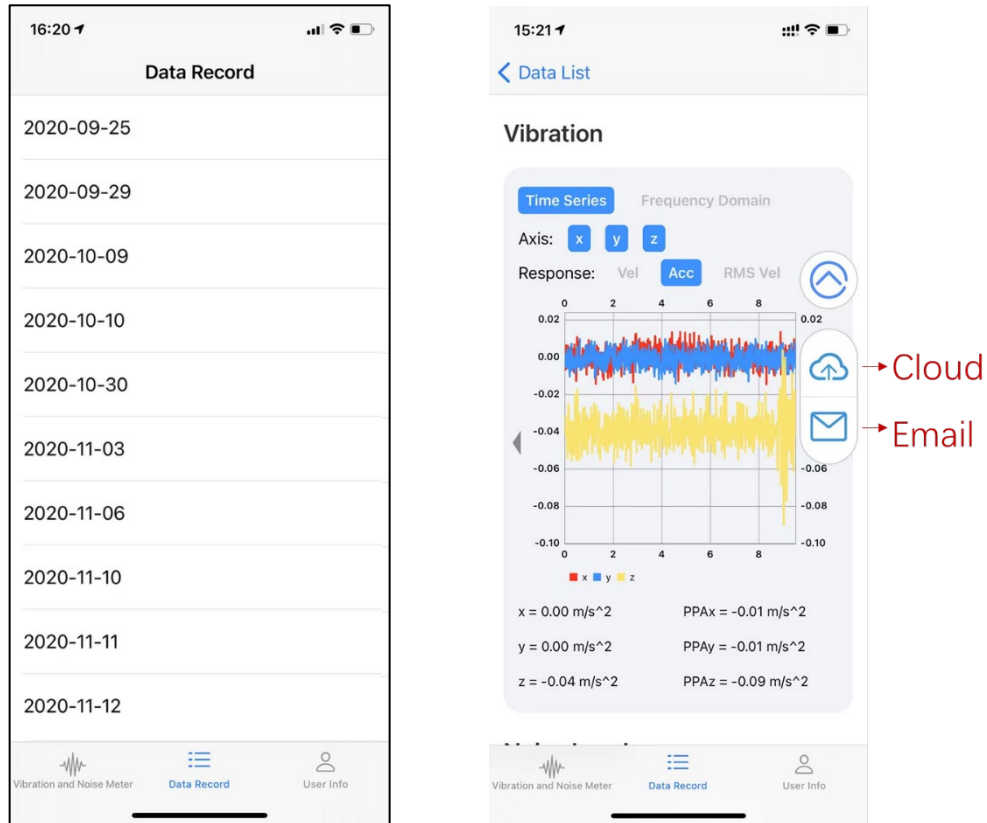
When checking data, two options are available *Cloud* and *Email*:

a. *Cloud*: Transfer the current monitoring data file to the Firebase cloud for storage.

b. *Email*: Email the current monitoring data file.

3.7. Data Output

The data records sent by email contain the user name, project information, user ID, recording time, text remarks (if any), and major measurement results in .txt format, which include acceleration time history, velocity time history, PPV, and noise level.

The .txt files for acceleration, velocity, and PPV consist of four columns, in which the first column represents time, while the other three columns represent corresponding values in three orthogonal axes (i.e. x, y, and z). The values of acceleration and velocity may be positive or negative depending on the direction of the smartphone (as shown in Section 3.1.1). The noise file contains the A-weighted sound level at the last measurement second (i.e. instantaneous level), continuous equivalent sound level during the measurement period (i.e. LAeq), as well as the maximum and minimum sound level (i.e. Lmax and Lmin).

3.8. Data Interpretation

3.8.1. PPV

Peak particle velocity (PPV) is defined as the maximum velocity of the measured surface during a time interval (BSI, 1993), usually with a unit of mm/s. The V&N App measures the acceleration signal $a(t)$ first. In numerical calculation, the velocity signal $v(t)$ is given by integration of $a(t)$, which can be expressed as follows:

$$v(t) = \int_0^t a(t)dt$$

PPV limits are given in most of the ground vibration control standards (including GEO, 2006). The V&N App measures and reports PPV in all three perpendicular directions every 5 seconds, namely, PPVx, PPVy, and PPVz, in x, y, and z directions, respectively.

