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# User manual

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Aquastructures AS
Kjøpmannsgata 21
7013 Trondheim
Norway

# Contents

# 1 Introduction

AquaHarmony is an addon to the software package AquaSim. AquaSim is an analysis tool developed by Aquastructures AS, which utilizes the Finite Element Method (FEM) for calculation and simulation of structural response. It is suited for a range of structural configurations exposed to environmental loads such as:

- waves
- currents
- wind
- impulse loads
- operational conditions
- resonance

AquaHarmony is a data processing software for denoising and filtering current of measurements. **Note (1)**. This manual describes the theory and functionality of the software. The software provides a visual presentation of the processed data for further application in e.g., site reports.

**Note (1)**

As per AquaSim version 2.16, AquaHarmony is provided as a beta-version. Care should be taken when applied, and the validity of the results must be assessed.

## 1.1 Terminology

Through this manual, certain terms appear. Some of them are defined below.

| Term | Definition |
|---|---|
| Denoising condition | The filtering criteria applied to the dataset when it is transformed from frequency domain to time domain. |
| Fourier Analysis | The study of how general functions can be presented as the sum of simpler harmonic functions. |
| Fourier Transform | Transformation of a function from time domain to frequency domain. |
| Fast Fourier Transform | Algorithm for transforming data form time domain to frequency domain. |

# 2 Theoretical background

In this chapter, the theoretical basis of AquaHarmony is presented. AquaHarmony apply Fast Fourier Transform (FFT) for denoising of datasets. Fourier Transform (FT) is a linear representation of data. It transforms a function $f(t)$ to a new function $F(\omega)$ by means of integration. In the succeeding chapters, the basics of Fourier Analysis, Fourier Transform and Fast Fourier Transform is presented.

## 2.1 Fourier Transform

Fourier analysis is the study of how general functions can be presented as the sum of simpler harmonic functions. This is the basic concept of the software and is reflected by the name Aqua*Harmony*: harmonic functions.

Consider a function $f(t)$, that may represent measurements of certain data as function of time $t$. Because of the time variable, the function $f$ is represented in the time domain. By Fourier Transform the function $f(t)$ is transformed from the time domain to a function in the frequency domain $F(\omega)$. Where $\omega$ represents the frequency. The advantage of transform from time domain to frequency domain is that it allows for analyzing the measurements from different mathematical perspectives. In denoising analysis, high frequency and steady state measurements is filtered out. For more information about Fourier Transform see e.g., (Wikipedia, 2021a).

### 2.1.1 Definition of Fourier Transform

A Fourier Transform consist of a real and a complex part. The real part of the transformation consists of sinus-waves and the complex part of cosine-waves. Let $f(t)$ represent a function of measurements. The Fourier Transform of $t$ is defined by:

$$F(\omega) = F[f(t)] = \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt$$

*Equation 1*

where $i$ is the complex unit $\sqrt{-1}$. Equation 1 tells us that a function is the infinite sum of harmonic components. This is illustrated in Figure 1.

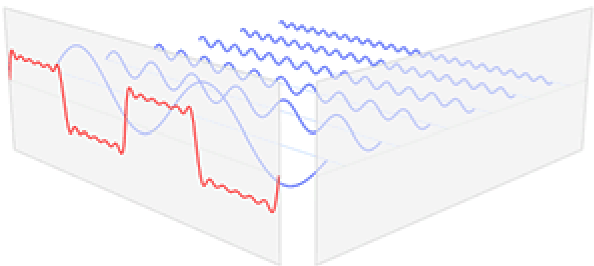


*Figure 1 Fourier series with a linear combination og sine- and cosine-curves. From (Wikipedia, 2021a)*

It is also possible to transform the Fourier Transform from frequency domain back to time domain, this is called Inverse Fourier Transform:

$$f(t) = F^{-1}[F(\omega)] = \frac{1}{2\pi} \int_{-\infty}^{\infty} F(\omega) e^{-i\omega t} dt$$

*Equation 2*

In AquaHarmony, the denoising condition is defined in terms of periods. Then the data is transformed to frequency domain for filtering. After filtering, the data is transformed back into time domain by the Inverse Fourier Transform. The purpose of inverting the dataset back to time domain is because this format is required in further processing and analysis of the filtered data.

