Data set from long-term wave, wind and response monitoring of the Bergsøysund Bridge

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Abstract

Wind, wave, displacement and acceleration data have been collected in a measurement campaign on the Bergsøysund Bridge between the years 2014 and 2018. The data set is now available in an open-access research entry published on Zenodo, for free access and download. The data is collected in two h5-files (hierachical data format), with sampling rates 2 Hz and 10 Hz, downsampled from the raw sampling rate of 200 Hz. Note that the data has undergone some minimal signal processing and adjustment, in line with that applied to the Hardanger Bridge data described in [1]. Some examples of how to import and browse through the data using a openly available Python package are also given.

1 Introduction

Experimental data of large bridges are often collected as part of structural health monitoring. The data is not very commonly made publicly available, even though it may have large potential for use in numerous scientific applications. Consequently, the structural measurement data of these structures are in high demand.

This paper describes the openly available database resulting from the monitoring of the Bergsøysund Bridge in Norway. We recently also published a similar dataset obtained from the monitoring of the Hardanger Bridge [1]. As part of the Coastal Highway E39 project led by the Norwegian Public Roads Administration (NPRA), where floating bridges are considered as viable solutions for many of the crossings to replace the current ferry connections, several aspects of the floating Bergsøysund Bridge have been studied in the last decade [2, 3, 4, 5, 3, 6, 7, 8, 9, 10]. A crucial part of the studies has been the collection and analysis of experimental data on the environmental actions on and structural response of the bridge. Consequently, a large amount of data have been gathered during the measurement campaign. This data is now made available for open access on the online repository Zenodo [11], and the current paper describes the major aspects of the data set. This includes descriptions of the data hierarchy, metadata, monitoring system, and examples for import and retrieval of the data.

2 Site description

The Bergsøysund Bridge, shown in Figure 1, is located on the western coast of Norway and opened for traffic in 1992. The geographic location of the bridge is depicted in Figure 2. At the time of opening, it was the longest floating bridge without side-anchoring in the World. It is still a unique structure, and its simple and symmetric geometry makes it an ideal case study for measurement campaigns, with potential of large transferable value to other floating bridges. The Norwegian west coast is also typically exposed to harsh winds and waves. It stretches 930 meters in total, with

Figure 1. Photograph of the Bergsøysund Bridge. Photo: NTNU/K.A. Kvåle.