The resultant PPV can be approximated by the peak vector sum (PVS), which is the square root of the sum of the squares of the individual PPV values in all three vector directions (SIS, 1999). The PVS is the parameter used in the vibration control of the construction site activities.

$$PPV \approx PVS = \sqrt{PPV_x{}^2 + PPV_y{}^2 + PPV_z{}^2}$$

3.8.2. RMSV

The evaluation of vibration impact on sensitive equipment is typically based on the root-mean-square (RMS) velocity in the 1/3 octave band spectrum, in accordance with BS 5228-2: 1993 "Code of Practice for Noise and Vibration Control on Construction and Open Site – Part 2: Vibration" (BSI, 2009). The V&N App provides RMS velocity in 1/3 octave band spectrum in both the time and frequency domains. The transformation from the time domain to the frequency domain is conducted through the fast Fourier transform (FFT).

The smartphone spectrum from 1 Hz to 50 Hz can be divided into seventeen 1/3-octave bands. Each band covers a specific range of frequencies whose upper band frequency is $\sqrt[3]{2}$ times the lower band frequency (ANSI S1.1-1986, R1998). The lower band-edge frequency f_l and the upper band-edge frequency f_u are determined from the equations below:

$$f_l = 2^{-\frac{1}{6}} f_c$$

$$f_u = 2^{\frac{1}{6}} f_c$$

where f_c is the center frequency for each 1/3 octave band. More detailed descriptions and applications of RMS velocity in 1/3 octave band spectrum can be found in BS 5228-2: 1993.

3.8.3. A-Weighting Noise Level

According to the relevant technical memoranda for noise assessment from construction sites (EPD, 1997a & 1997b), the A-weighted noise level in decibel (dB(A)) should be adopted for environmental noise measurement. The V&N App provides the noise levels, including instantaneous level, LAeq, Lmax and Lmin, with unit dB(A).

The A-weighting curve is mandated by the IEC 61672-1: 2013 "Electroacoustics – Sound level meters – Part 1: Specifications" (IEC, 2013) and various national standards. Considering the fact that the human ear is not as sensitive to lower frequencies as it is to higher frequencies, the A-weighted noise level arithmetically adds values to the measured sound pressure levels in dB, which are listed by octave bands. A graph of the gain in the A-weighted frequency response is shown below.
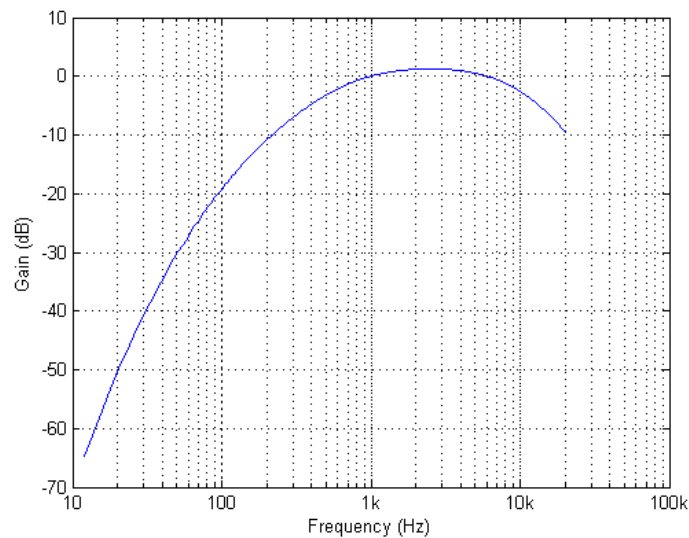
3.8.4. LAeq

The equivalent continuous sound pressure level (Leq) is widely adopted when measuring the impact of noise during a given period, which contains the same total energy as the fluctuating noise. The definition of Leq can be found in IEC 801-22-16 (IEC, 2008). When noise is measured with A-weighted level, it is customary to denote the equivalent continuous sound pressure level as LAeq. The equation for LAeq is given as follows:

$$L_{Aeq,T} = 10\log(\frac{1}{T}\int_{0}^{T} 10^{0.1L_A}\, dt)$$

where T is a given time period, and L_A is the A-weighted instantaneous noise level.