## 2.2 Fast Fourier Transform

Fourier analysis may be conducted in several ways. AquaHarmony is based on the algorithm Fast Fourier Transform. The Fast Fourier Transform (FFT) is an improvement of the Fourier analysis named Discrete Fourier Transform (DFT). The DFT converts a finite number of measurements, in time domain, into sequencies of equally spaced measurements in the frequency domain. Computing the transformation directly from the definition of DFT is a slow process due to the size of the generated matrixes. The FFT easily computes the transformation by factorization of the DFT matrix into smaller factors. Hence, FFT offers fast and efficient transformation of large datasets. An example of application is shown in Figure 2.

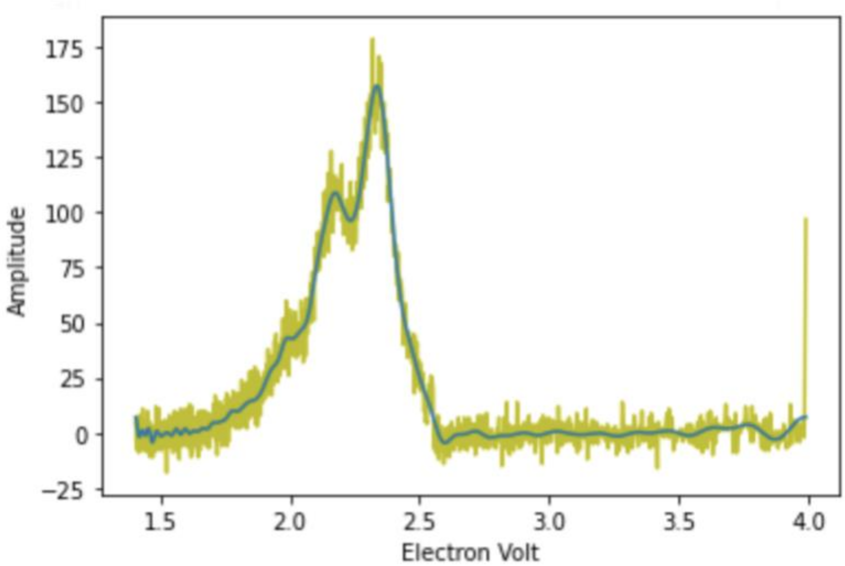



*Figure 2 Measurements (green line) and FFT of the measurements (blue line). From (Chen, 2020a).*

In short terms, the analysis by FFT is done in four main steps:

1. Original data with noise is imported to AquaHarmony.
2. The denoising condition is set by means of a low period cut-off- and harmonic periods.
3. The data is transformed from time domain to frequency domain through FFT and filtered according to the defined denoising condition.
4. The denoised data is inverted from frequency domain, back to time domain.

# 3 Interface

In this chapter, the interface of AquaHarmony is presented. First, some basics of the file format the software is customized for. Further, the interface and functionality are presented.

## 3.1 File formats and loading AquaHarmony

AquaHarmony loads .xlsx-files of a certain format. Meaning the Excel-files must be built up with a certain structure of rows and columns. This is to ensure the input-data is treated correctly when imported. An example of an input file is shown in Figure 3.

```
cell       1            13           22                         cell      1             13           22
data_type    magnitude    directions   pd_pressure_sensor_depth_m  magnitude    directions   pd_pre
                                               total_depth      time
2017-02-22 11:59:33 0,12    207,85  27,9    0,11    209,95  15,9    0,09    209,98  6,9     30
2017-02-22 12:19:33 0,11    211,5   27,7    0,11    207,27  15,7    0,11    212,01  6,7     30
2017-02-22 12:39:33 0,09    211,81  27,55   0,1 215,94  15,55   0,1 201,16  6,55        30,25
2017-02-22 12:59:33 0,08    212,91  27,39   0,12    222,34  15,39   0,1 196,1   6,39        30
2017-02-22 13:19:33 0,08    223,48  27,22   0,08    223,51  15,22   0,1 186,71  6,22        29
2017-02-22 13:39:33 0,06    214,25  27,09   0,09    235,59  15,09   0,07    192,8   6,09
2017-02-22 13:59:33 0,05    193,24  26,98   0,07    248,04  14,98   0,04    181,3   5,98
2017-02-22 14:19:33 0,03    172,65  26,92   0,03    285,64  14,92   0   116,57  5,92        29
2017-02-22 14:39:33 0,01    101,31  26,86   0,02    339,15  14,86   0,03    30,96   5,86
2017-02-22 14:59:33 0,05    43,26   26,85   0,08    5,06    14,85   0,04    31,43   5,85
2017-02-22 15:19:33 0,07    79,54   26,86   0,08    11,74   14,86   0,09    10,3    5,86
2017-02-22 15:39:33 0,08    79,63   26,93   0,11    27,51   14,93   0,12    29,28   5,93
2017-02-22 15:59:33 0,08    77,96   27  0,13    28,12   15  0,13    23,48   6       29,714690
```

