ABOUT THE ACCURACY OF ESTIMATED FREQUENCIES WITH THE PyFEST SOFTWARE

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ABSTRACT: This paper presents a method to estimate frequencies with high accuracy that is based on an iterative method. The method consists in applying rectangular windows with different lengths to the acquired or generated signal in order to control the resulted frequency resolution. For each truncated signal we calculate the Discrete Fourier Transform (DFT), finally being overlapped all achieved spectra. So, we obtain a unique spectrum form all DFTs, which have an extremely fine frequency resolution. For the three biggest amplitude values found in the vicinity of the targeted frequency we perform an interpolation and find the regression curve and the maximum of it. This represent the true amplitude of the signal's targeted harmonic component. The inter-bin position on which this amplitude is found indicates the true frequency. The algorithm is transposed in an application written in the Python programming language and tests are made to find the accuracy of the proposed estimation method. Since we find frequency estimates very close to the generated frequencies, the method and the application are successfully validated.

KEY WORDS: Python programming language, Frequency estimation, Iteration, PyFEST software, Signal processing.

1. INTRODUCTION

An accurate estimation of the natural frequencies of engineering structures is essential both in the design as well as in operation. Unfortunately, if the frequency is estimated with standard DFT the accuracy of the estimates depends on the acquired signal length [1,2]. In many cases, especially for higher-order modes, the existence of the response signal is short in time and a row frequency resolution is the consequence.

Attempts made to overcome this inconvenient were made by numerous authors [3-9], most of them focusing to find the frequency on an inter-bin position by interpolation methods. To this aim, two or three DFT samples are involved.

In our prior research, we developed iterative methods that lead to spectra with fine resolution even for short signals [10-13]. With these methods, the frequency is found on the spectral bin that presents, in the overlapped spectrum, the local maxima for the amplitude. Another technique we approached is to perform interpolation on three DFT samples belonging to three different spectra of the same signal, found for different time lengths [14,15].

This paper introduces the PyFEST application, written in the Python programming language, which benefits from prior findings regarding the iterative frequency estimation methods. In the next section, we show how the application works and in section three we present estimation results attained for signals generated with known frequency in order to derive the errors and to validate the method.

2. THE PyFEST APPLICATION

Applications to solve engineering problems written in many programming languages are available in the literature [16,17]. Python is one preferred programming language in the scientific world, because it is free and has a large standard library. This huge library, which is one of its strengths, contains tools appropriate for various tasks. The application we developed for frequency estimation, PyFEST, is simple to be used and has a user-friendly interface, see Fig. 1.

The algorithm implemented in the PyFEST application is described in [14]. In following, we describe the algorithm and give details about the actions needed when using the application. The steps are:

1. Import the acquired or generated original signal
2. Define the maximum frequency of interest by inserting the value in the dedicated window (Fig. 2) and clock OK
3. The standard DFT is displayed in a new window (Fig. 3).
4. Select the frequency for which the analysis should be made by a right-click on the bullet indicating the maximum amplitude in the desired frequency range (Fig. 3). Note that if the signal contains more harmonics, all of them will be displayed in the DFT until the selected maximum frequency of interest is reached.
5. Iterative crop of the signal is made by applying a rectangular window and the DFTs are calculated for each resulted signal. The process is repeated until a time length corresponding to three raw estimated periods *T* is cropped from the original signal. The peaks for all DFTs are represented in the overlapped spectrum (Fig. 4). Note that three maxima are always found, that correspond to the number of cycles contained in the truncated signal.
6. Select the number of cycles remained in the signal that will be analyzed by right-clicking the button on the top of the curve.
7. The maximum amplitude found in the iteratively realized DFTs that belong to the signal with the selected number of cycles is displayed. The regression curve is derived for the three biggest amplitudes and its maximum is found. In the window are displayed the estimated frequency, the calculated amplitude and the true amplitude (estimation) calculated by considering the number of samples contained in the signal.

