Evaluation study of *iRobot Roomba Create 2* mechanical response for the requirement definition of a mobile robot platform

Irene Fiori (EGO), Federico Paoletti (INFN-Pisa)

Fabio Bonsignorio (Heron Robots)

Jan Harms (GSSI)

Tomasz Bulik (AOWU), Maria C. Tringali (AOWU)

04 August 2019

Technical report

VIR-0787A-19

Abstract

The *iRobot Roomba Create 2* is considered as a first easy and cheap off-the-shelf solution to serve as preliminary experimental test-bed for the development of a multi-sensory fusion network robotic platform for noise characterization of GW interferometers. We report here on the preliminary tests performed on the Roomba as a movable platform for seismic sensors to monitor soil vibration noise. One requirement is that this platform is rigid, free from mechanical modes, and well connected to the soil in the frequency band of interest of seismic measurements. We report about measurements of mechanical transfer functions of this platform and characterization of its first mechanical modes. We comment on its use as seismic platform and suggest mechanical features for a more performing platform that could be designed ad-hoc. There are hints that a platform able to work properly in a frequency band up to 50 Hz, i.e. in the Newtonian Noise frequency window, could be developed with limited improvements over the simple platform that we have used for our study. Our tests suggest that the same platform could actually be used as-it-is for micro seismic measurements in the 1-10 Hz frequency band.

European Gravitational Observatory - Via E. Amaldi 56021 S. Stefano a Macerata - Cascina (PI)

Tel +39 050 752511 Fax +39 050 752550

Introduction

As first easy and straight approach the *iRobot Roomba "Create 2"* (*"Roomba"* in the following) programmable robot is considered as mechanical platform for a robotized movable seismometer to measure soil vibrations. One possible application could be in seismic arrays for Newtonian Noise cancellation (NNC) [1] where the position of the sensors could be optimized by machine learning based optimization algorithms. Another possible application is for low-frequency (1-10Hz) seismology with a network of sensors installed on mobile robot platforms.

A suitable platform needs to be "well connected" to ground in the frequency region of interest. In particular, to set a reasonable reference, for the purpose of seismometers of NNC seismic array the usable band is between 5Hz to 50Hz. This means that ideally the platform to soil mechanical transfer function should be flat (free of internal modes) between 5Hz and 50Hz and dropping at the most by 3dB at 5Hz and 50Hz. We used a pair of vibration sensors to measure the transfer function and characterize the modal response of the Roomba.

We prepared two measurement setups. In the first setup we used the *Innoseis* geophone sensors of the NNC array deployed in the Virgo North experimental hall (NEB), we describe this measurement and results in Section 1. In the second setup was installed in the EGO Electronics lab and used accelerometers in different configurations to perform a modal analysis of the platform and test the use of conical tips, we describe this measurement and results in Section 2. We conclude in Section 3.

1. Measurements with NEB array sensors

We performed a measurement of the transfer function of vertical vibrations from the soil to the top of the Roomba body. We used two sensors of the array currently deployed on the concrete floor of the Virgo North end experimental area (NEB) [2, 3]. Innoseis sensor [4] has flat velocity response in the 5Hz to 50Hz band. Sensors have been attached to NEB floor using double side-tape.

A huddle test of two sensors is performed first (Figure 1, Left). One hour of recorded data with the typical background seismic noise is used to compute the coherence between the two. The result is show in Figure 2, blue line. Good coherence is measured between 1Hz and 10Hz, while between 10Hz and 32Hz we measure coherence drops at the level of 1% or less.

Subsequently, we just laid the Roomba on the NEB floor nearby one Innoseis sensor and moved the other sensor onto the Roomba body attached with double-side tape. The coherence is shown in Figure 2, red line. From 1 to 10Hz the coherence is not bad (drops at the level of 1%), then coherence drops significantly between 10 and 16Hz and between 24 and 30Hz.

Drops of coherence denote a not good mechanical contact with soil which can occur because of a not enough rigid contact. One reason for not rigid contact is that the Roomba bottom surface as multiple contacts, one way of improving it is to use three conical tips (see Section 2). Large drops of coherence can happen at the frequencies of mechanical modes of the Roomba body. At these frequencies the accelerometer on the Roomba body moves significantly respect to the soil. This is explored in Section 2.