*Figure 3 Example of input data, current measurements*

A template for importing data is provided along with this software, this is found in your installation folder in terms of an .xlsx-file.

To load AquaHarmony simply double click on the AquaHarmony shortcut on your desktop or search it up in your folder system.

## 3.2 Main View

Figure 4 presents the main view upon loading AquaHarmony. It consists of:

1. Top Menu bar,
2. Denoising Condition parameters for individual series of input-data,
3. Input dataset,
4. and Filtered dataset.

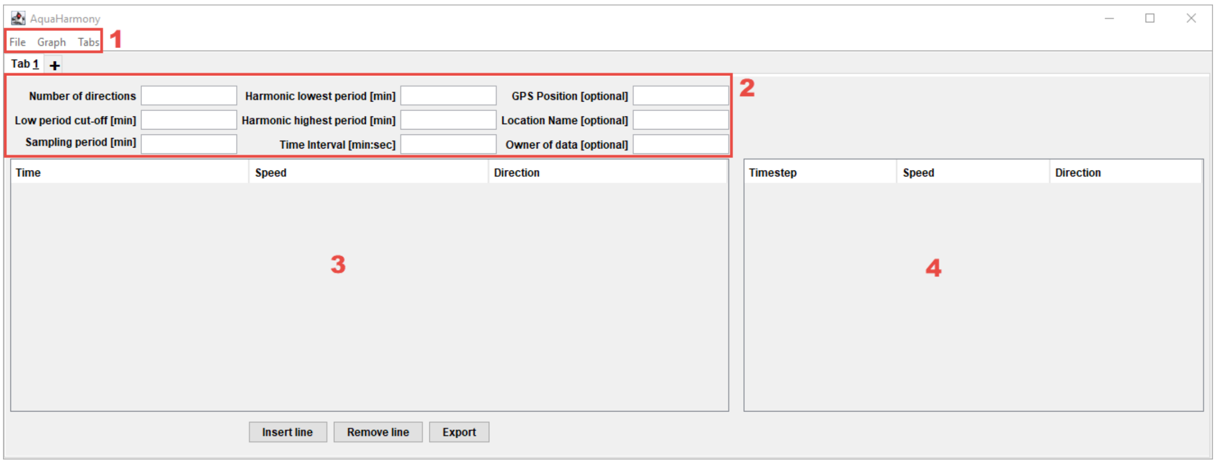



*Figure 4 The main view of AquaHarmony*

## 3.3 Top Menu bar

The Top Menu bar is found in the top left corner of the Main View. It provides access to import data, graphing results, and other setting. The different options are illustrated in Figure 5.

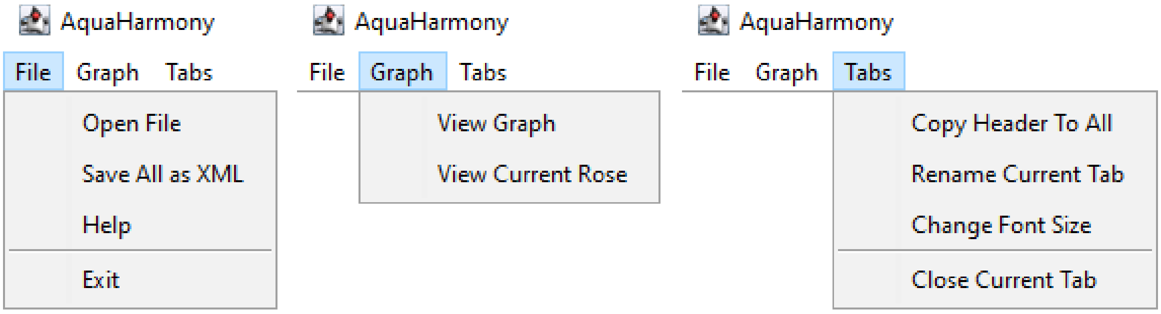



*Figure 5 Options in the Top Menu bar*

Detailed description of the option is found in Table 1.