3.9.   User Info

The User Info interface contains basic information, including username, project information, and user ID. In addition, it includes four modules: **Cloud Data**, **Manage Group**, **App Info**, and **Acknowledgement**.
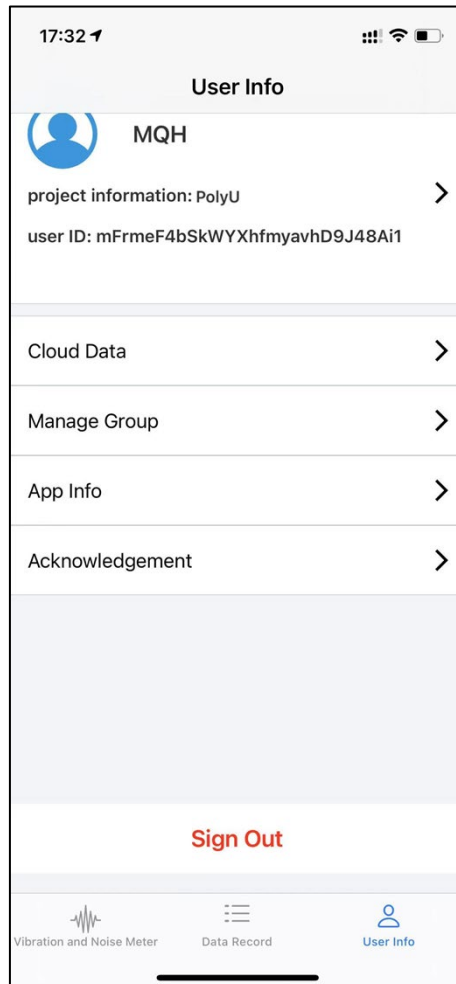
3.9.1. Cloud Data

The **Cloud Data** module contains historic data recordings uploaded by the current user account. Operators are enabled to check the detail of data and analysis results on multiple devices. The format of data records in the **Cloud Data** module is the same as the data record in **the Data Record** tab.

3.9.2. Manage Group

The Manage Group module provides the function of user/data management within one project/group.

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Create new group

Tap the *New Group* button and enter a group name, then tap the *Commit* button to create a new group.
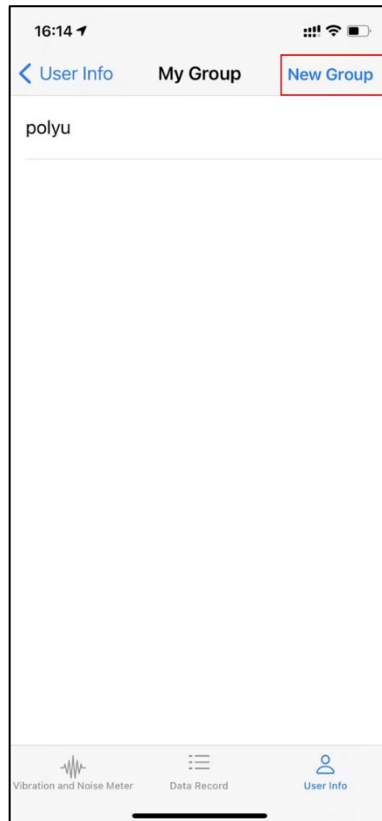
Group detail