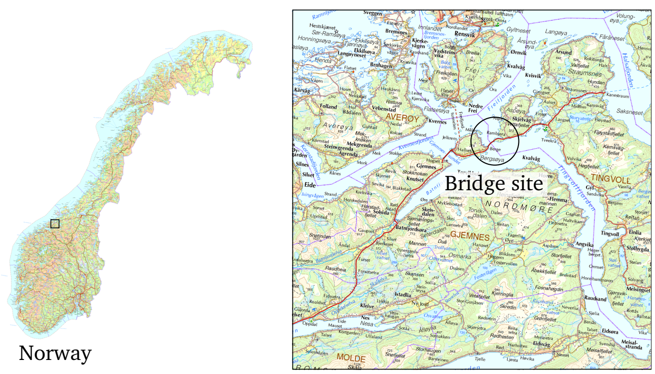
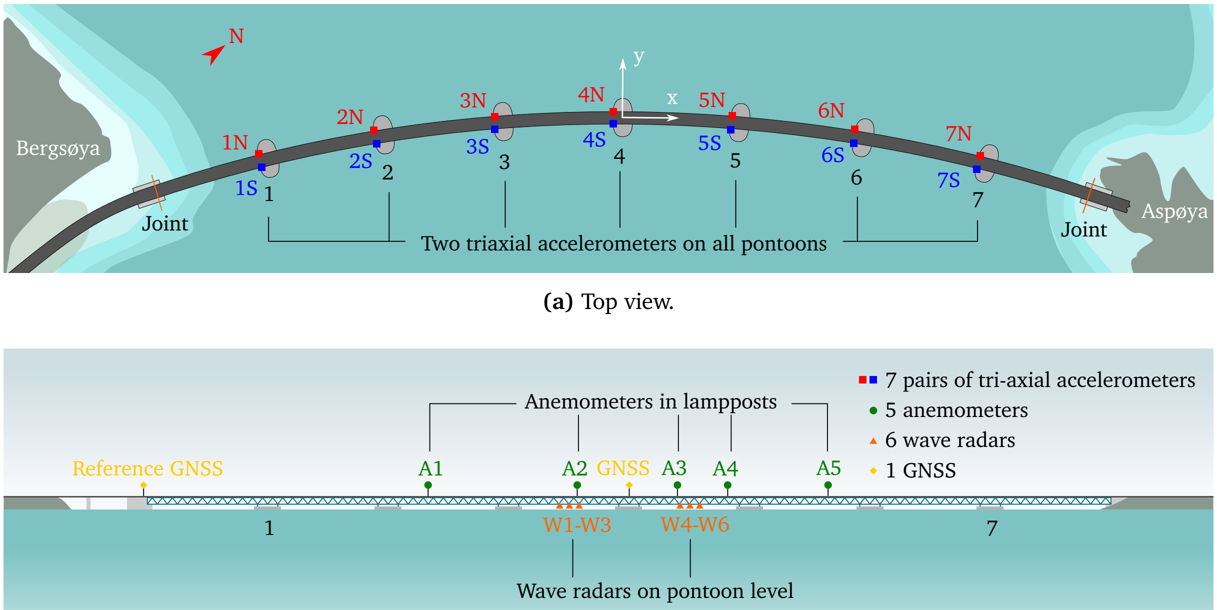


Figure 2. Map section showing location of the Bergsøysund Bridge. Maps: ©Kartverket.

a floating span of 830 meters, between the islands of Aspøya and Bergsøya, near Kristiansund in Møre og Romsdal county.

3 Monitoring system

Figure 3 depicts the main sensor layout of the monitoring system, consisting of 14 triaxial accelerometers, six wave radars, five ultrasonic anemometers and a global navigation satellite system (GNSS) displacement sensor. The sensor types and specifications are summarized in Table 1. Photographs of all sensor types are shown in Figure 4. Each pontoon contains a separate logger unit connected to several nearby sensors by ethernet cable, which furthermore communicates with a main logger unit via WiFi. The data from the loggers are synchronized by GPS antennae. The data is resampled to 200 Hz before transmission to the main logger for storage. For more details on the measurement system and the bridge, it is referred to [3].



(a) Top view.

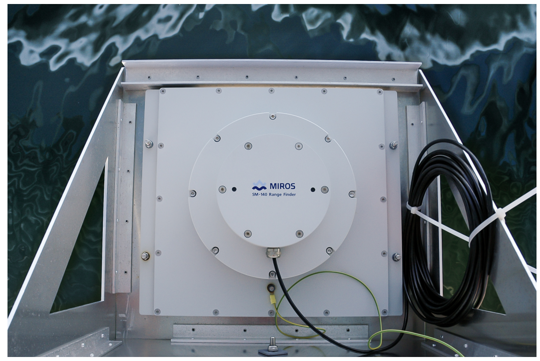
(b) Side view.

Figure 3. Monitoring system operating on the Bergsøysund Bridge. Reproduced from [3] with permission from Elsevier.

Table 1. Sensor specifications.

Sensor type	Sensors	Model	Samplerate	Description
Accelerometer	1S–7S, 1N–7N	Canterbury Seismic Instruments CUSP-3	200 Hz	Triaxial MEMS accelerometer
Anemometer	A0–A5	Gill Instruments WindMaster Pro	32 Hz	Ultrasonic 3D anemometer
GNSS displacement sensor	GNSS	Trimble RTK GNSS	20 Hz	Real-time kinematics (RTK) GNSS sensor with reference sensor to adjust for disturbances
Wave radar	W1–W6, W1b–W6b	Miros SM-140 Range Finder	50 Hz	Triangular Frequency Modulated Continuous Wave microwave sensor, that provides single point measurements of distance to sea surface

(a) Miros SM-140 Range Finder, wave radar.