*Table 1 Options in the Top Menu bar*

| **Option** | **Description** |
|---|---|
| **File** | |
| Open file | Opens file directory for selection on input-data files. |
| Save All as XML | Enable the user to save both input-data and results as an .xml-file. |
| Help | Opens this user manual. |
| Exit | Exits and closes the software. |
| **Graph** | |
| View Graph | Opens a new dialog box and visualize both input-data and results in a graph. |
| View Current Rose | Opens a new dialog box and visualize results as a function of orientation angle i.e., from 0 degrees to 365 degrees. |
| **Tabs** | |
| Copy Header To All | Copy the parameters in the Denoising Condition-area from the current viewed tab to the other tabs. |
| Rename Current Tab | Enable the user to give the current viewed tab a new name. |
| Change Font Size | Changes the size of all fonts in AquaHarmony. Default font size is 12. |
| Close Current Tab | Closes the current viewed tab. |

## 3.4 Denoising Condition

For each set of input-data a denoising condition must be set. Normally, a dataset of current velocities consists of measurements for several water depths. AquaHarmony recognize the different datasets for each water depth and presents them in different tabs. Each tab has the same options for defining the denoising condition and information parameters, as illustrated in Figure 6.

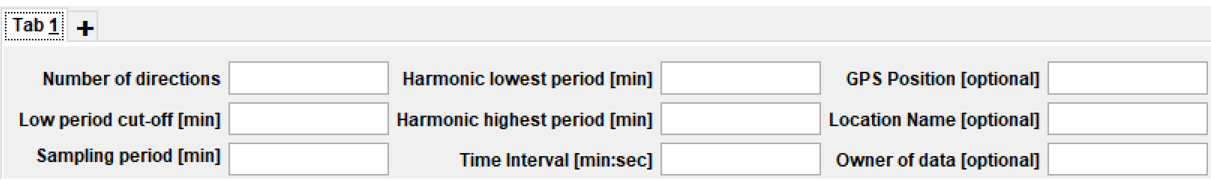



*Figure 6 Denoising Condition and information parameters*

Detailed description of the parameters is found in Table 2.

*Table 2 Description of denoising condition and information parameters*

| Option | Description |
|---|---|
| **Denoising condition** | |
| Number of directions | Number of sectors the current rose will be divided into. For each sector, a maximum value of filtered data is presented. When the sectors are established, AquaHarmony set 0 degrees (north) as the starting mid-point. Then it is divided ± from 0 degrees into a total of $360^{\circ}/Number\ of\ directions$ number of sectors. |
| Low period cut-off | Parameter for filtering of low-period measurements from the input-data. All periods below this defined value are removed (in other words, filtered). E.g., if a dataset contains 10 measurements and the Low period cut-off removes 2 values, 8 measurements are returned. Removed data will result in a "smoother" dataset. Unit [minute]. |
| Sampling period | Time interval between individual data-points. Current measurements are often logged with a time interval of 10 minutes. The user may identify this by considering the time between measurements in the input-data. Unit [minute]. |
| Harmonic lowest period | Parameter for filtering of harmonic measurements, such as effect of tide. The lowest harmonic period is defined here. Removes all periods shorter than this defined value. Unit [minute]. |
| Harmonic highest period | Parameter for filtering of harmonic measurements, such as effect of tide. The highest harmonic period is defined here. Removes all periods longer than this defined value. Unit [minute]. |
| Time Interval | The same as "Sampling period". Only this is automatically detected by AquaHarmony. **Note (2)**. The unit is *Minutes:Seconds*. The purpose of this parameter is to check the dataset for errors that may affect the filtering analysis. |

**Note (2)**

The algorithm in AquaHarmony assume that the time-interval between individual data-points is constant. This means, data with varying time-intervals would not provide optimal data processing. If the time-interval between two succeeding measurements exceeds the average time interval by 5%, AquaHarmony will notify this. The user must then type an appropriate time interval for the data-point in question.