Tap the *Group detail* to review the group information. Data uploaded to the cloud will be shown in the group. The corresponding time and user will be shown accordingly. Operators in the same group can share data among one another.
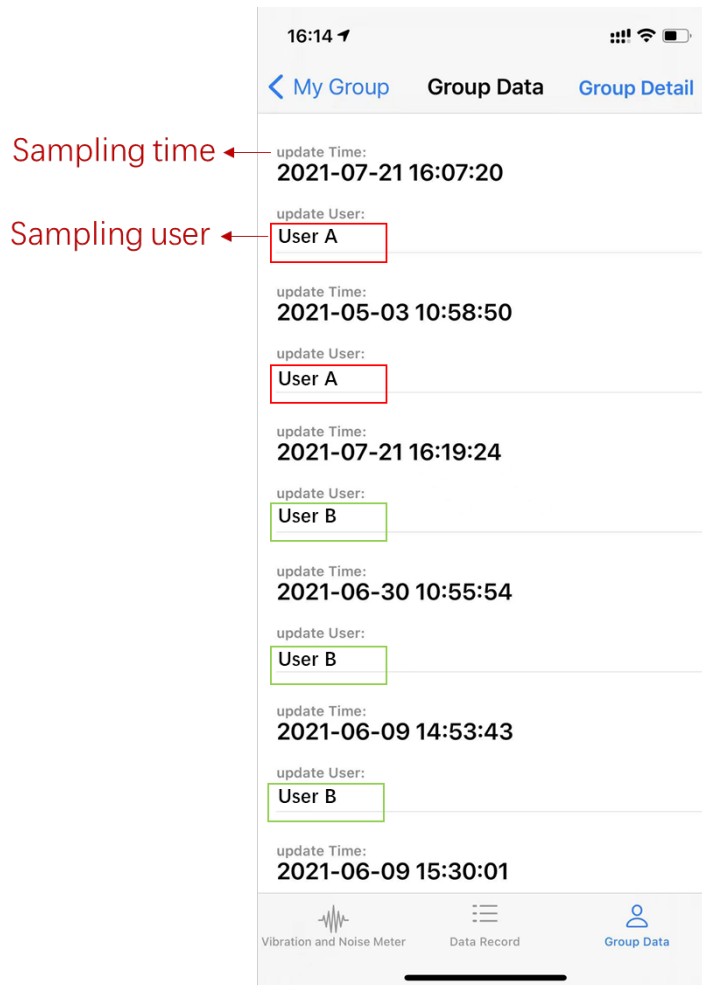
Invite new group member

Tap the *invite new member* to invite new group members through email. The email address does not need to be the email address used by the current operator.
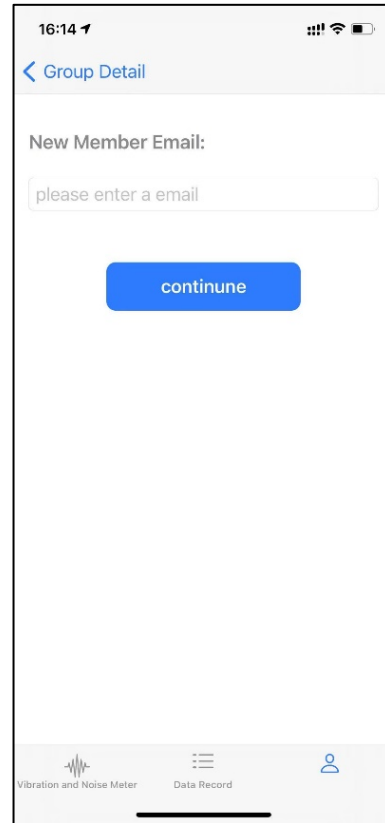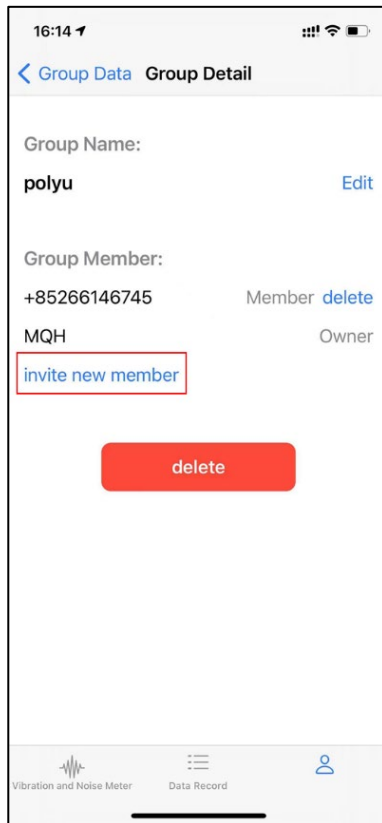
3.9.3. App Info

The **App Info** module contains the "Specifications for Smartphone-based Vibration and Noise Monitoring".

