Kinematic deformation monitoring of bridge structures

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Introduction:

Geodesy science is obsessed with measurement of different objects using multiple approaches with variant goals. Since the measured objects can deform or move, we need to monitor this deformation for the safety of human life and also the object itself (if it's something built or important for the user).

For example we can control deformation of dam, bridges, buildings and natural features under different loads and so on. With monitoring the deformation of an object, it's behavior can be seen and predicted for a near future.

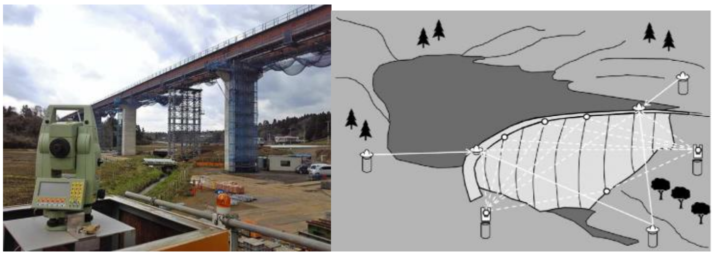

Figure 1: examples of deformation monitoring

(3d monitoring system-DAMSYS- www.keisokunet.com/details)

(on the integrity of deformation monitoring- P.J.G Teunissen, Safoora Zaminpardaz C.C.J.M. Tiberious)

Input of such process can be measurements of a geodetic block and maybe forces that are applied to the geodetic network of interest, the process of the input data consists of adjustment and stochastic calculations. The output could be a vector of deformation and its stochastic model.

The transportation infrastructure is quickly aging. Increases in traffic, in both urban and rural areas, puts more strain on the bridge networks than was originally intended. Bridge engineers need a reliable way to assess structural integrity of bridges to maintain the continuous operation of the road network while ensuring the safety of the public.

(Definition of bridge health monitoring - https://www.lrrb.org/pdf/200929.pdf)

Purpose:

Modeling the changes in dynamic behavior of the structure and calculating its model parameters using a method named SSICOV. From measurements of PCB ICP quartz accelerometers data, amplitude, frequency, phase shift and damping ration coefficients can be estimated. (Damping ratio coefficient was not estimated in this project).

Data acquisition and measurement setup:

The data needed for this purpose is provided by PCD ICB quartz accelerometers to get a reliable evaluation of vibration measurement system for civil structures. And the measurement has been done on mensa footbridge with the layout mentioned below. The reference accelerometer data which is used in this project has the sampling frequency of 2000. So for time saving purposes the data is resampled with the step of 21 and has the approximate frequency of 100Hz.

In this Method We used the least squares estimation (LSE) for adjustment. Fourier coefficients are used to calculate the amplitude and phase shift at different frequencies, and finally the shape of the eigenforms can be calculated (Figure2).

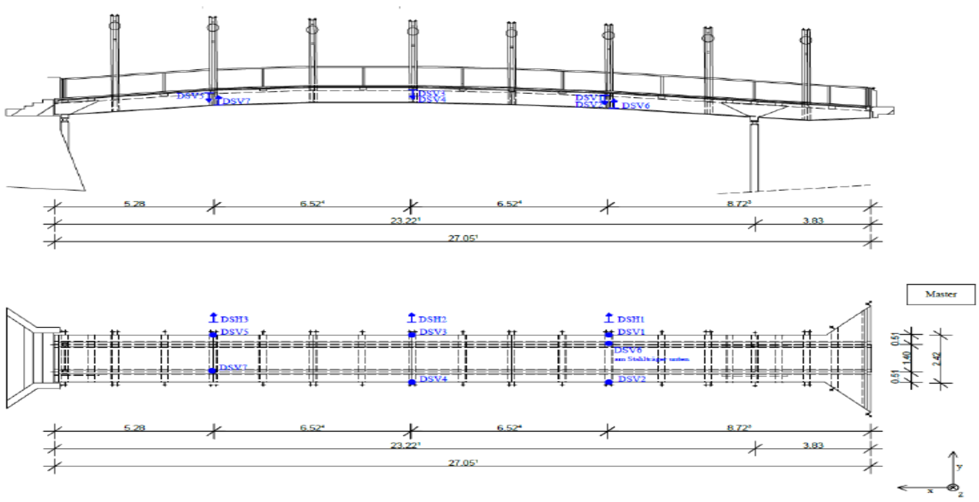

Figure 2: measurement setup on mensa footbridge

Leibniz University Hannover, Institut of Concrete Construction - www.ifma.uni-hannover.de

the SSI COV method was used to estimate the specific frequencies and damping coefficients. Then, using the above coefficients, the Fourier coefficients are calculated. There are various methods for calculating Fourier coefficients. For example, one method is to use FFT and base on FFT phase shift and amplitude can be calculated. (Figure3)

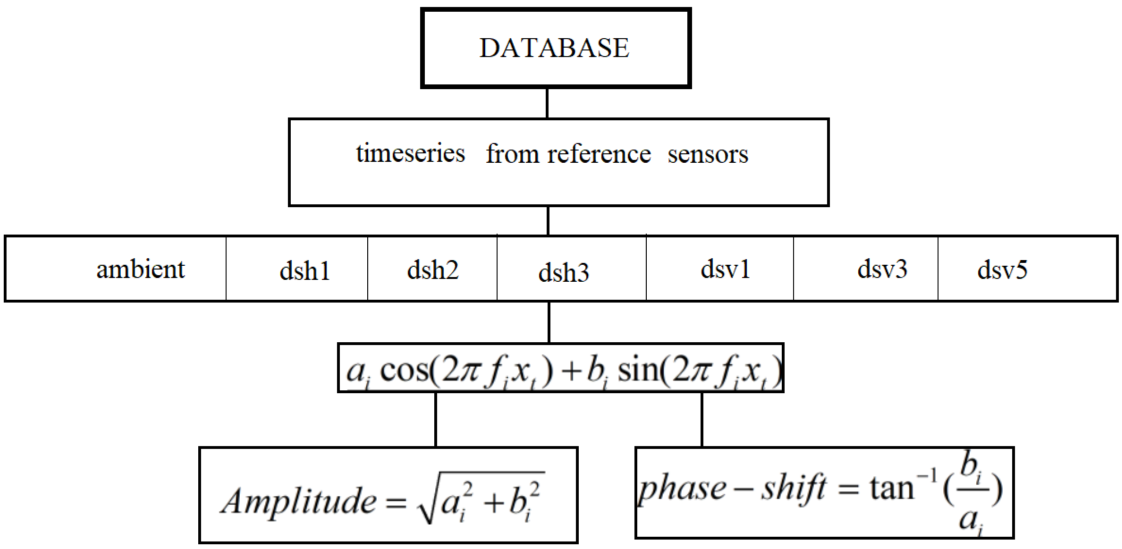

Figure 3: Process analysis

Welch Method

An improved estimator of the PSD is the one proposed by Welch. The method consists of dividing the time series data into (possibly overlapping) segments, computing a modified periodogram of each segment, and then averaging the PSD estimates. The result is Welch's PSD estimate. The toolbox function pwelch implements Welch's method. The averaging of modified periodograms tends to decrease the variance of the estimate relative to a single periodogram estimate of the entire data record. Although overlap between segments introduces redundant information, this effect is diminished by the use of a nonrectangular window, which reduces the importance or weight given to the end samples of segments (the samples that overlap). However, as mentioned above, the combined use of short data records and nonrectangular windows results in reduced resolution of the estimator. In summary, there is a tradeoff between variance reduction and resolution. One can manipulate the parameters in Welch's method to obtain improved estimates relative to the periodogram, especially when the SNR is low.