(b) Miros SM-140 Range Finder, wave radar.

(c) Gill Instruments WindMaster Pro, anemometer.

(d) Trimble RTK GNSS, displacement sensor.

(e) Canterbury Seismic Instruments CUSP-3, triaxial accelerometer.

(f) Canterbury Seismic Instruments CUSP-3, triaxial accelerometer

Figure 4. Photos of sensors. Photo: NTNU/K.A. Kvåle.

Table 2. Sensor layout history. Anemometer A0 which was part of the *Basic* sensor layout had a temporary sensor location only used during this stage, underneath the bridge deck. Its recordings are therefore highly affected by the surrounding truss and water surface, but included in the database regardless, as it might provide some useful insight for interpreting the corresponding wave data. Wave radars with suffix *b* (in layout *Alternative*) refer to new locations, as described in Section 3.1.1.

Layout	Period	Sensors			
		Accelerometers	Anemometers	Wave radars	Displacement sensors
Preliminary	–2014/12/06	2S–6S and 2N–6N	-	-	-
Basic	2014/12/07–2015/03/24	1S–7S and 1N–7N	A0	W1–W6	-
Main	2015/03/25–2017/05/30	1S–7S and 1N–7N	A1–A5	W1–W6	GNSS
Alternative	2017/05/31–	1S–7S and 1N–7N	A1–A5	W1b–W6b	GNSS

Figure 5. Damaged anemometer A3 needed to be changed during sensor layout revision *Main*.

3.1 Revision history

Several revisions to the sensor layout have been made throughout the campaign, as access to new sensors or new applications have emerged. The revision history of the sensor layout is given in Table 2. It is noted that some of the anemometers were mounted slightly skewly (maximum 5 degrees off) in the period 2015/03/25–2015/09/28, but were corrected through transformation matrices corresponding to the measured angles.

3.1.1 Rearranging wave radars

Initially, the monitoring system was designed to study wave correlation and potential inhomogeneity, and not to characterize the directionality of the sea state. In the last revision of the monitoring system, the positions of the wave radars were adjusted to enable this. More details about the reasoning behind the resulting updated layout is given in [6]. The updated layout was to a large extent decided by the following guidelines developed by [12]:

- No identical distance vectors between two sets of wave radars

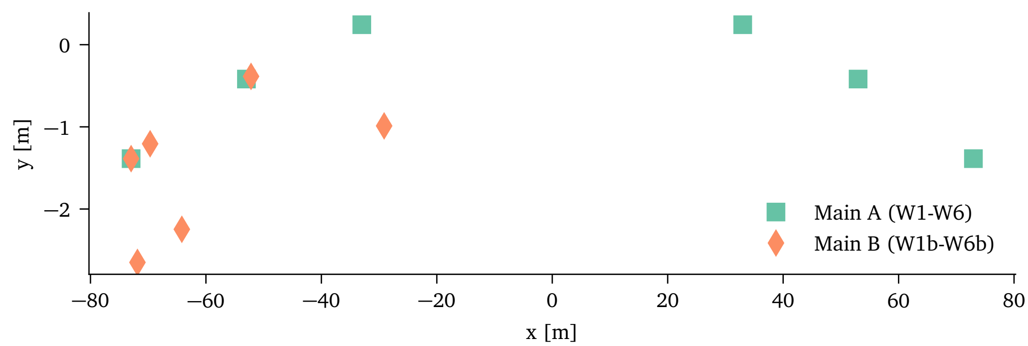


Figure 6. Old and new arrangement of wave radars.