Figure 1. Pictures of the setup at Virgo North end experimental building (NEB). Left: Huddle test of two Innoseis geophones, both attached to the NEB concrete floor with double side tape. Right: one Innoseis sensor is attached on the Roomba platform using double side-tape.

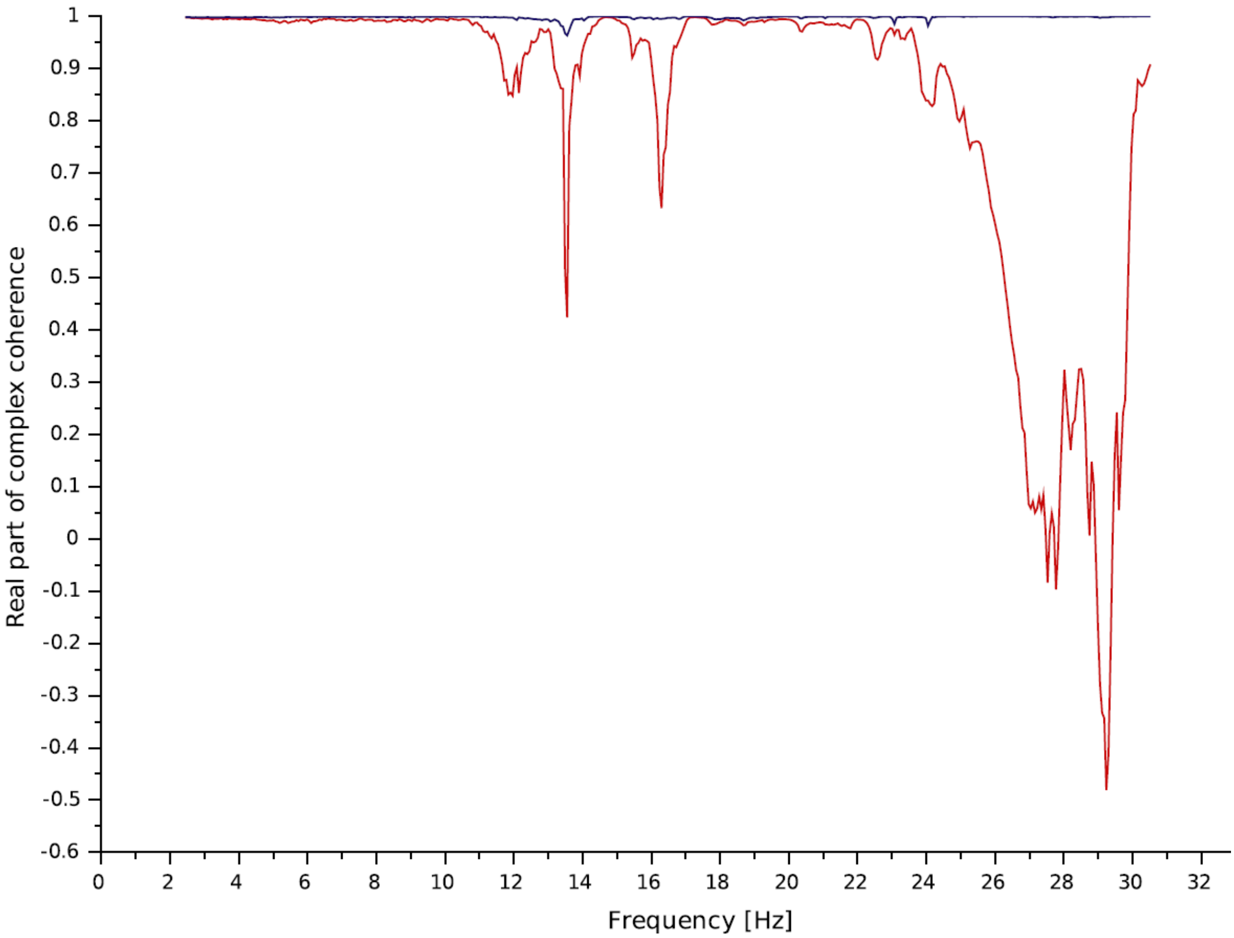


Figure 2. Real part of coherence between NEB innoseis sensors n.6 and n.7 in two cases. BLUE: n.7 is on roomba; RED: n. 7 is on the floor next to n.6.