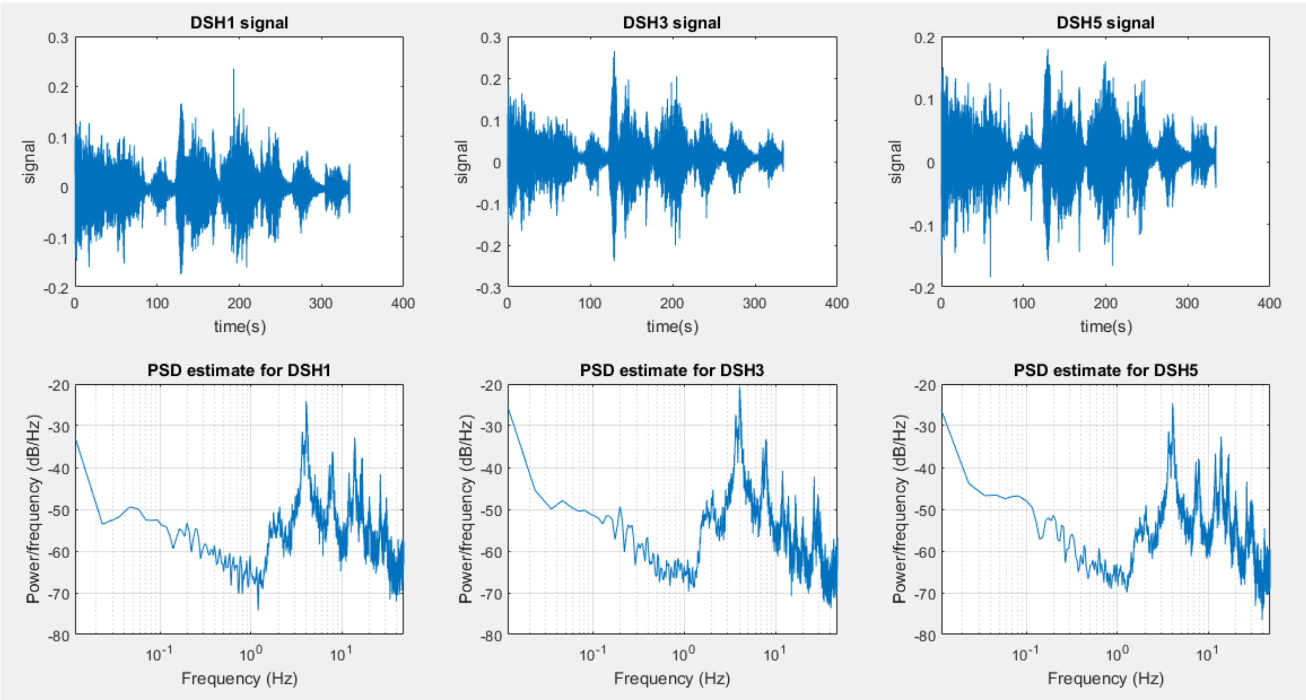

Figure 4: time series of the acceleration measurements (m/s ^2) recorded from three different sensors (up) and the PSD(welch) estimates of the acceleration measurements (down) for (ambient time series)

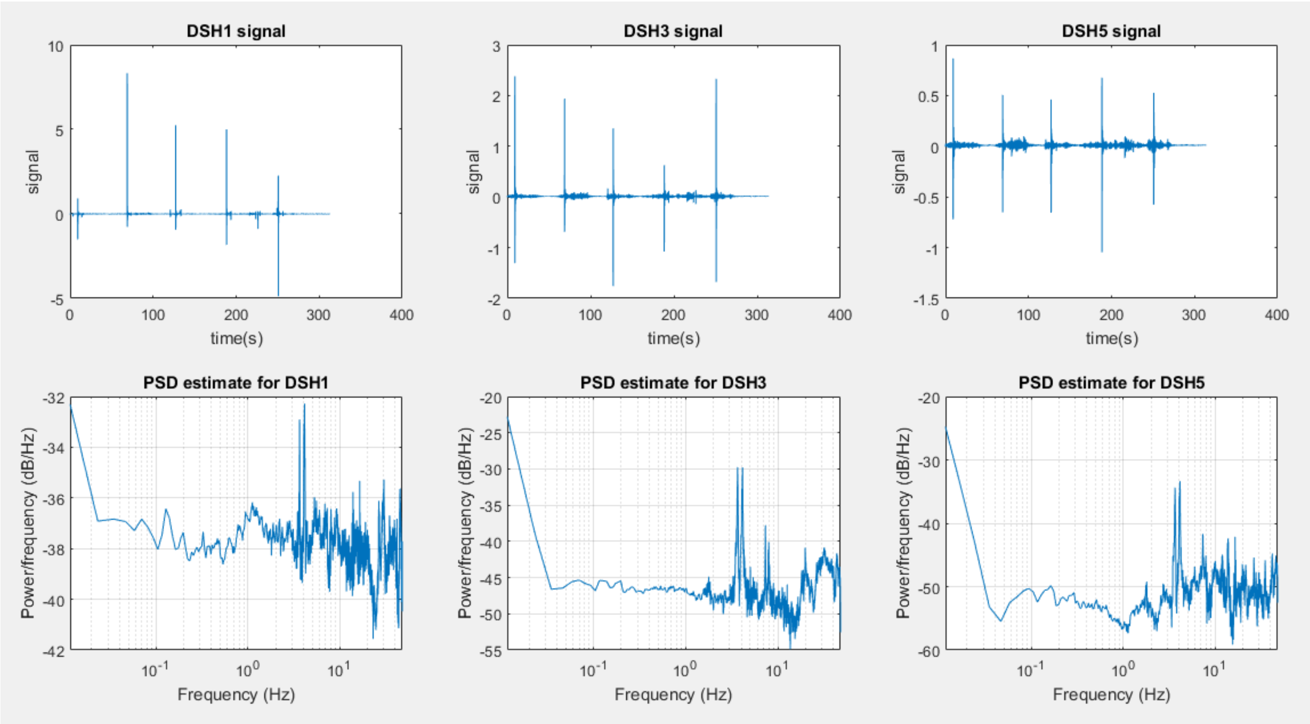

Figure 5: time series of the acceleration measurements (m/s ^2) recorded from three different sensors (up) and the PSD (welch)estimates of the acceleration measurements (down) for (dsh1 time series)