- Uniformly distribution of distance vectors between all wave radars
- The smallest distance vector should be able to capture the highest frequency (shortest) waves of interest

Some practical limitations were of course also present, such that the sensor positions could not fully satisfy the listed guidelines. The original (layout *Main*) and updated (layout *Alternative*) wave radar positions are depicted in Figure 6. As indicated in [13], the suggested layout performs well with characterizing the directional waves for the relevant sea states at the site.

4 Data

The following section describes some crucial aspects concerning the data, such as the processing conducted and its structure. For the most part, this is in line with that reported in [1] describing the data set obtained with a similar monitoring system on the Hardanger Bridge.

4.1 Triggering schemes, recording lengths and naming convention

It is worth noting that the monitoring system has been operating under different triggering schemes and recording durations during the campaign period. For most of the time, it has been measuring in 30-minute long time periods, triggered by a sensor reporting values exceeding some predefined threshold value. However, for some periods, the triggering has been continuous, meaning that each recording successively followed the previous one until manually stopped. Furthermore, some of the recordings are also shorter.

The recordings are named after their triggering time, using the following pattern: NTNU142M-YYYY-MM-DD_hh-mm-ss, where YYYY-MM-DD is the date, hh-mm-ss is the time based on a GMT+0 time schedule, and NTNU142M is the name of the main logger unit.

4.2 Processing

The data from the monitoring system is reported with respect to the local coordinate system (CSYS) of each sensor. As described in the succeeding Section 4.4, a transformation matrix is provided as metadata for all sensors, as well as an description of the global CSYS. The transformation matrix $[T]$ is used in the following manner to transform the data from the local CSYS to the global CSYS:

$$\{q(t_k)\} = [T]\{\bar{q}(t_k)\} \tag{1}$$

where $\{q(t_k)\} = [q_x, q_y, q_z]^T$ is the data quantity expressed in a global CSYS at time t_k, whereas $\{\bar{q}(t_k)\}$ represents the corresponding local data. Each row in the 3-by-3 matrix $[T]$ is simply the unit direction vectors describing the local axes for the sensor. In practice, the transformation is conducted by transforming the entire data matrix, containing the 3D data for all time instances, in one operation:

$$[Q] = \left([T][\bar{Q}]^T\right)^T \tag{2}$$

where $[Q]$ and $[\bar{Q}]$ are the data matrices with components stacked column-wise and time instances row-wise, represented in global CSYS and local CSYS, respectively.

The following steps of processing are conducted for all sensors:

1. *Fixing corrupt data, interpolating and scoring data.* Data far outside some predefined valid ranges are removed, and filled by interpolated data. The valid ranges are defined separately for all sensor types. If the data from a component is constant for a time period above 0.5 seconds, the same procedure is carried out. Based on the amount of correction required during this step, all recordings are given a quality score: good (no correction required), acceptable (less than 10 seconds of data affected) or poor (more than 10 seconds affected). If the data is given the score *poor*, the entire data signal of the component is set to NaN (not a number), to avoid the analysis of that data causing erroneous results.

2. *Downsampling.* The downsampling is conducted using the MATLAB function `resample`, which lowpass filters the data prior to downsampling, to avoid aliasing.

3. *Transformation to global CSYS.* All three-dimensional data are in general transformed to a global CSYS by Equation 2. As the anemometer provides polar data, some special treatment of this is required. The wave radar provides 1D data of the vertical distance to the sea surface, and does thus not require any transformation.

4.2.1 Special anemometer considerations

Due to the polar nature of the data output from the anemometers, the resulting local data has to be transformed to cartesian wind coordinates prior to transformation to the global coordinate system. Finally, the global cartesian data is transformed back to a polar format. Furthermore, traditional arithmetic means will provide misleading results when dealing with the measured wind angle. The same can be argued on other statistical quantities, such as standard deviations. Therefore, the statistical operations are applied to vectors representing the angular values, which are used to establish the final mean angles that are inserted in the database.