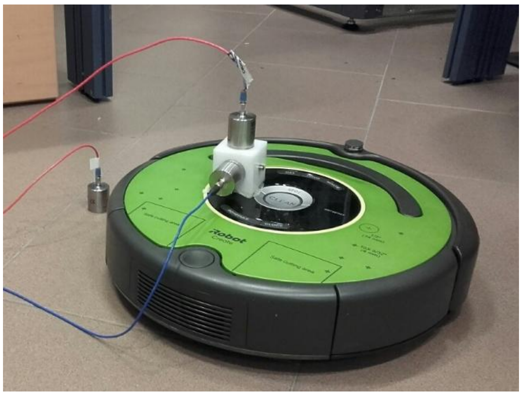
2. Measurements in EGO Lab

We used three Meggit mod. 731-207, sensitivity 10V/g, range 0.2-1300 Hz (-3dB) spectral noise 0.09 µg/sqrt(Hz) at 10Hz and one ONO-SOKKI spectrum analyser CF-3600A. Figure 3 shows pictures of the setup and Table 1 lists the measured configurations. We used double side tape which assures good contact of the accelerometer to the surface. To orient the accelerometer horizontally we used a solid *Teflon* (PTFE) cube. We find that jumping on the floor nearby is an efficient and practical way to excite the system and perform TF measurements, at least for the purpose of this preliminary test.

Preliminary, a Huddle test (accelerometer pair measuring nearby) proved that the accelerometer pair had transfer function (TF) consistent with 1 in the band 1Hz to 200Hz.
A first set of measurements is done with the Roomba "as it is" just resting on the floor and accelerometers in different configurations: n.1 to n.5 in Table 1 and Figures 1 to 5.

The first two measurements (n.1 and n.2) are with one accelerometer on Roomba top (vertical or horizontal) and one on the ground nearby. We repeated them (n.3 and n.4) adding a weight (1kg approximately) onto the Roomba. We then performed one measurement (n.5) with the two accelerometers on the sides.

Subsequently, we took three conical steel tips from one Trillium C20 seismometer and attached them with double side tape to the Roomba bottom. We repeated two of the previous measurements (n.1 and n.5) with this layout. These were measurements n.6 and n.7.



Left: accelerometers setup. Right: Roomba bottom with 3 steel conical tips attached.

Figure 3. Pictures of the setup in the EGO Electronics Lab.

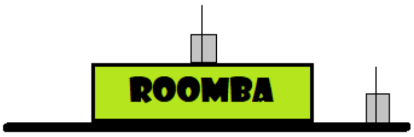
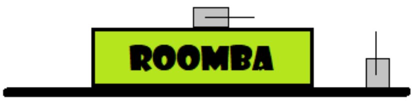
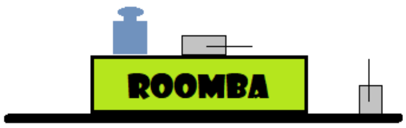
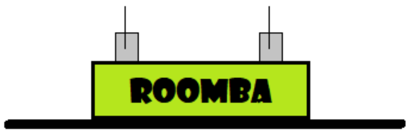
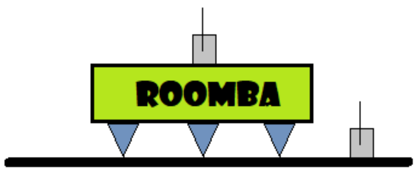
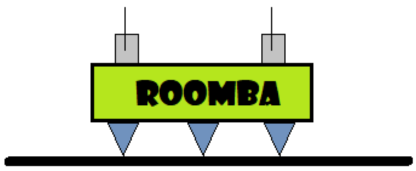
Configuration number	Description	Sketch drawing
1	One Vertical accelerometer on Roomba, one Vertical accelerometer on ground	
2	One Horizontal accelerometer on Roomba, one Vertical accelerometer on ground	
3	As n.1 but added extra weight (1kg) on the Roomba	
4	As n.2 but added extra weight (1kg) on the Roomba	
5	One Vertical accelerometer on Roomba left side, one Vertical accelerometer on Roomba right side.	
6	As n.1 but placing the Roomba onto 3 rigid tips	
7	As n.5 but placing the Roomba onto 3 rigid tips	

Table 1. Test setup configurations.