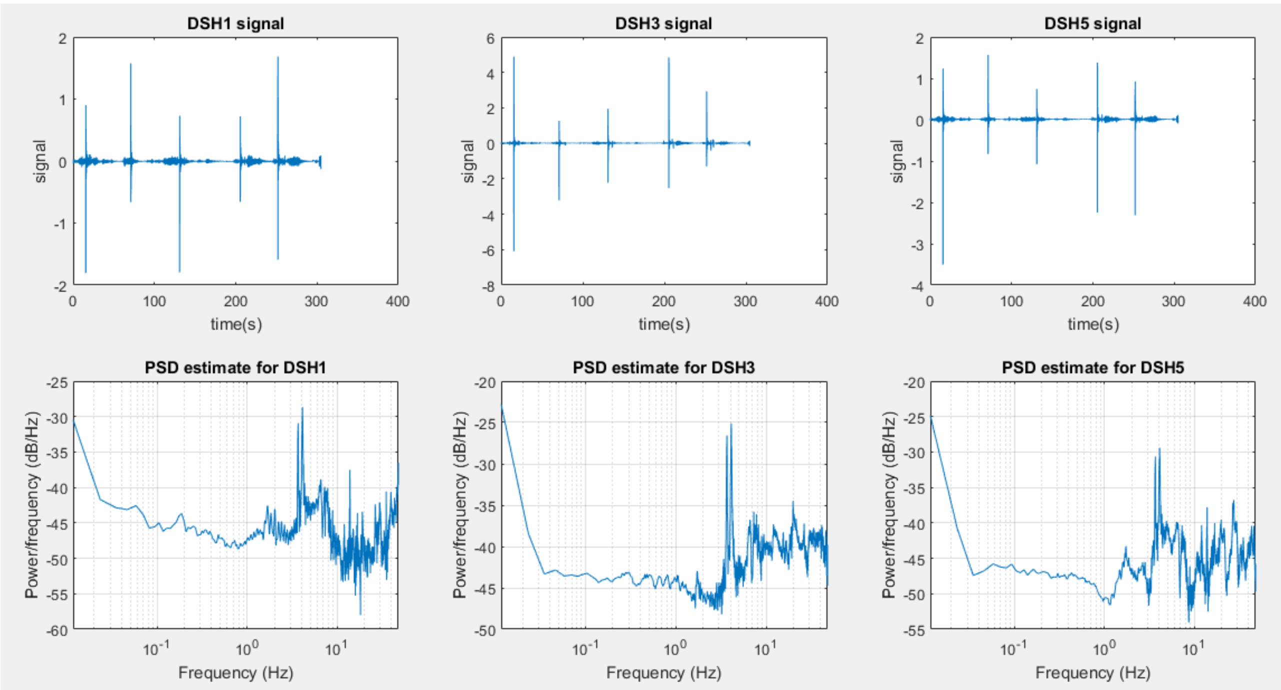

Figure6: time series of the acceleration measurements (m/s ^2) recorded from three different sensors (up) and the PSD(welch) estimates of the acceleration measurements (down) for (dsh2 time series)

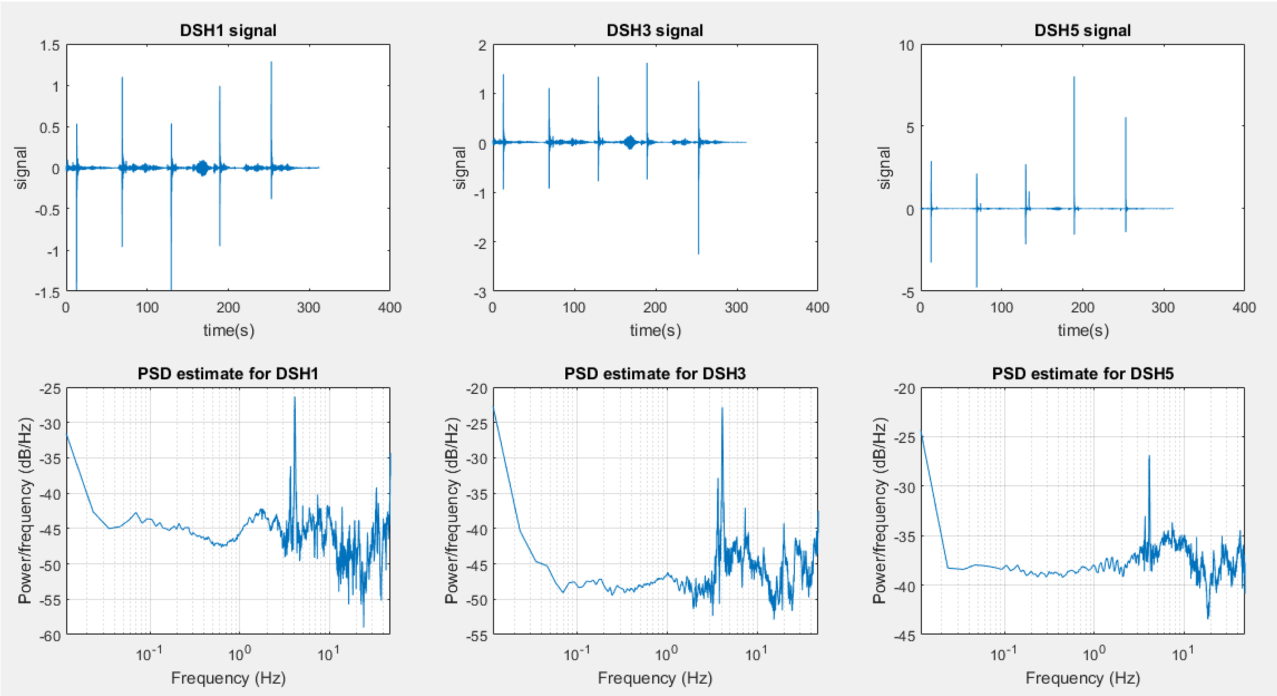

Figure 7: time series of the acceleration measurements (m/s ^2) recorded from three different sensors (up) and the PSD(welch) estimates of the acceleration measurements (down) for (dsh3 time series)

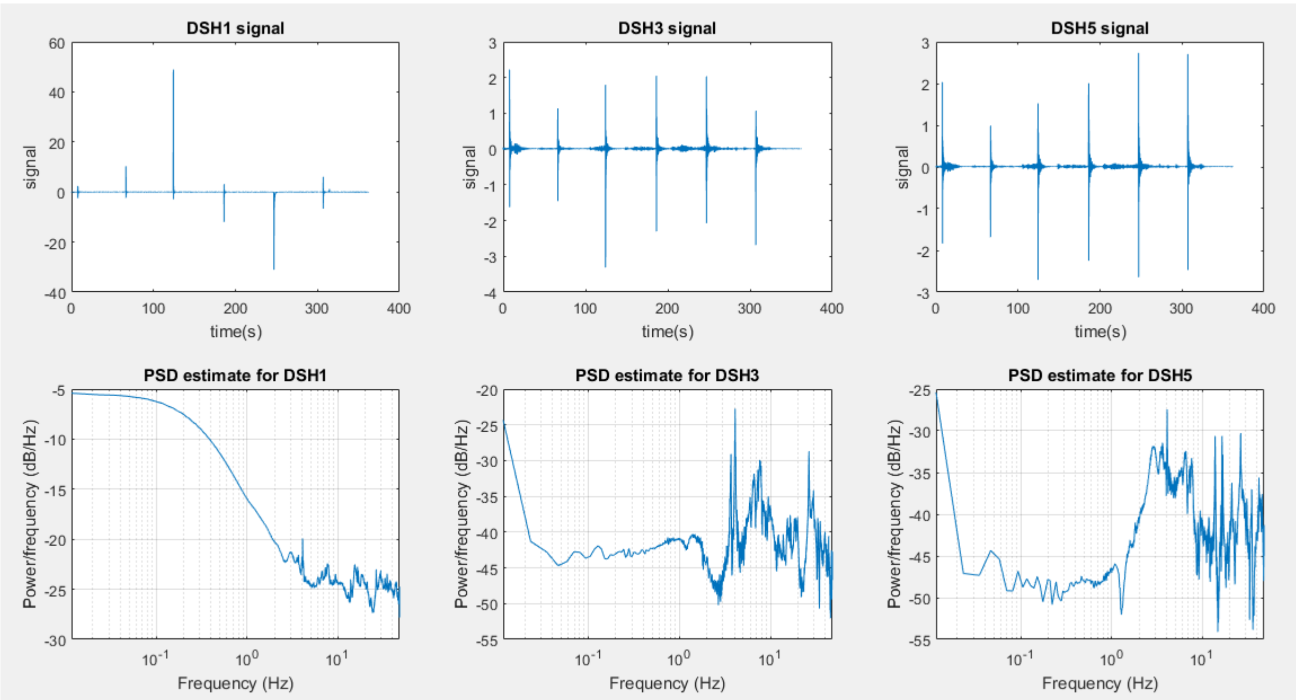

Figure 8: time series of the acceleration measurements (m/s ^2) recorded from three different sensors (up) and the PSD(welch) estimates of the acceleration measurements (down) for (dsv1 time series)