### 3.4.1 Low period cut-off

The Low period cut-off allows to cut the low periods (or high frequencies) of the measurements. In AquaHarmony, this value is interpreted as a period criterium. All periods below this defined value are removed from the dataset, resulting in fewer data points. The relation between the Low period cut-off and the frequency is described as:

$$T_{crit} = \frac{1}{f}$$

*Equation 3*

where $T_{crit}$ is the Low period cut-off and $f$ being the frequency of the data points. The filtering is based on the unfiltered input-data.

### 3.4.2 Harmonic lowest period and Harmonic highest period

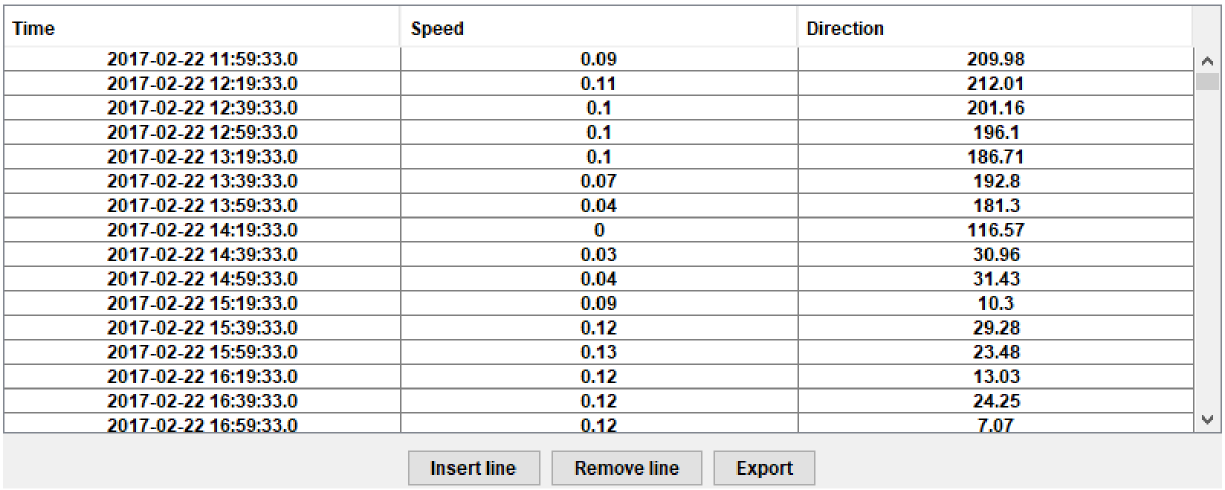
These parameters are intendent for filtering of harmonic measurements, such as the effect of tidal currents. Typical period of tidal current is 6 hours. Periods within the range of the lowest and highest periods are filtered and removed from the dataset. The filtering is based on the unfiltered input-data. **Note (3)**.

**Note (3)**

Results from filtering applying Harmonic lowest/highest period and Low period cut-off is filtered and reported in separate files.

## 3.5 Input dataset

The Input dataset field is illustrated in Figure 7, where the raw data from the measurements are presented. It contains a table for presentation of measurement time, currents speed and the current direction. More detailed information is presented in Table 3.



| Time | Speed | Direction |
|---|---|---|
| 2017-02-22 11:59:33.0 | 0.09 | 209.98 |
| 2017-02-22 12:19:33.0 | 0.11 | 212.01 |
| 2017-02-22 12:39:33.0 | 0.1 | 201.16 |
| 2017-02-22 12:59:33.0 | 0.1 | 196.1 |
| 2017-02-22 13:19:33.0 | 0.1 | 186.71 |
| 2017-02-22 13:39:33.0 | 0.07 | 192.8 |
| 2017-02-22 13:59:33.0 | 0.04 | 181.3 |
| 2017-02-22 14:19:33.0 | 0 | 116.57 |
| 2017-02-22 14:39:33.0 | 0.03 | 30.96 |
| 2017-02-22 14:59:33.0 | 0.04 | 31.43 |
| 2017-02-22 15:19:33.0 | 0.09 | 10.3 |
| 2017-02-22 15:39:33.0 | 0.12 | 29.28 |
| 2017-02-22 15:59:33.0 | 0.13 | 23.48 |
| 2017-02-22 16:19:33.0 | 0.12 | 13.03 |
| 2017-02-22 16:39:33.0 | 0.12 | 24.25 |
| 2017-02-22 16:59:33.0 | 0.12 | 7.07 |



*Figure 7 Input dataset*

Each column in the table is editable.