2.1 Results

The Roomba "as it is" has a sort of flat TF from 2Hz to 10Hz, the coherence however is not so good denoting a bad contact with soil. Note that below 2Hz the measurement is likely not reliable because of the limited performance of the accelerometers that we have used for this test. At 25Hz it appears the first resonance of the Roomba, and correspondently a loss of coherence (Figure 4). The same 25Hz is present also in the horizontal direction, where a 15Hz mode also appears (Figure 5).
Adding the weight does not improve significantly the coherence, although it moves the 25Hz frequency slightly down (24Hz) as expected (Figures 6 and 7).
When putting the two accelerometers at the opposite sides of the Roomba body we find a very clean 25Hz (Figure 8) which progressively disappears when moving both accelerometers closer to the centre

(not shown). This identifies the 25Hz as a roll mode of the structure around the axis passing through the two driving wheels (see Figure 3, right picture).

When the Roomba sits on the 3 tips (arranged in 120deg configuration) the vertical TF to ground improves significantly: the coherence is now larger and the transfer function is now flat between roughly 1Hz and 30Hz (Figure 9). The first mechanical mode is now at 60Hz (Figure 10). We verified, but not showing here, that this is a vertical mode of the body.

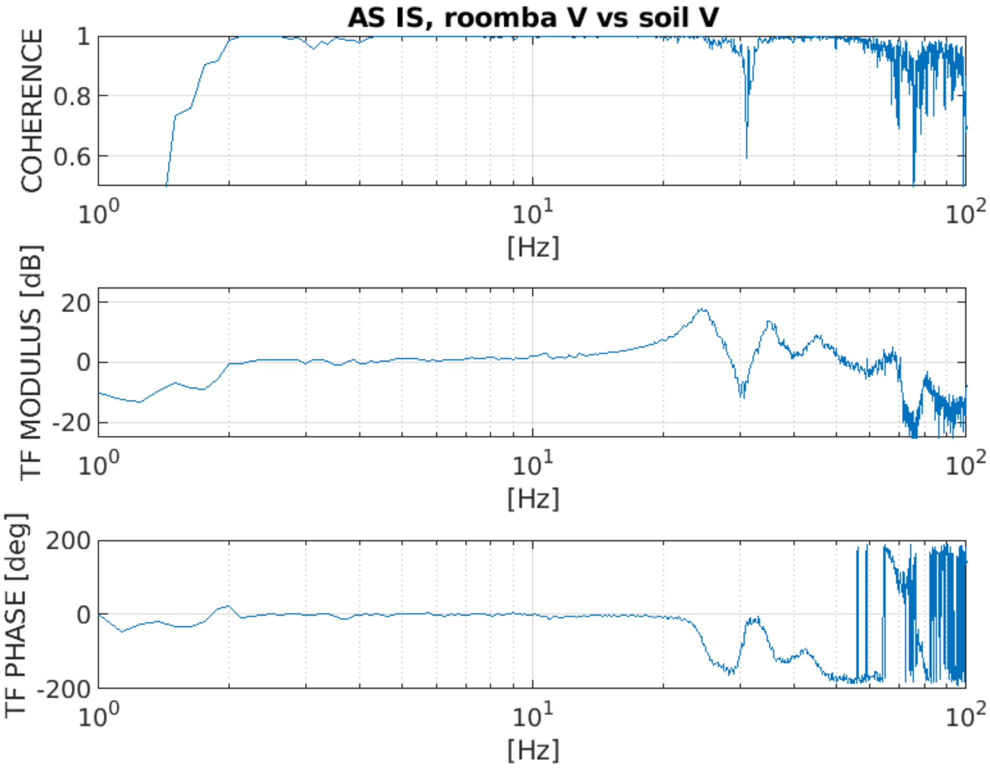


Figure 4. Two accelerometers in configuration n.1, (top) real part of coherence, (middle) modulus of the transfer function, (bottom) phase of the transfer function.