4.3 Data format and hierachical structure

All recordings are collected in a single h5-file for each enforced sample rate. In the current database, the sample rates of 2 Hz and 10 Hz was used. However, for applications requiring higher sample rates, please contact the authors and we will attempt to provide data in higher rates. We consider the HDF format very well suited for sharing the data. The hierarchical nature of the format ensures that the data itself is structured, ensuring a more intuitive usage, and consequently reduces the need for metadata describing the data structure. Furthermore, metadata is added in several of the levels of the hierarchy, to fully describe the data sets. Figure 7 depicts the structure of the data (2 Hz and 10 Hz versions share identical hierarchy and structure). Furthermore, to simplify the task of retrieving a useful time series for further analysis, some global statistics, i.e., mean values and standard deviations, are collected in a separate group called *.global_stats* at the root of each file. The hierarchy of the statistics group is given in Figure 8.

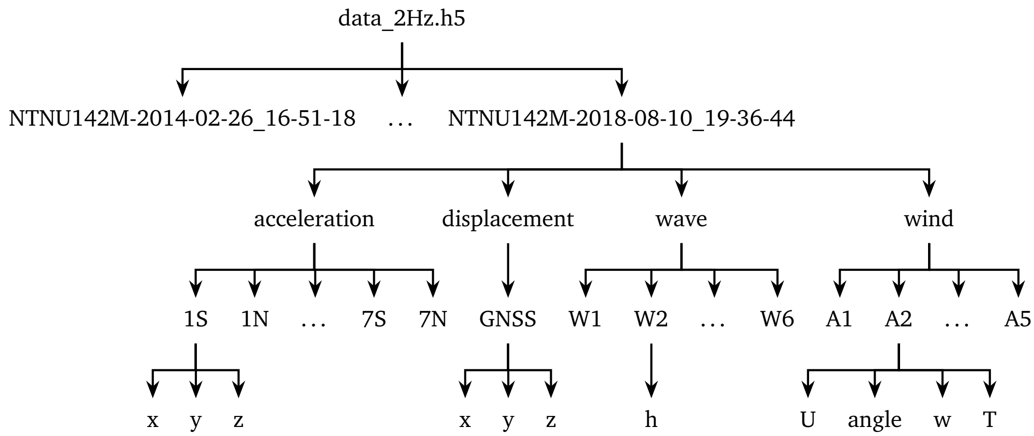


Figure 7. Hierachy of data set in h5-format.

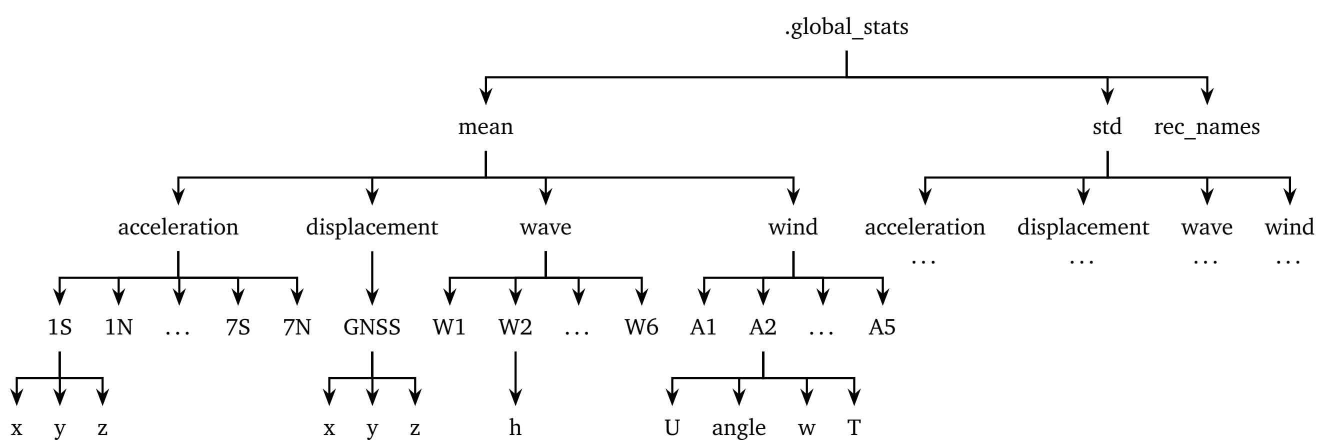


Figure 8. Hierachy of global statistics appended to h5-file.