*Table 3 Options in the Input dataset field*

| Option | Description |
|---|---|
| Time | Time when measurements were made. Format: *Year-month-day Hour:Minute:Seconds* |
| Speed | Magnitude of the measured speed/ velocity. The unit depends on what the sensor reports, but is usually measured in *m/s*. |
| Direction | The direction of the measurements. The value should be interpreted as direction TOWARDS. Meaning that a value of e.g., 180 is interpreted as towards south. The unit is *degrees*. |
| Insert line | Generates a new empty row in the table. The user may type appropriate values for each column in the generated row. |
| Remove line | Deletes the selected row in the table. To select a row, simply right click on a row in the table. |
| Export | Starts the analysis. Analysis includes filtering of the input-data based on the parameters in the defined denoising condition. The filtered data will automatically be viewed in the Filtered dataset-area. |

## 3.6 Export

The Export button starts the filtering of the dataset. Upon selecting Export, a dialog box for selecting a file directory appears. The user should then assign the analysis a name. When selecting Save, the filtering analysis is conducted. 12 ASCII-formatted files are generated, an example is provided in Figure 8. In this example the analysis is named "results". AquaHarmony automatically adds the name of the tab to the generated files, which in this example is "22".

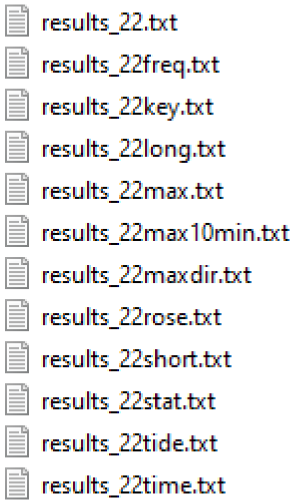



*Figure 8 Example of result files.*

Each result file contains information about the filtered dataset and analysis information. More detailed information about the content is provided in Table 4.

*Table 4 Files generated from AquaHarmony*

| Filename | Description |
|---|---|
| <filename>.txt | Rearranged unfiltered data. The first row summarizes the parameters defined in the denoising condition. Then unfiltered data and corresponding direction in [degrees]. |
| <filename>freq.txt | Unfiltered and filtered data transformed to frequency domain. The relation between the frequency $f$ $[1/min]$ and period $T$ $[min]$ is given as: $T(min) = (1/f) \cdot Sampling\ period \quad [min]$ The second column contains unfiltered input-data converted to frequency domain. The third column is the filtered frequencies. If 0.0E+00, then this means that frequencies are removed and filtered form the dataset. |
| <filename>key.txt | Key data about software version and license information. |
| <filename>long.txt | Filtered data. Reports all data with periods longer than "Harmonic highest period". |
| <filename>max.txt | First column numbers the directions/ sectors. Second column is the directions/ sectors, unit [degrees]. Third column is maximum unfiltered input-data within the corresponding direction/ sector. Fourth column is maximum filtered data within the corresponding direction/ sector. Fifth column is the difference between unfiltered and filtered data, absolute value. |

| | |
|---|---|
| <filename>maxdir.txt | Filtered data. First column numbers the directions/ sectors. Number of the last row should correspond to the value defined in “Number of directions”. Second column is the directions/ sectors, unit [degrees]. Third column is maximum unfiltered input-data within the corresponding direction/ sector. Fourth column is maximum filtered data within the corresponding direction/ sector. Fifth column is the difference between unfiltered and filtered data, absolute value. |
| <filename>rose.txt | Data basis for the Current Rose graph. First dataset, in this file, is filtered data (maximum value within a direction/ sector) based on “Low period cut-off”, polar coordinates. Second dataset is unfiltered data, polar coordinates. Third dataset is the same as the first dataset, only presented in cartesian coordinates. Fourth dataset is the same as the second dataset, only presented in cartesian coordinates. |
| <filename>short.txt | Filtered data. Reports all data with periods shorter than “Harmonic lower period”. |
| <filename>stat.txt | All data presented (not only maximum within a direction/ sector). First column is numbering of each row. Second column is unfiltered data. Third column is filtered data. Fourth column is the difference between unfiltered and filtered data, absolute value. |
| <filename>tide.txt | Filtered data based on the denoising condition in “Harmonic lowest period” and “Harmonic highest period”. “Lowest period cut-off” is not included. Cartesian coordinates. |
| <filename>time.txt | Same as <filename>.txt, only this is filtered data. |