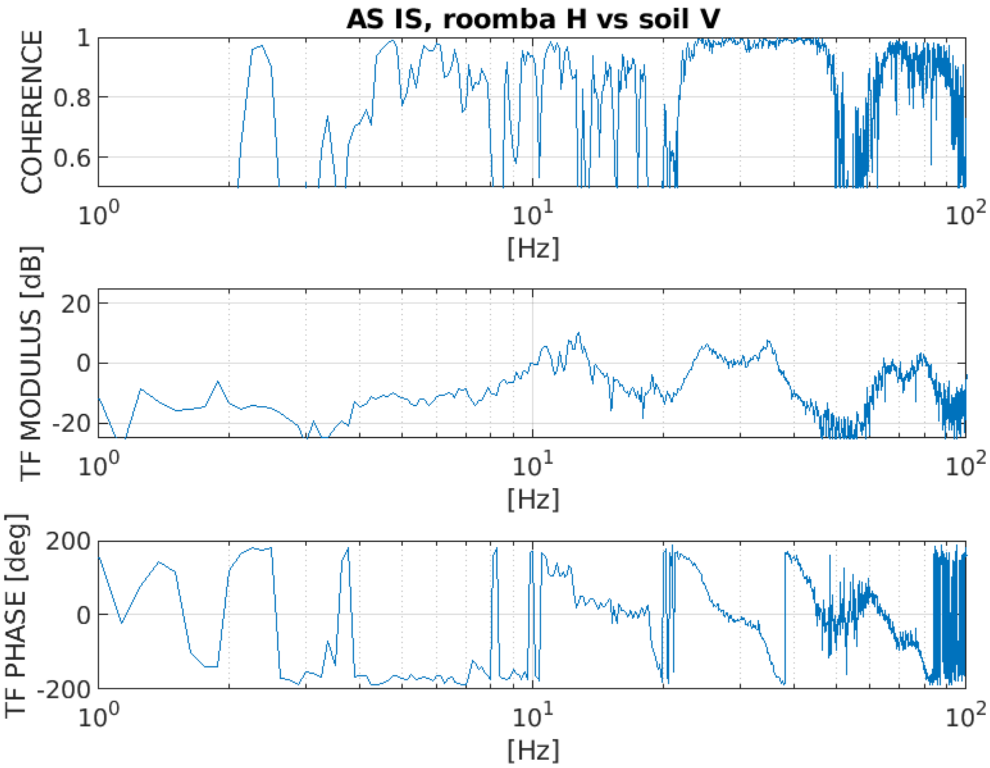


Figure 5. Two accelerometers in configuration n.2, (top) real part of coherence, (middle) modulus of the transfer function, (bottom) phase of the transfer function.