3.9.4. Acknowledgement

The **Acknowledgement** module contains the acknowledgement and disclaimer of the V&N App.

3.10. Data Security

3.10.1. App Security

The V&N App only collects certain data with permission from your device in order to provide services (e.g., location, microphone, and camera). The Apple platform uses various technologies to prevent Apps from accessing users' personal information without permission. Users are eligible to set or change permission rules as needed in the Settings in the devices. For further information, please refer to

https://support.apple.com/en-gb/guide/security/secc01781f46/1/web/1.

The monitoring records stored in the flash storage of the iPhone are protected by the Apple data encryption technologies, which means that the local data is only accessible to the current device. The V&N App would not access local data or automatically upload it to the cloud system unless further operations. For further details of the Apple Data Protection technology, please refer to

https://support.apple.com/en-gb/guide/security/secf6276da8a/1/web/1.

The V&N App downloaded from the App Store is protected by the Apple tightest protection method called sandbox, which can effectively provide your device from viruses, malware, or unauthorized attacks. For more information about the sandbox protection, please refer to

https://support.apple.com/en-gb/guide/security/sec35dd877d0/1/web/1

3.10.2. Firebase Security

Once uploaded to the Firebase cloud system, the data is protected by privacy and security rules in the Firebase. Extensive security measures are employed to keep user data safe. In general, the Firebase also encrypts data in transit using HTTPS and Cloud Storage. In addition to this, Firebase restricts data access rigorously. Data neither be shared with third parties nor accessed by users without permission. For more Firebase security and privacy information, please refer to

https://firebase.google.com/support/privacy#firebase_data_processing_and_security_terms.

4. Reference Specification Clauses

Use of Smartphone(s) and V&N App for Vibration and Noise Monitoring

1) The Contractor shall submit to the Architect's/Engineer's Representative for the Contract for approval details of the smartphone(s) (model name, model number, and serial number) proposed to be used for monitoring.

2) The Contractor shall install the smartphone(s) according to the method given in the "V&N Installation and User Guide" for the type of surface encountered at the required location(s) of monitoring.

3) The Contractor shall provide a lead technically competent person to supervise the smartphone installation works at the monitoring location(s), carry out comparative monitoring tests, collect the required data to an acceptable accuracy (within $\pm 5\%$ when compared with conventional seismograph and sound meter methods), process the data collected and provide the monitoring results in accordance with the Specification and the requirements of the relevant regulators.

4) The lead technically competent person shall have good knowledge and practical experience in measuring noise and/or vibration, and presenting, processing, and interpreting the monitoring results, to allow decisions to be made on whether the allowable limits have been exceeded, and whether additional specialist support is needed.

5) The lead technically competent person shall supervise the supporting technically competent personnel, provide training to them and assess their competence in the use of the smartphone(s) and the V&N App.

6) For vibration monitoring, the Contractor shall carry out comparative monitoring tests using a conventional seismograph placed side by side to one of the smartphones to be used. The seismograph shall have a valid calibration certificate approved by the Architect's/Engineer's Representative.

7) For noise monitoring, the Contractor shall carry out comparative monitoring tests using a sound meter placed as close as possible to and in the same orientation as the smartphones to be used. The sound meter shall have a valid calibration certificate approved by the Architect's/Engineer's Representative. A 1 kHz tone at 94 dB(A) shall be used in the comparative monitoring tests which shall be carried out in a quiet location.

8) The comparative monitoring tests shall be conducted in the first smartphone application on site and at appropriate times during the construction activities, to verify the accuracy of the smartphone measurements. For each smartphone model to be used in the Contract, the test shall be carried out at least once for every 100 applications using the smartphone.

9) The Contractor shall submit a report on each comparative monitoring test to the Architect's/Engineer's Representative within one day of completion of the test.