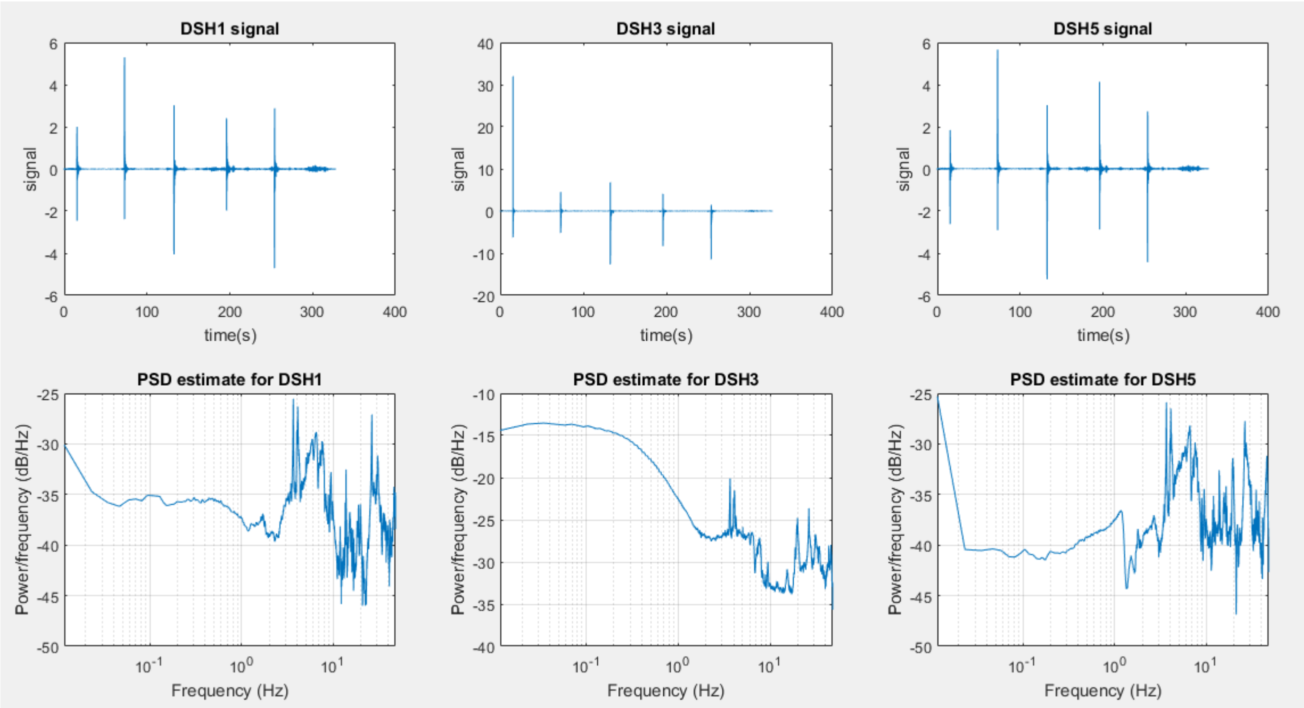

Figure 9: time series of the acceleration measurements (m/s ^2) recorded from three different sensors (up) and the PSD(welch) estimates of the acceleration measurements (down) for (dsv 3time series)

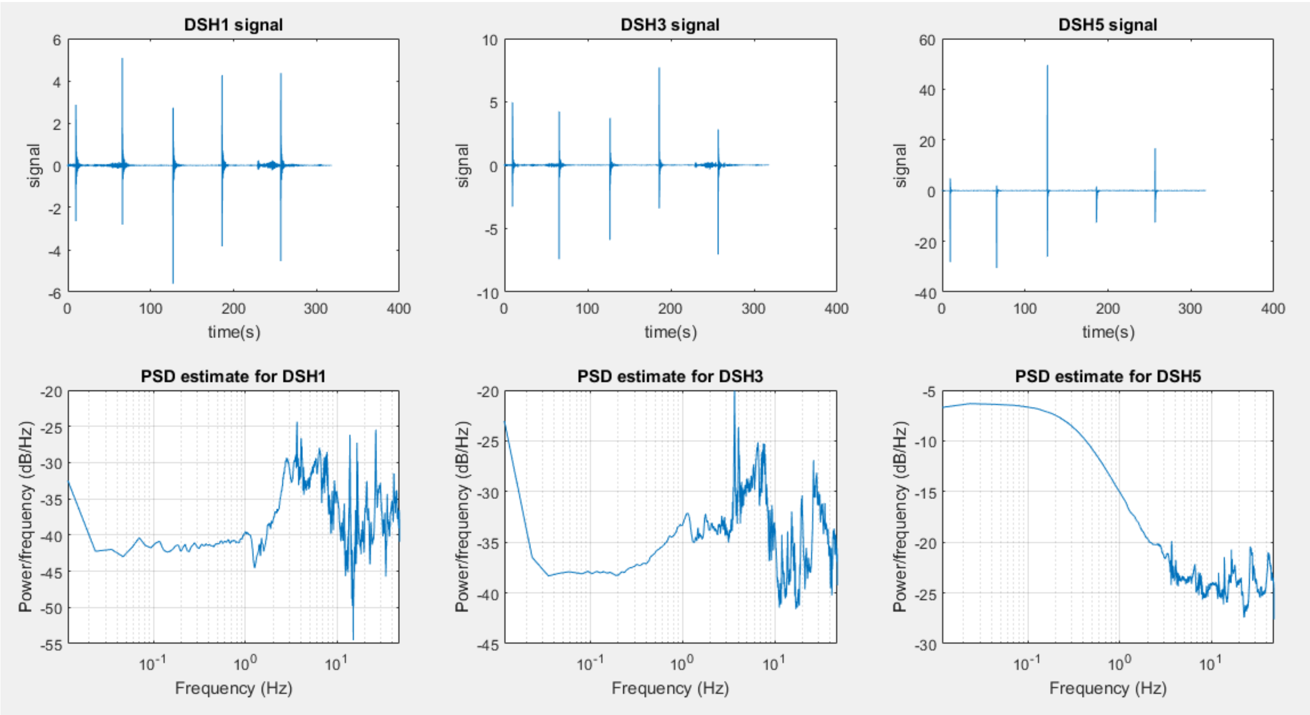

Figure 10: time series of the acceleration measurements (m/s ^2) recorded from three different sensors (up) and the PSD(welch) estimates of the acceleration measurements (down) for (dsv5 time series)

results related to eigenfrequencies and damping rates are calculated by SSICOV method and their result according to different time series data in different sensors follows table (1).