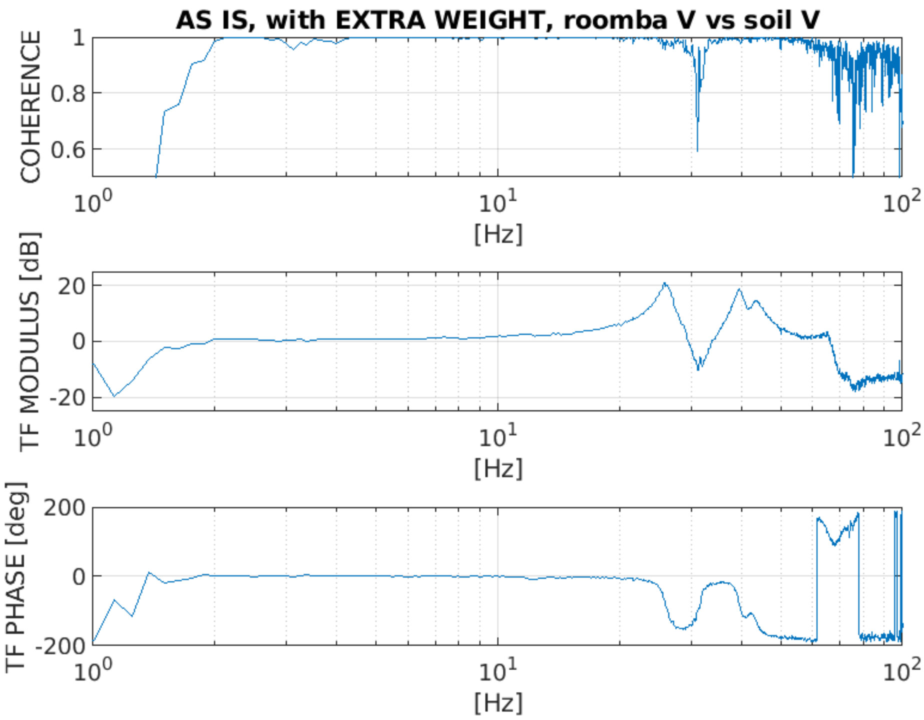


Figure 6. Two accelerometers in configuration n.3, (top) real part of coherence, (middle) modulus of the transfer function, (bottom) phase of the transfer function.

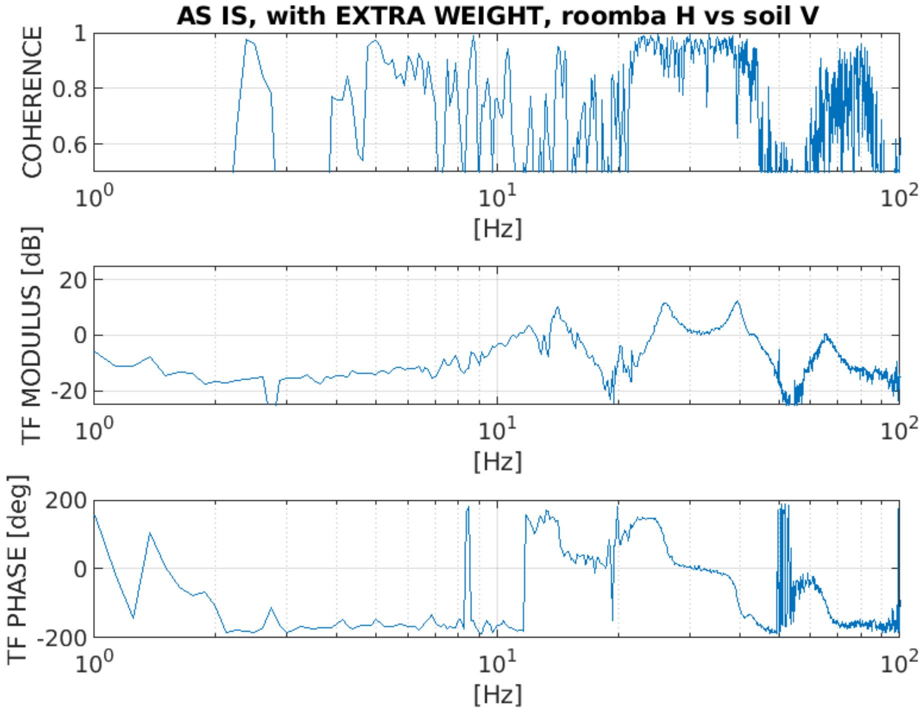


Figure 7. Two accelerometers in configuration n.4, (top) real part of coherence, (middle) modulus of the transfer function, (bottom) phase of the transfer function.