Table 3. Description of selected metadata variables.

Hierarchy level	Name	Description
Project	*coordinate_system*	String describing the global coordinate system with words, including position of origin and the global axes directions.
	samplerate	The samplerate provided on the project level is given as a string as it is descriptive rather than a precise float number. Also, for some future projects, it might be relevant to gather data of several different sample rates in the same files.
Recording	*starttime*	String describing the date and time in GMT+0 that the recording was triggered. This has the structure **YYYY-MM-DD**T**hh**:**mm**:**ss**.
Sensor	*channel*	Channel for storing of data in raw data. Only used if accessing raw data is needed.
	location	String describing position of sensor.
	position	Array with coordinates of the sensor, with respect to the predefined global coordinate system.
	transformation_matrix	Transformation matrix (3x3 array) used to transform the sensor data to the global coordinate system. See Section 4.2 and specifically Equation 1. As described in the referred section, the rows of the matrix indicate the local axes of the sensor as mounted on the structure.
	type	Model name of the sensor.
Component	*data_quality*	String characterizing the quality of the data. This is established during the preprocessing of the data.
	conversion_factor	Conversion factor to establish data of specified unit. Not used for the Bergsøysund data, but included for future flexibility.
	unit	Unit of the data after the application of the conversion factor.

4.4 Metadata

Important metadata are distributed across different levels of the file hierarchy. This is depicted in Figure 9. For the most part, the metadata entries are self-explanatory. However, some of them would benefit from an elaboration. Selected metadata entries are therefore described in Table 3.

5 Open access database

The data is published in the open-access repository Zenodo under the Creative Commons license CC-BY 4.0 [11]. The data can be accessed by the following link: https://doi.org/10.5281/zenodo.5827293. Zenodo is an open-access repository developed under CERN's OpenAIRE program, stored in CERN Data Center. As the data set itself has both a DOI and Zenodo supports version DOIs, the data might be updated at some point. We will strive to retain the described structure of the data in any future version releases.

5.1 Python examples

Some useful functions for data import, processing and visualization are provided in the Python package `opyndata` on GitHub [14]. The package will be updated and revised in the future, hopefully keeping core functionality backwards compatible. Please refer to the package documentation for more details about installation and usage.