Parameterization of SSICOV: Ts=20, Nmin =2, Nmax =50

Tabel1: Detectable eigenfrequencies $f\,(Hz)$ and damping ratio coefficient $\xi(\%)$ for different time series(ambient,dsh1,dsh2,dsh3,dsv1,dsv3,dsv5)

$f_{ambient}$	**3.6677**	**3.8967**	**4.0762**	**4.211**	**7.2378**	**7.3831**	**7.88328**	**11.9962**	**13.62**	**16.74**
$\xi_{ambient}(\%)$	0.9303	1.1070	0.0138	0.9114	0.2111	0.2957	0.4010	0.8185	0.105	0.1338
f_{dsh1}	**3.65**	**4.1**	**12.8**	**45.7**	**45.9**	**57.74**	-	-	-	-
$\xi_{dsh1}(\%)$	0.7	0.6	11.5	3.9	5.3	-	-	-	-	-
f_{dsh2}	**4.09**	**4.100**	**30.78**	**31.35**	-	-	-	-	-	-
$\xi_{dsh2}(\%)$	0.7	0.5	8.02	0.49	-	-	-	-	-	-
f_{dsh3}	**4.09**	**47.5**	**57.92**	**58.59**	-	-	-	-	-	-
$\xi_{dsh3}(\%)$	0.6	0.9	2.20	2.54	-	-	-	-	-	-
f_{dsv1}	**3.67**	**4.08**	**26.32**	**35.10**	-	-	-	-	-	-
$\xi_{dsv1}(\%)$	0.58	0.68	0.71	1.61	-	-	-	-	-	-
f_{dsv3}	**3.65**	**3.66**	**4.13**	**26.31**	**57.63**	-	-	-	-	-
$\xi_{dsv3}(\%)$	0.44	0.44	0.59	0.64	0.74	-	-	-	-	-
f_{dsv5}	**3.66**	**4.07**	**16.43**	**26.26**	**31.49**	-	-	-	-	-
$\xi_{dsv5}(\%)$	0.55	1.07	0.45	0.64	3.00	-	-	-	-	-

Table 2: estimate **amplitude** for **ambient** data in different eigenfrequency

Amplitude-ambient	**Dsv1**	**Dsv2**	**Dsv3**
Eigenfrequence1	0.0010	0.0016	0.0010
Eigenfrequence2	0.0004	0.0006	0.0004
Eigenfrequence3	0.0011	0.0016	0.0010
Eigenfrequence4	0.0018	0.0026	0.0016
Eigenfrequence5	0.0024	0.0022	0.0014
Eigenfrequence6	0.0016	0.0038	0.0025
Eigenfrequence7	0.0017	0.0028	0.0020
Eigenfrequence8	0.0025	0.0025	0.0014
Eigenfrequence9	0.0030	0.0033	0.0019
Eigenfrequence10	-0.0034	0.0038	0.0022
Eigenfrequence11	-0.0073	0.0036	0.0061
Eigenfrequence12	-0.0049	0.0020	0.0079
Eigenfrequence13	-0.0065	0.0010	0.0048
Eigenfrequence14	-0.0084	-0.0013	0.0061

Table3: estimate **amplitude** for **pos-dsh1** data in different eigenfrequency

Amplitude pos-dsh1	Dsv1	Dsv3	Dsv5
Eigenfrequence1	0.0015	0.0021	0.0013
Eigenfrequence2	0.0010	0.0004	0.0002
Eigenfrequence3	0.0008	0.0017	0.0011
Eigenfrequence4	0.0032	0.0023	0.0018
Eigenfrequence5	0.0027	0.0021	0.0017
Eigenfrequence6	-0.1411	-0.0069	0.0495

Table 4: estimate **amplitude** for **pos-dsh2** data in different eigenfrequency

Amplitude pos-dsh2	Dsv1	Dsv3	Dsv5
Eigenfrequence1	0.0007	0.0014	0.0009
Eigenfrequence2	0.0024	0.0018	0.0024
Eigenfrequence3	0.0314	0.0856	0.0236
Eigenfrequence4	0.0280	0.0826	0.0216

Table5: estimate **amplitude** for **pos-dsh3** data in different eigenfrequency

Amplitude pos- dsh3	Dsv1	Dsv3	Dsv5
Eigenfrequence1	0.0020	0.0029	0.0018
Eigenfrequence2	0.0576	0.0431	0.0478
Eigenfrequence3	0.0444	0.1123	0.1443
Eigenfrequence4	0.0346	0.0398	0.0353

Table 6: estimate **amplitude** for **pos-dsv1** data in different eigenfrequency

Amplitude pos-dsv1	Dsv1	Dsv3	Dsv5
Eigenfrequence1	0.0032	0.0015	0.0008
Eigenfrequence2	0.0028	0.0024	0.0016
Eigenfrequence3	0.0626	0.0029	0.0182
Eigenfrequence4	0.1878	0.0179	0.0385

Table7: estimate **amplitude** for **pos-dsv3** data in different eigenfrequency

Amplitude pos-dsv3	Dsv1	Dsv3	Dsv5
Eigenfrequence1	0.0022	0.0044	0.0022
Eigenfrequence2	0.0022	0.0023	0.0019
Eigenfrequence3	0.0015	0.0019	0.0009
Eigenfrequence4	0.1406	0.1008	0.1175
Eigenfrequence5	-0.0560	0.1333	0.0525
Eigenfrequence6	-0.0971	0.3708	0.1397

Table 8: estimate **amplitude** for **pos-dsv5** data in different eigenfrequency

Amplitude pos-dsv5	Dsv1	Dsv3	Dsv5
Eigenfrequence1	0.0040	0.0067	0.0042

Eigenfrequence2	0.0020	0.0026	0.0048
Eigenfrequence3	0.0199	0.0103	0.0380
Eigenfrequence4	-0.1496	0.1431	0.1480
Eigenfrequence5	-0.0337	0.0795	0.1652

Table9: estimate **Phase shift** for **ambient data** in different eigenfrequency

Phase shift ambient	Dsv1	Dsv3	Dsv5
Eigenfrequence1	-32.5454	-27.9450	-28.9264
Eigenfrequence2	80.5076	82.6127	82.8768
Eigenfrequence3	86.5747	87.1749	85.1741
Eigenfrequence4	18.1245	19.2239	17.5783
Eigenfrequence5	-62.3059	-70.7315	-75.7511
Eigenfrequence6	-1.1280	-6.9623	-17.4087
Eigenfrequence7	-80.7002	-77.9117	-74.5845
Eigenfrequence8	-89.6628	-89.7277	-89.8156
Eigenfrequence9	-87.0870	54.2651	-50.8268
Eigenfrequence10	16.8805	54.2651	21.7782
Eigenfrequence11	-14.6072	-28.4349	-14.6185
Eigenfrequence12	-43.0243	-46.2348	-42.2573
Eigenfrequence13	-0.6040	-10.6300	-6.0303
Eigenfrequence14	-44.5447	-55.1299	-44.2650

Table 10: estimate **Phase shift** for **pos-dsh1 data** in different eigenfrequency

Phase shift pos-dsh1	Dsv1	Dsv3	Dsv5
Eigenfrequence1	5.6925	7.5181	3.4839
Eigenfrequence2	-50.9309	-52.5298	-53.9776
Eigenfrequence3	-13.0790	-19.1786	-39.2167
Eigenfrequence4	-75.6851	-82.8961	88.1941
Eigenfrequence5	55.2242	25.8647	-3.0710
Eigenfrequence6	-81.7047	-82.4824	41.4685

Table 11: estimate **Phase shift** for **pos-dsh2 data** in different eigenfrequency

Phase shift pos-dsh2	Dsv1	Dsv3	Dsv5
Eigenfrequence1	-80.4930	85.6156	-89.8689
Eigenfrequence2	69.6465	67.8787	69.3290
Eigenfrequence3	66.0372	68.6449	48.8442
Eigenfrequence4	-72.8781	-52.3534	-87.3933

Table 12: estimate **Phase shift** for **pos-dsh3** data in different eigenfrequency

Phase shift pos- dsh3	Dsv1	Dsv3	Dsv5
Eigenfrequence1	50.0615	43.4920	59.7654
Eigenfrequence2	-3.5911	-6.7630	-6.9973
Eigenfrequence3	-11.8931	86.4433	84.0882
Eigenfrequence4	78.6787	-5.5869	-26.0415