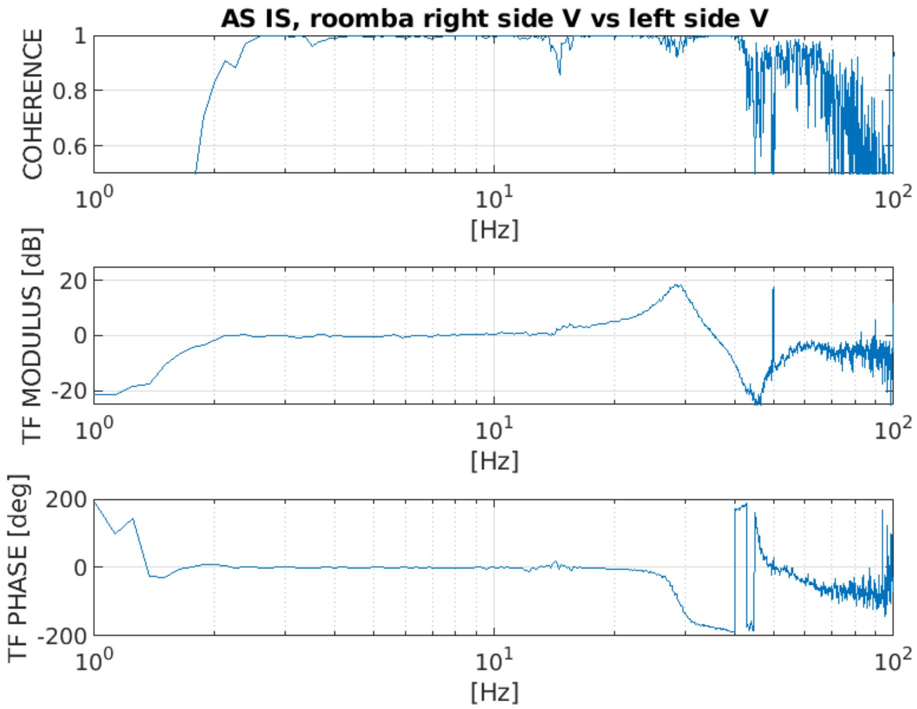


Figure 8. Two accelerometers in configuration n.5, (top) real part of coherence, (middle) modulus of the transfer function, (bottom) phase of the transfer function.

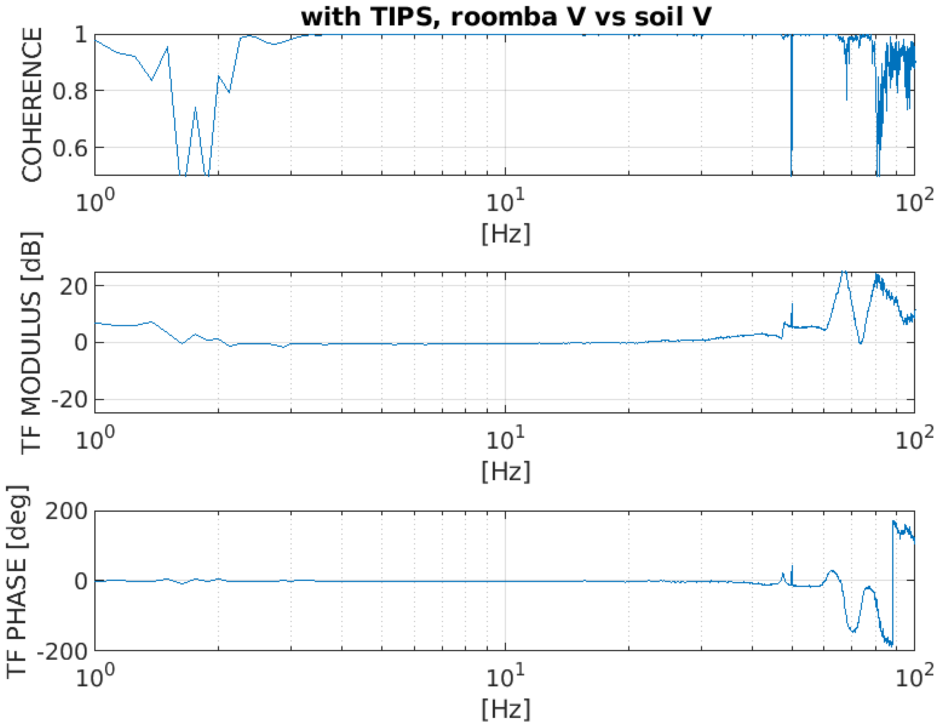


Figure 9. Two accelerometers in configuration n.6, (top) real part of coherence, (middle) modulus of the transfer function, (bottom) phase of the transfer function.