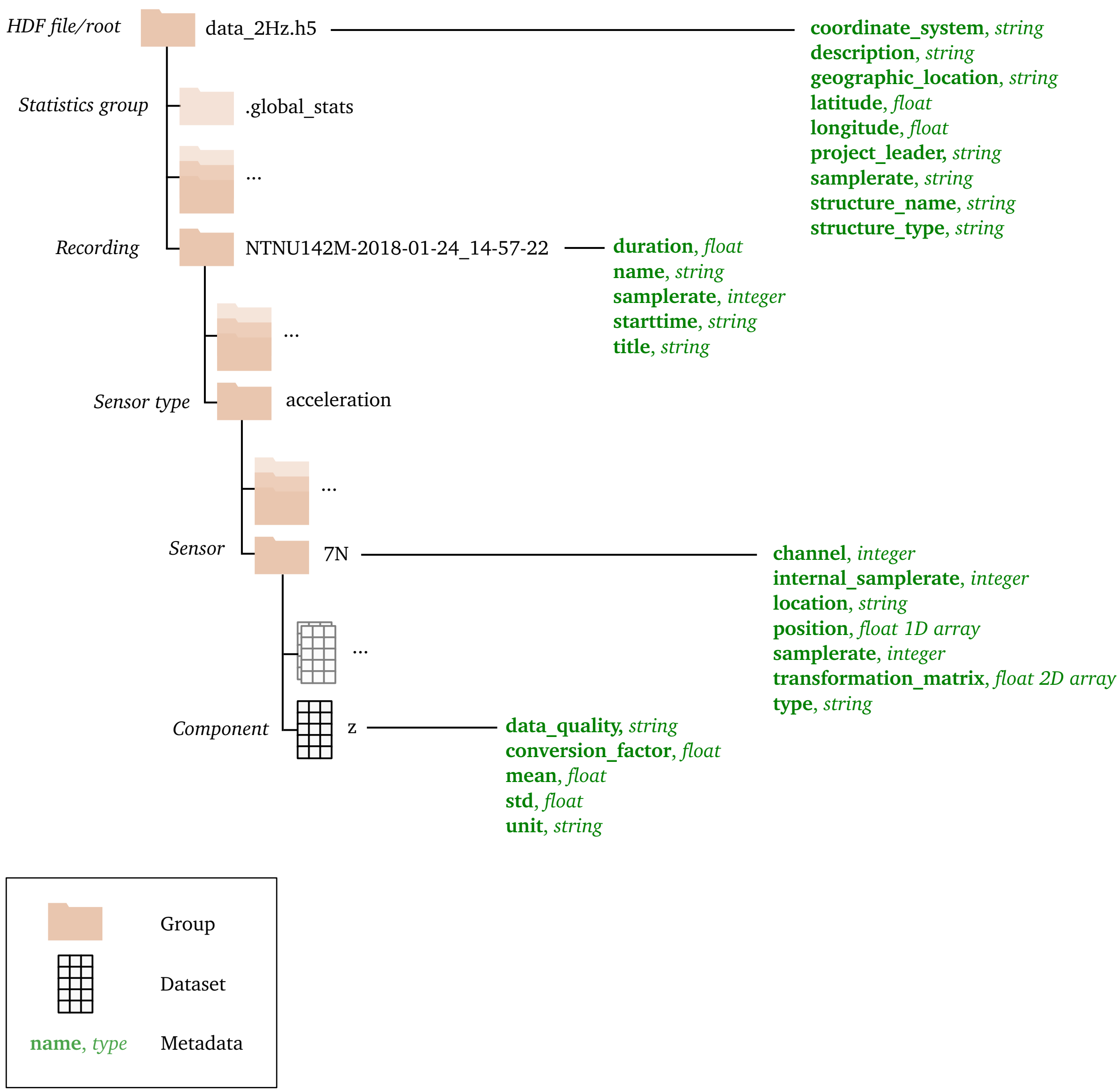


Figure 9. Metadata in HDF files.

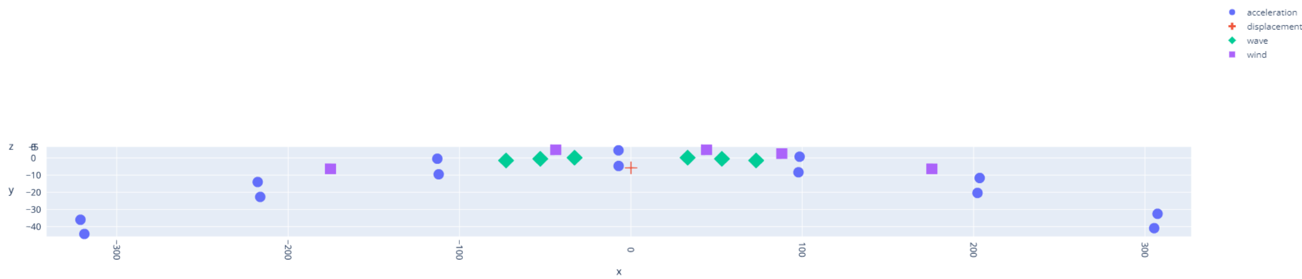


Figure 10. Resulting sensor position plot, based on metadata in h5-file. The plotting function is based on the `plotly` package.