10) For the monitoring works during each day of the construction activities requiring monitoring under the Contract or by the regulators, the Contractor shall prepare a report containing the locations, date and time of monitoring, and the monitoring results. The Contractor shall submit the report, which shall be signed by the lead technically competent person, to the Architect's/Engineer's Representative. The report shall be submitted within one day of completion of the monitoring works. The report shall document any signs of distress or anomaly observed when compared against the baseline conditions of the sensitive receivers surveyed prior to the construction activities.
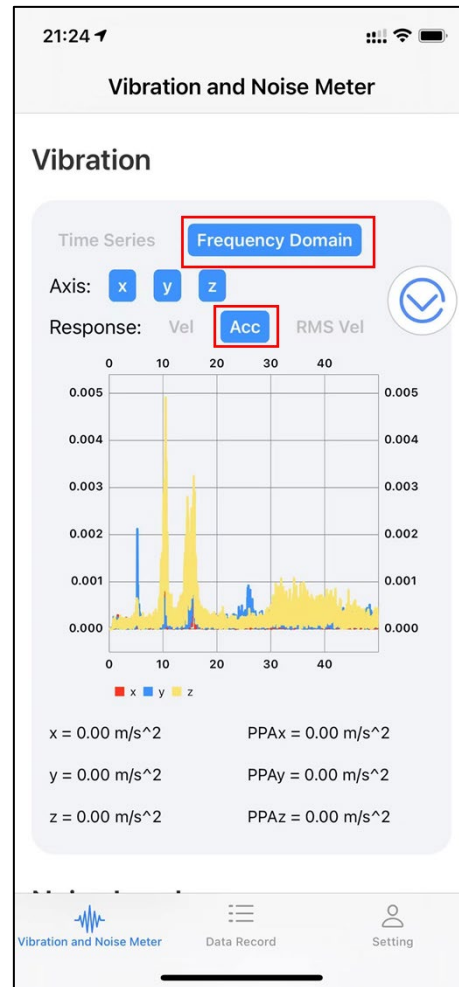
5. Examples

5.1. Checking acceleration records

Tap *Acc* and *Time Series/Frequency Domain* to check the acceleration records in the time domain or in the frequency domain.
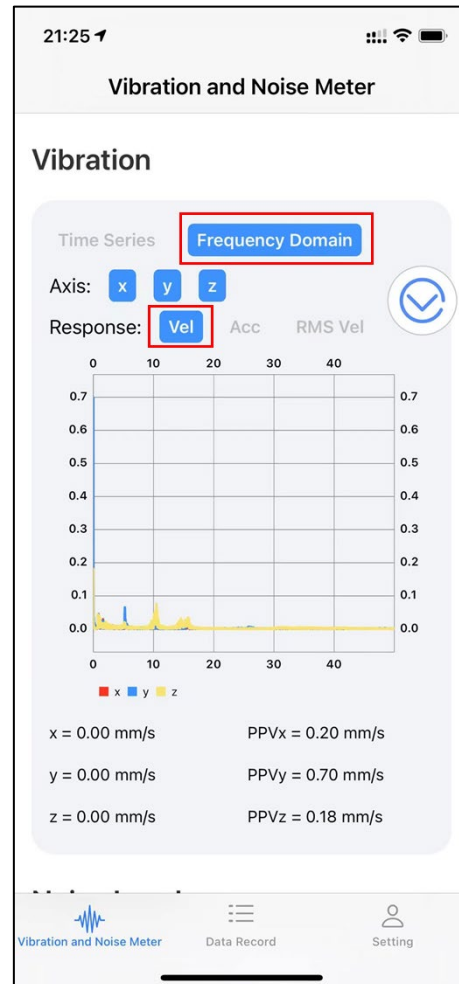

(a) Time domain   (b) Frequency domain

5.2. Checking velocity records

Tap *Vel* and *Time Series/Frequency Domain* to check the velocity records in the time domain or in the frequency domain.