Table 13: estimate **Phase shift** for **pos-dsv1** data in different eigenfrequency

Phase shift pos-dsv1	Dsv1	Dsv3	Dsv5
Eigenfrequence1	65.2538	35.7971	33.4806
Eigenfrequence2	-52.6103	-21.8574	-11.2550
Eigenfrequence3	39.2093	65.4704	-88.3690
Eigenfrequence4	33.9924	-78.0464	38.9703

Table14: estimate **Phase shift** for **pos-dsv3** data in different eigenfrequency

Phase shift pos-dsv3	Dsv1	Dsv3	Dsv5
Eigenfrequence1	27.7492	-44.8189	-22.5025
Eigenfrequence2	37.1137	81.7973	38.7349
Eigenfrequence3	-67.005	-67.005	-56.3618
Eigenfrequence4	-78.6794	-10.4132	-69.6578
Eigenfrequence5	-86.9219	-10.7068	80.0954
Eigenfrequence6	-64.9297	-83.8487	-64.3497

Table2. 1: estimate **Phase shift** for **pos-dsv5** data in different eigenfrequency

Phase shift pos-dsv5	Dsv1	Dsv3	Dsv5
Eigenfrequence1	-1.9126	2.3691	-18.7772
Eigenfrequence2	-16.5252	-19.8382	-26.4424
Eigenfrequence3	5.0109	53.4140	25.6915
Eigenfrequence4	-52.8515	60.6097	31.1283
Eigenfrequence5	-20.4194	1.2347	-32.9982

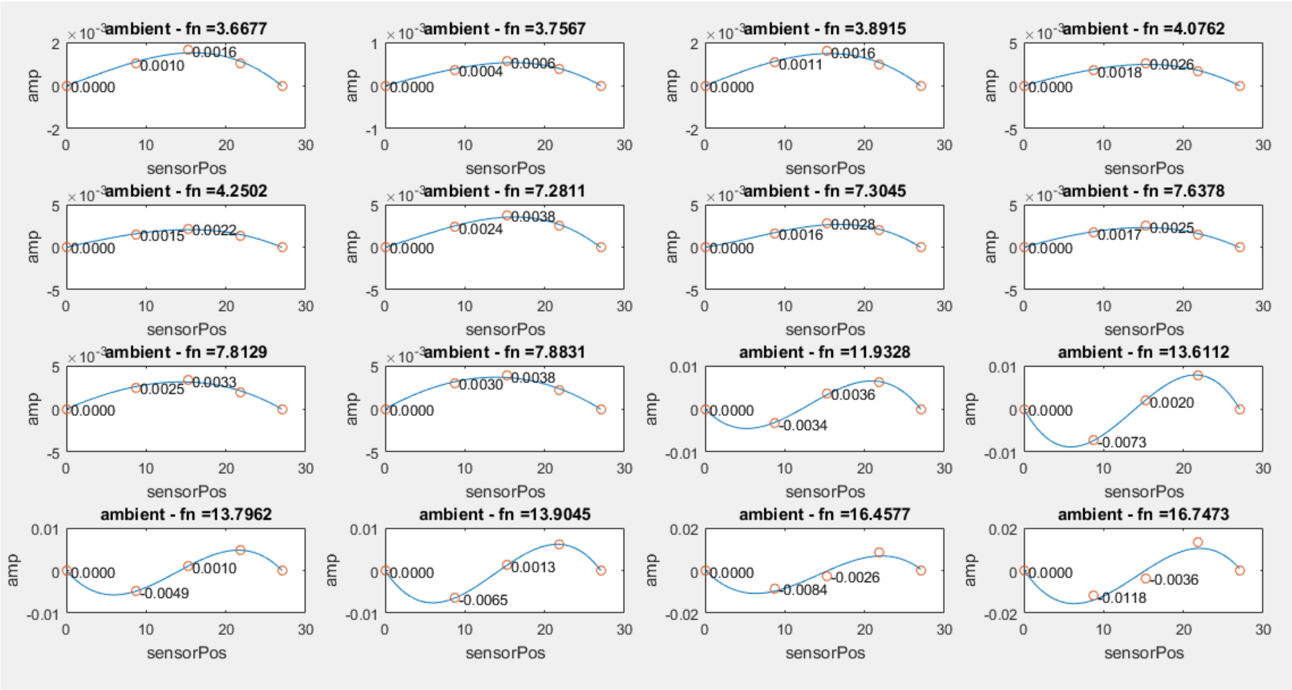

Figure 11: eigenforms calculated for different eigenfrequencies (**ambient** time series). The texts for each eigenform represent estimated amplitude

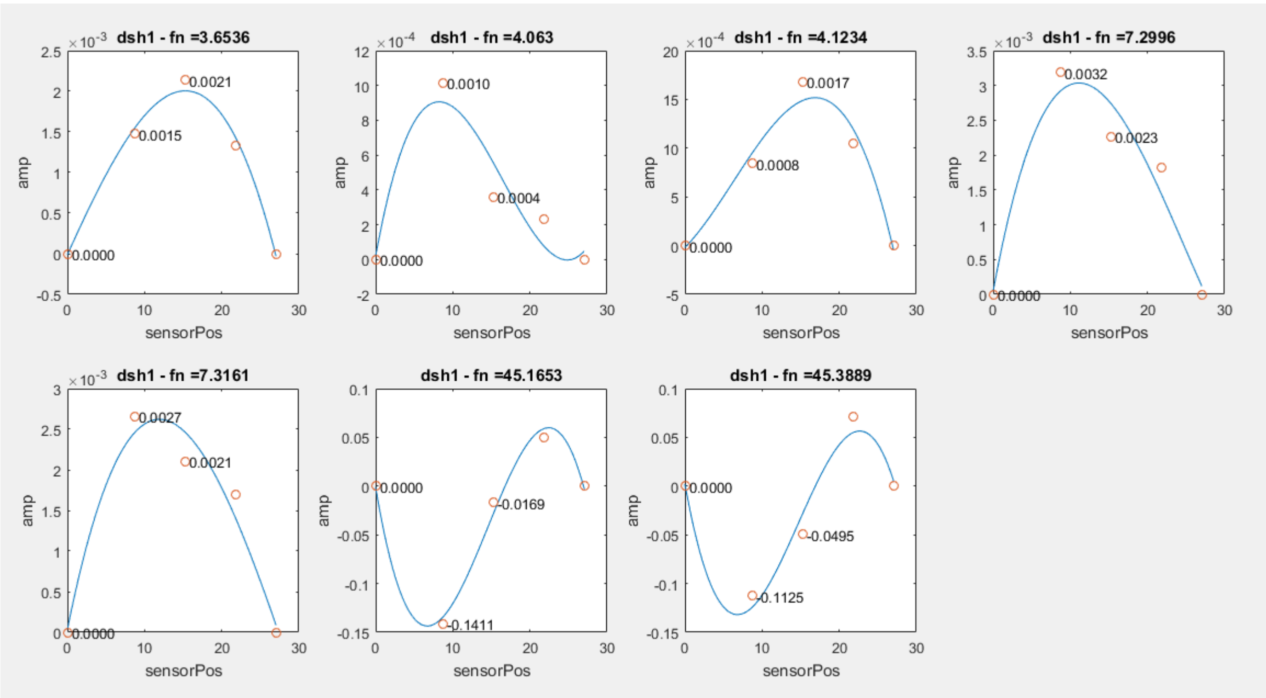

Figure 12: eigenforms calculated for different eigenfrequencies (**dsh1** time series). The texts for each eigenform represent estimated amplitude