In the following sub-sections, some examples of import and visualization of the data set are provided for convenience. The examples are also published on the `opyndata` GitHub repository [14].

5.1.1 Load data set from single recording and visualize sensor positions

The following code, also available in *example_single_rec.py* in `opyndata`, is run to create a sensor plot and import the data of a selected recording from the h5-file as a Pandas Dataframe object:

```
from opyndata.data_import import export_from_hdf
from opyndata.visualization import plot_sensors
import h5py
import plotly.io as pio

pio.renderers.default='browser'

# Define file and recordings
fname = 'data_2Hz.h5'
rec_name = 'NTNU142M-2017-03-14_22-27-06'

# Plot sensors
with h5py.File(fname, 'r') as hf:
    hf_rec = hf[rec_name]
    fig = plot_sensors(hf_rec, view_axis=2)
    fig.show()

# Choose components to import
comp_dict = {'wave': ['h'],
             'acceleration': ['x', 'y', 'z'],
             'wind': ['U']}

# Import recording from h5 file as Pandas dataframe
with h5py.File(fname, 'r') as hf:
    data_df = export_from_hdf(hf[rec_name], component_dict=comp_dict)
    data_df = data_df.set_index('t')    # set time as index
```

The sensor plot is shown in Figure 10. The resulting Pandas Dataframe object is depicted in Figure 11.

5.1.2 Browse data graphically in web browser

The following code, also available in *visualize_h5_data.py* on `opyndata`, is run to create a dashboard to browse the h5-files:

```
In [13]: data_df
Out[13]:
                 1N/x      1N/y      1N/z  ...       A3/U       A4/U       A5/U
t                                          ...
0.000000    -0.007905  0.004950  0.006578  ...  13.869278  12.712683  14.593049
0.500135    -0.008379  0.005662  0.007062  ...  19.269735  16.723706  20.224925
1.000269    -0.008771  0.007042  0.007946  ...  17.010411  16.311568  20.195921
1.500404    -0.008432  0.005991  0.007348  ...  14.365299  17.823151  20.028311
2.000539    -0.007540  0.003182  0.006636  ...  15.028133  17.680238  19.545321
...               ...       ...       ...  ...        ...        ...        ...
1817.989461 -0.007382  0.004636  0.006542  ...  11.967637  13.074667   7.391795
1818.489596 -0.007418  0.004859  0.006112  ...  10.084129  12.951186   7.078698
1818.989731 -0.008067  0.007212  0.006316  ...  10.338453  12.938737   5.244156
1819.489865 -0.007614  0.005700  0.006916  ...  10.678658  14.856558   4.856929
1819.990000 -0.007157  0.004072  0.007203  ...   9.861242  10.529835   5.550638

[3640 rows x 53 columns]
```

Figure 11. Dataframe resulting from import code.

```
from opyndata import visualization

data_path = 'data_10Hz.h5'
app_setup = visualization.AppSetup(data_path=data_path)
app = app_setup.create_app()

server = app.server

# ------------ RUN SERVER -------------
if __name__ == '__main__':
    app.run_server(debug=False)
```

This uses the `dash` Python package to host a local web page at http://127.0.0.1:8050/. By accessing this IP-address through a browser, a GUI appears, such that the data can be browsed in a graphical manner. Figure 12 depicts its appearance. The three sections show the statistical data, the data from the recording selected and the corresponding sensor layout. By providing this simple tool for browsing the data, it will hopefully become more available and accessible.

6 Summary

In this data paper, we introduced and described a data set containing large amount of data retrieved from the Bergsøysund Bridge in Norway between the years 2014 and 2018. Also, the monitoring system used to collect the data is described. The data is available for free access under the CC-BY 4.0 license on Zenodo. The DOI corresponding to the data will be permanent, and if changes are made, the different versions of the data will be available under different version DOIs. Finally, by the usage of the Python package `opyndata` available on GitHub, the import and visualization of the data sets were exemplified, for convenience.

Figure 12. Graphical interface for browsing h5-files.

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