## 3.7 Filtered dataset

Upon selecting Export, the filtered dataset will appear in the Filtered dataset-area, as illustrated in Figure 9. The time is converted from the format *Year-month-day Hour:Minute:Seconds* to timesteps. The timestep start at 1.0 and ends at the last unfiltered measurement. Each column in this table is editable. To select and edit a row, double click on the appropriate cell in the table.

| Timestep | Speed | Direction |
|---|---|---|
| 1.0 | 0.096327 | 217.2512 |
| 2.0 | 0.089553 | 203.7712 |
| 3.0 | 0.091017 | 197.7391 |
| 4.0 | 0.094387 | 187.111 |
| 5.0 | 0.064483 | 193.9162 |
| 6.0 | 0.03863 | 181.3461 |
| 7.0 | 2.6863E−8 | 123.6901 |
| 8.0 | 0.026305 | 35.92329 |
| 9.0 | 0.035052 | 36.5174 |
| 10.0 | 0.083716 | 11.08253 |
| 11.0 | 0.105483 | 33.80637 |
| 12.0 | 0.115683 | 26.59882 |
| 13.0 | 0.110447 | 14.17965 |
| 14.0 | 0.106578 | 27.54498 |
| 15.0 | 0.113095 | 7.504049 |
| 16.0 | 0.126247 | 1.6907E−5 |

*Figure 9 Filtered dataset*

## 3.8 Graphs

Both the input dataset and the filtered dataset may be presented is graphs; as a function og time or as a function of direction. The latter is referred to as Current Rose.

### 3.8.1 View Graph

The graph is found in Graph > View Graph, a new window will appear. The measurements are presented as a function of time. It is possible to view both the unfiltered (input) and the filtered dataset separately or together, as exemplified in Figure 10.