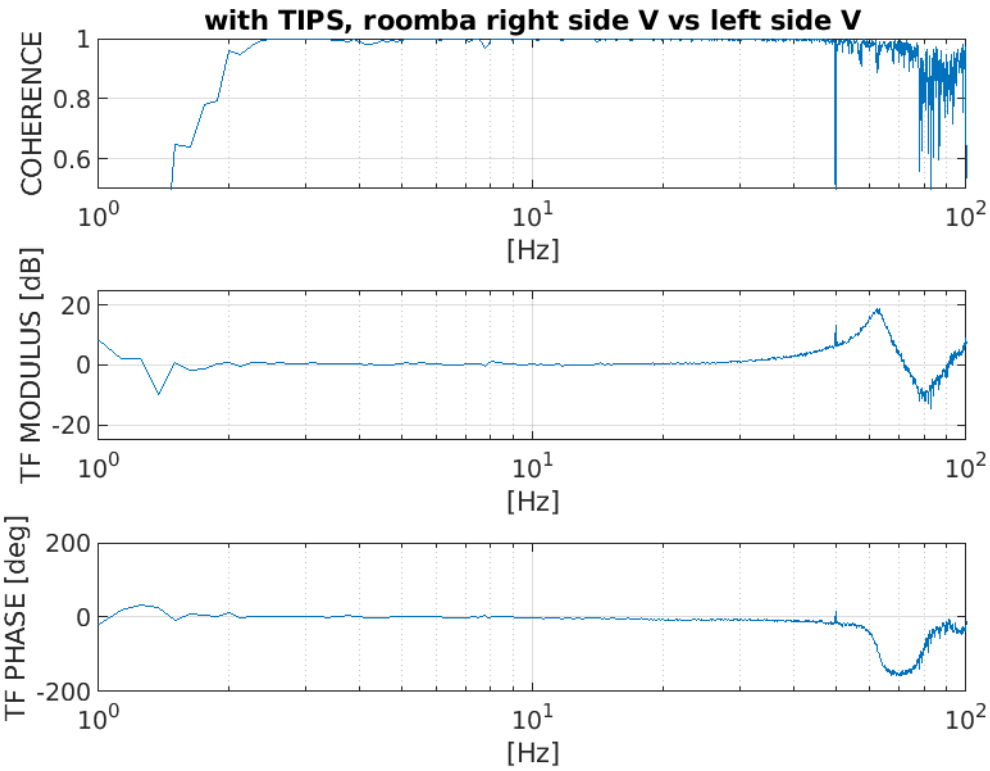


Figure 10. Two accelerometers in configuration n.7, (top) real part of coherence, (middle) modulus of the transfer function, (bottom) phase of the transfer function.

3. Conclusions

If we target Newtonian Noise cancellation, the Roomba "as it is" does not offer a good enough mechanical contact to the soil, as proven by the poor coherence and because of the presence of a first roll mode (25Hz) falling in the target frequency band for Newtonian Noise. Also, the simple action of adding extra weight (but not such to prevent the Roomba to lift up and move around) does not improve the contact with soil.

A simple way to realize a good contact is to make the support platform rest on 3 rigid conical tips. One possible solution is to realize a simple platform made of a rigid slab of Aluminium endowed with 3 steel tips (similar to the Trillium tips). A movable robotized wheeled cart would carry this platform and with its movable and retractile sort-of-arms gently deposit the platform on the soil on request. This will be object of future studies.

It is interesting for future studies that:

1. It exists a frequency band <10 Hz where the seismic noise measurements on the Roomba 'as it is' are coherent with those obtained by the same sensors fixed on the ground. This allows further experimentation on noise canceling and seismic noise characterization on a multisensory fusion robot network.
2. The 'good' frequency band on the Roomba "as it is" is not too far from what required by Newtonian Noise cancellation application (i.e. 10-50Hz). However, a similar platform designed ad hoc, with some tweaks like the three supporting pins, with no transversal compliance and improved k/m ratio would likely work.

The data collected so far will help the design of a dedicated mobile platform suitable for our purposes. We can expect that the new platform will not be significantly more complex or expensive than the Roomba.

References

[1] J Harms, Terrestrial Gravity Fluctuations, Living Reviews in Relativity, 2015

[2] Tomasz Bulik, presentation, Newtonian Noise Studies at Virgo, VIR-0491A-18

[3] Maria C. Tringali et al., Seismic array measurements at Virgo's West End Building for the configuration of a Newtonian-noise cancellation system, VIR-0505B-19, submitted for publication.

[4] Mark Beker et al, Innovation in seismic sensors driven by search for gravitational waves, The Leading Edge, 35(7), 590-593 (2016)