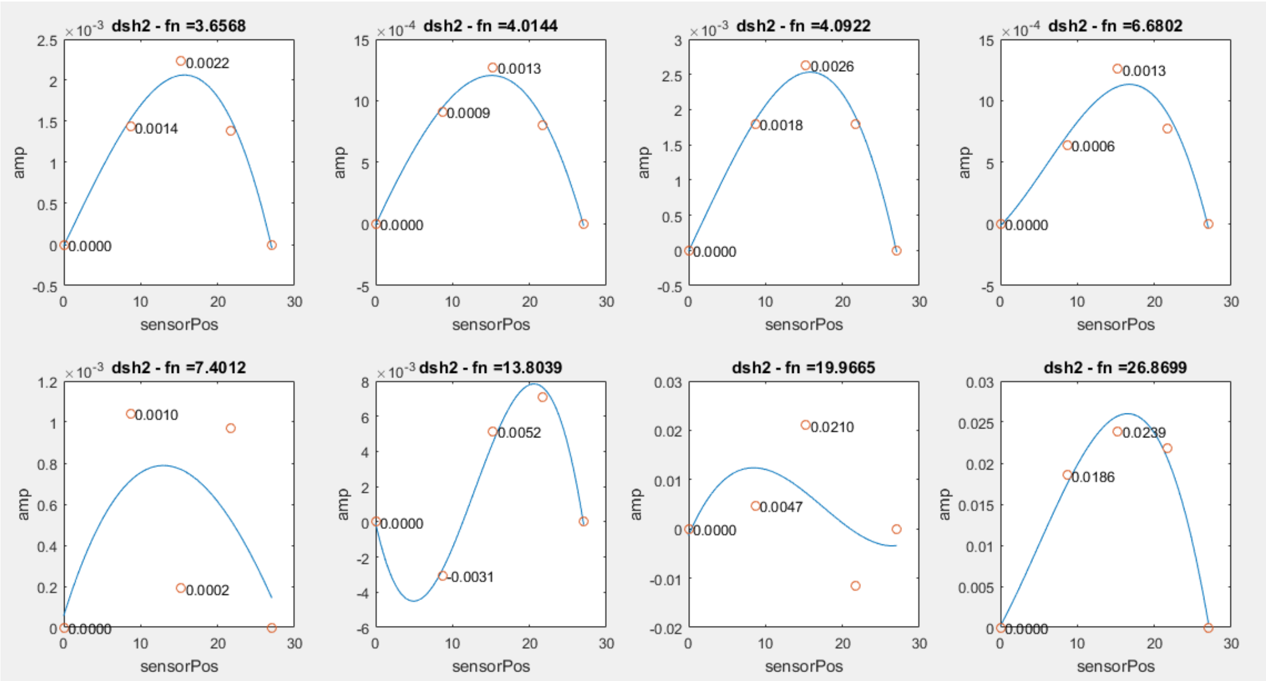

Figure 13: eigenforms calculated for different eigenfrequencies (**dsh2** time series). The texts for each eigenform represent estimated amplitude

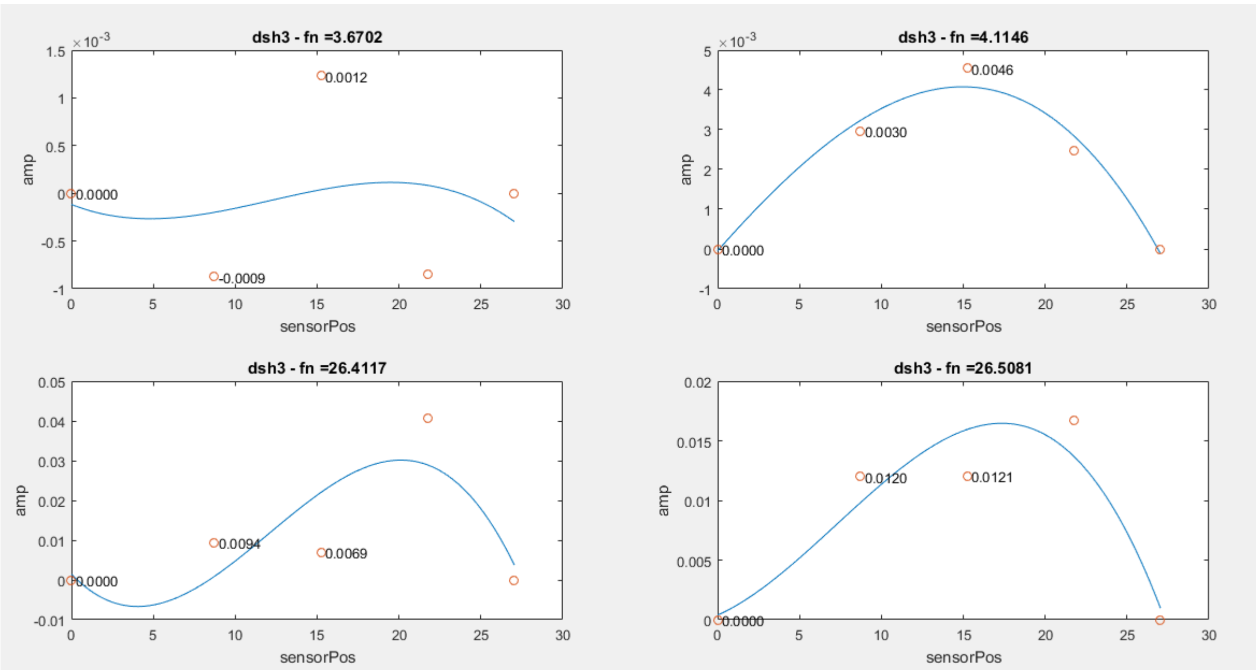

Figure 14: eigenforms calculated for different eigenfrequencies (**dsh3** time series). The texts for each eigenform represent estimated amplitude