(a) Time domain   (b) Frequency domain

5.3. Checking RMS velocity records

Tap *RMS Vel* and *Time Series/Frequency Domain* to check the RMS velocity in the 1/3 octave band spectrum in the time domain or in the frequency domain.
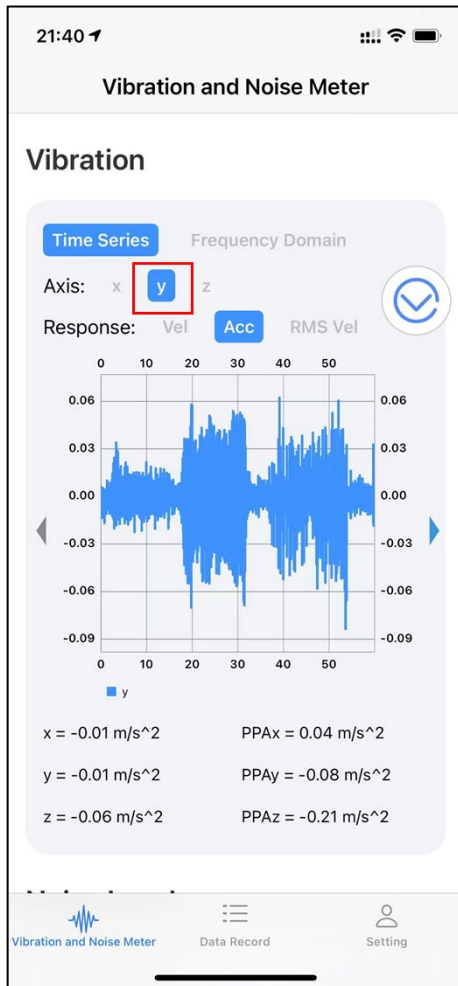

(a) Time domain   (b) Frequency domain

5.4. Checking data records in each axis

Tap *x*, *y*, or *z* alone or in combination to check data records in each axis or multiple axes. The options of Axis can be selected together with Response and Time Series/Frequency Domain.
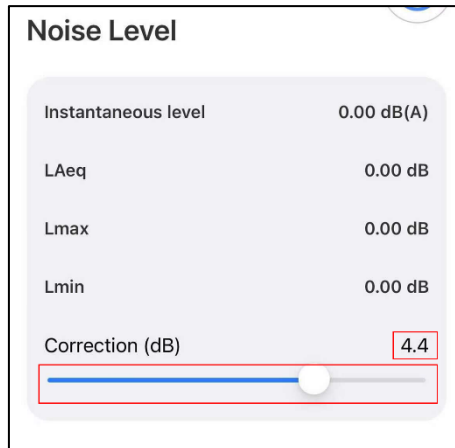

(a) Acceleration time history in y axis   (b) Acceleration time history in x axis and z axis

5.5. Adjusting correlation decibel

Slide the *Correlation (dB)* button to calibrate the noise level before starting the measurement. The adjusted noise level will be shown on the right side of the slide button.

6. References

ANSI S1.1-1986 (R1998). *Specifications for Octave-Band and Fractional-Octave-Band Analog and Digital Filters (ASA 65-1986)*. American National Standard Institute, the United States.

BSI (1993). *Evaluation and measurement for vibration in buildings – Part 2: Guide to damage levels from groundborne vibration (BS 7385-2: 1993)*. British Standards Institution, London.

BSI (2009). *Code of Practice for Noise and Vibration Control on Construction and Open Site – Part 2: Vibration (BS 5228-2: 1993)*. British Standards Institution, London.

EPD (1997a). *Technical Memorandum for the Assessment of Noise from Places Other Than Domestic Premises, Public Places or Construction Sites*. Environmental Protection Department, Government of the HKSAR, China.

EPD (1997b). *Technical Memorandum on Noise from Percussive Piling*. Environmental Protection Department, Government of the HKSAR, China.

GEO (2006). *Foundation design and construction*. Civil Engineering and Development Department, Government of the HKSAR, China.

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IEC (2013). *Electroacoustics - Sound level meters - Part 1: Specifications* (IEC 61672-1:2013). International Electrotechnical Commission, Switzerland.

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