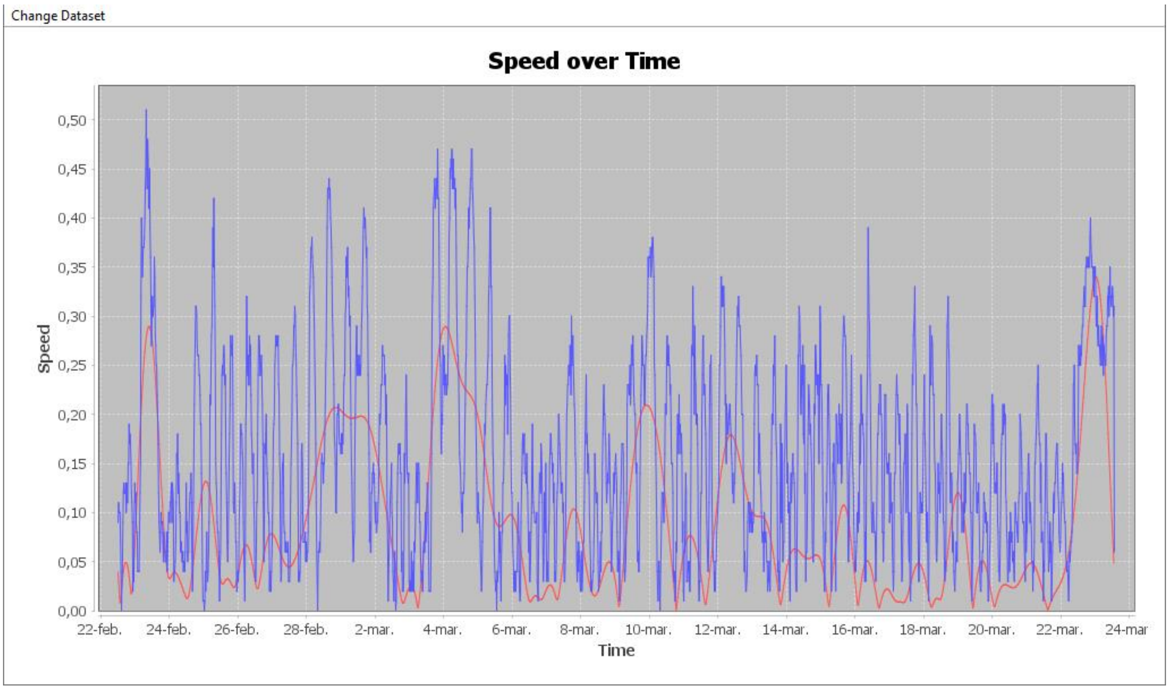



*Figure 10 Unfiltered data (blue line), filtered data (red line)*

### 3.8.2 View Current Rose

The Current Rose is found in Graph > View Current Rose. The Current Rose presents the dataset as a function of direction. As for the Graph, both unfiltered (input) and filtered data may be displayed. An example is seen in Figure 11.

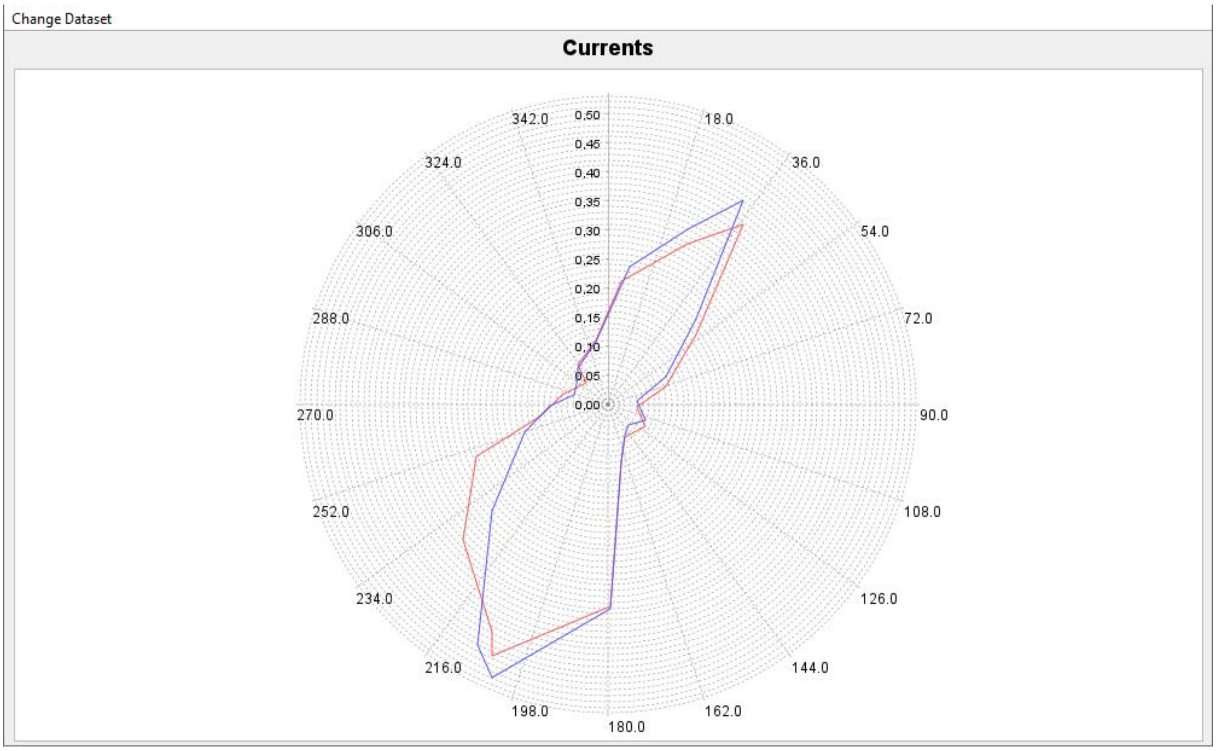



*Figure 11 Unfiltered data (red line), filtered data (blue line)*

# 4 References


Aquastructures . (2021). *The AquaSim Package Theory User Manual.*

Chen, N. (2020a, 12 01). *Ning Chen*. Hentet fra Deniosing Data with Fast Fourier Transform: https://kinder-chen.medium.com/denoising-data-with-fast-fourier-transform-a81d9f38cc4c

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