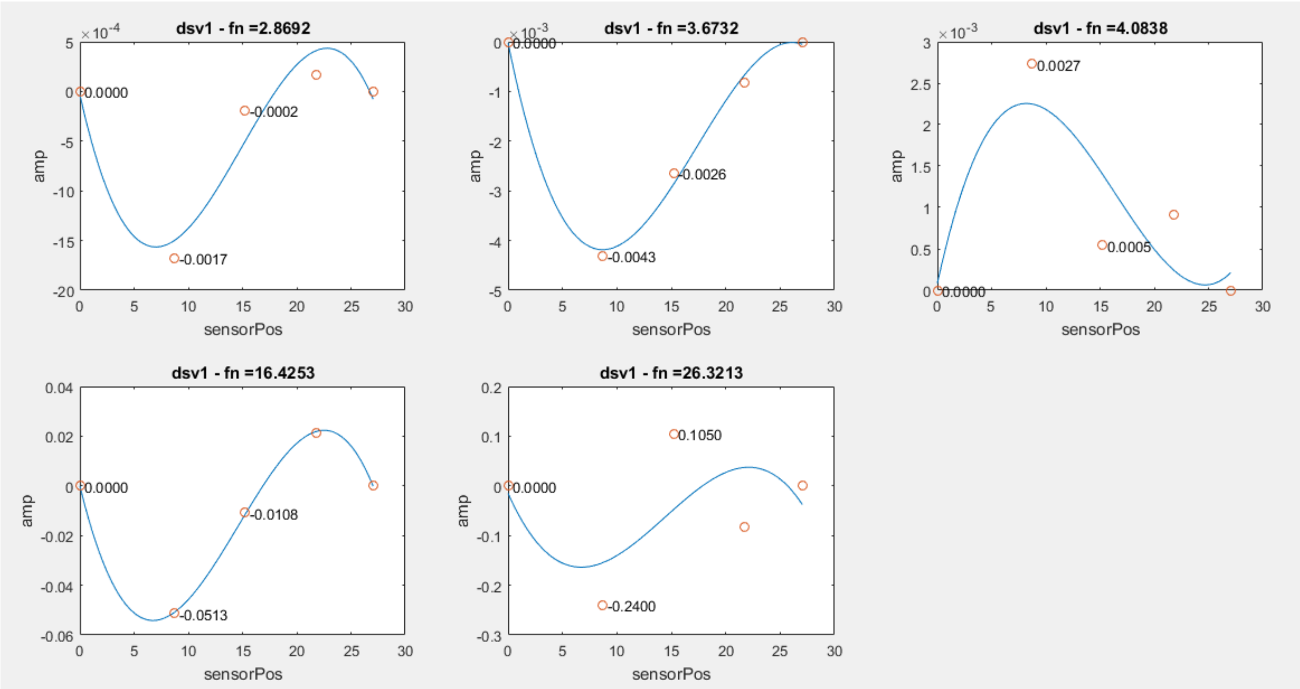

Figure 15: eigenforms calculated for different eigenfrequencies (**dsv1** time series). The texts for each eigenform represent estimated amplitude.

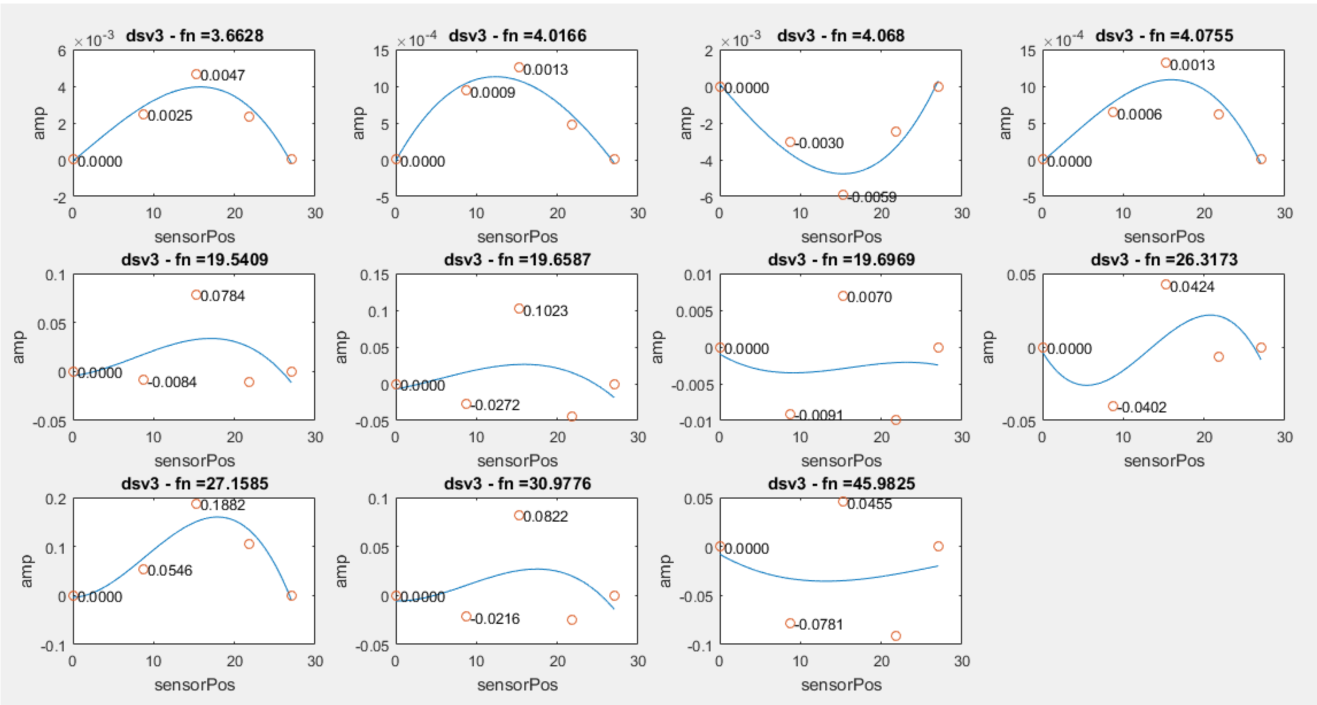

Figure 16: eigenforms calculated for different eigenfrequencies (**dsv3** time series). The texts for each eigenform represent estimated amplitude.

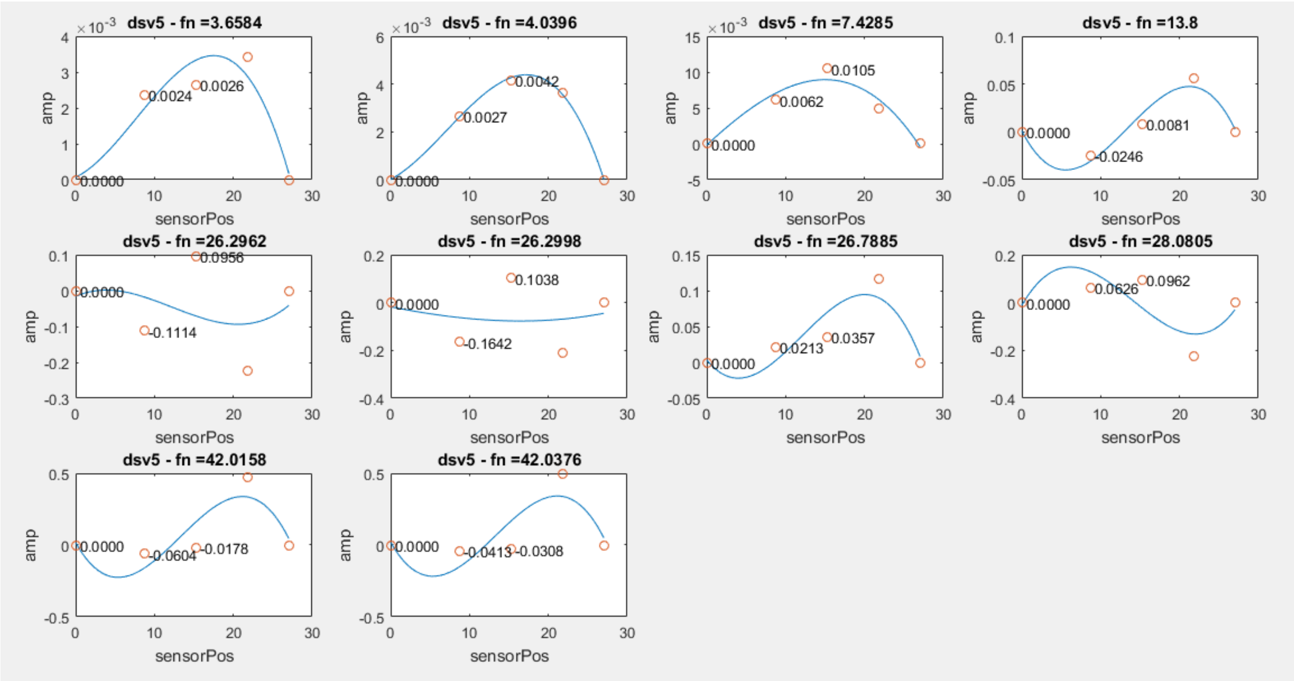

Figure 17: eigenforms calculated for different eigenfrequencies (**dsv5** time series). The texts for each eigenform represent estimated amplitude