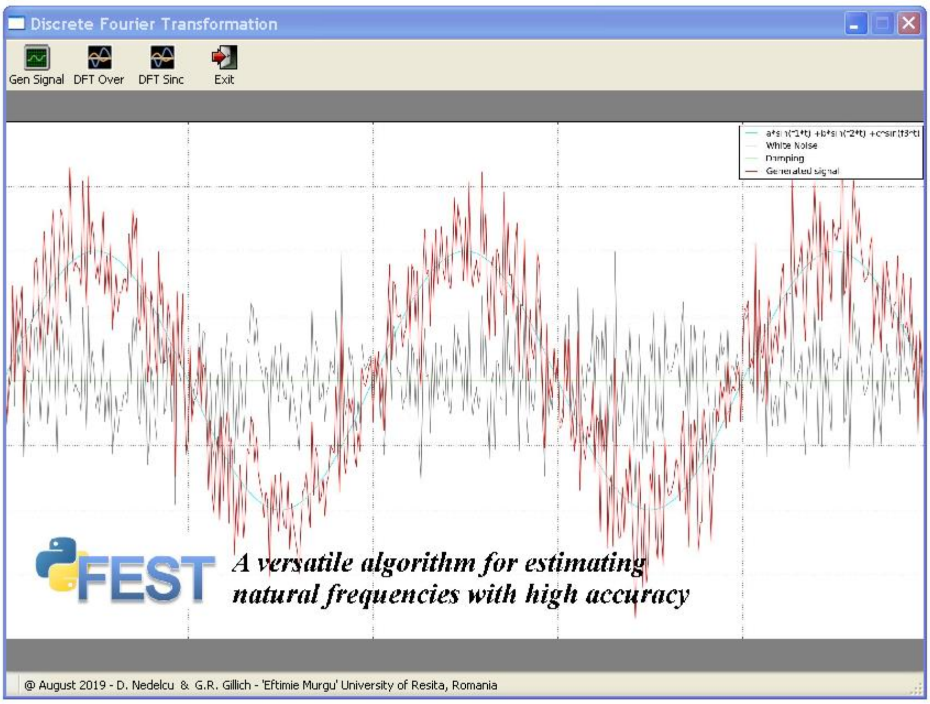

Figure 1. PyFEST application interface

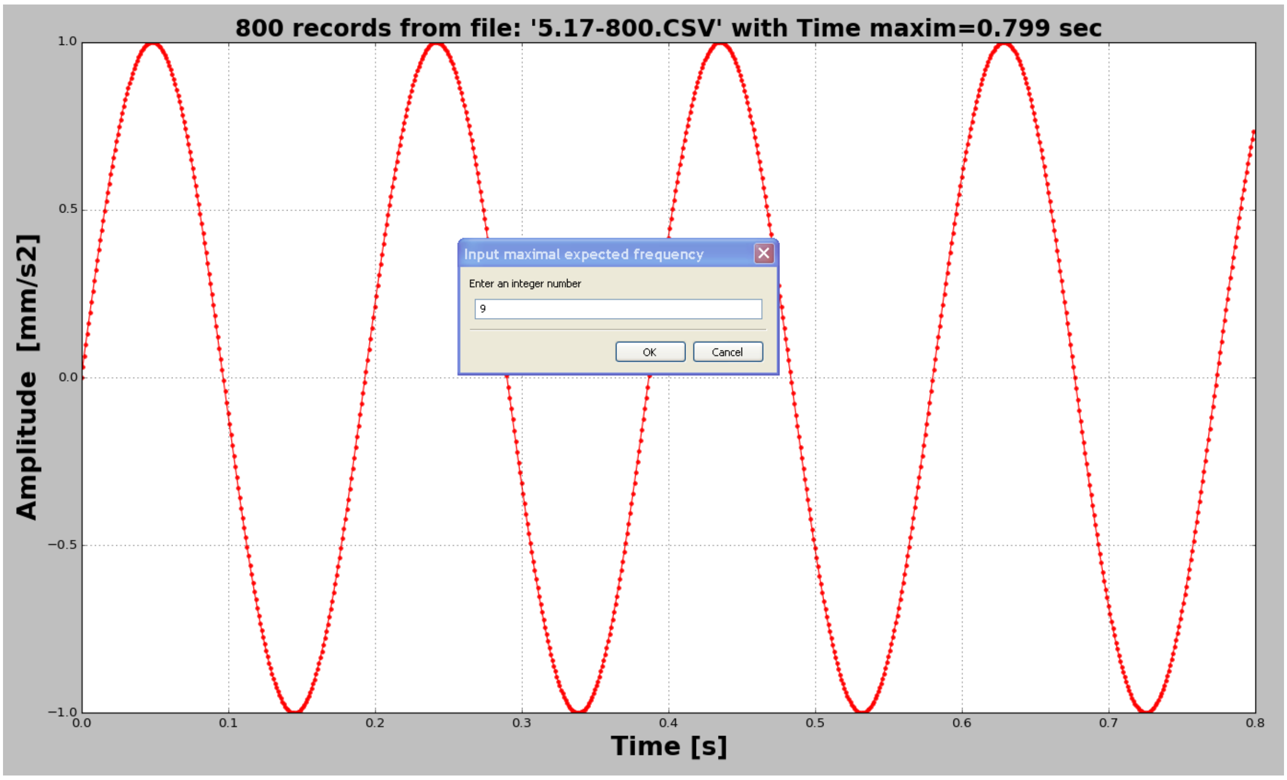

Figure 2. The window used to display the imported signal. In the center of the window is a command window used to set the highest frequency of interest. By right-clicking the OK button a new window opens.

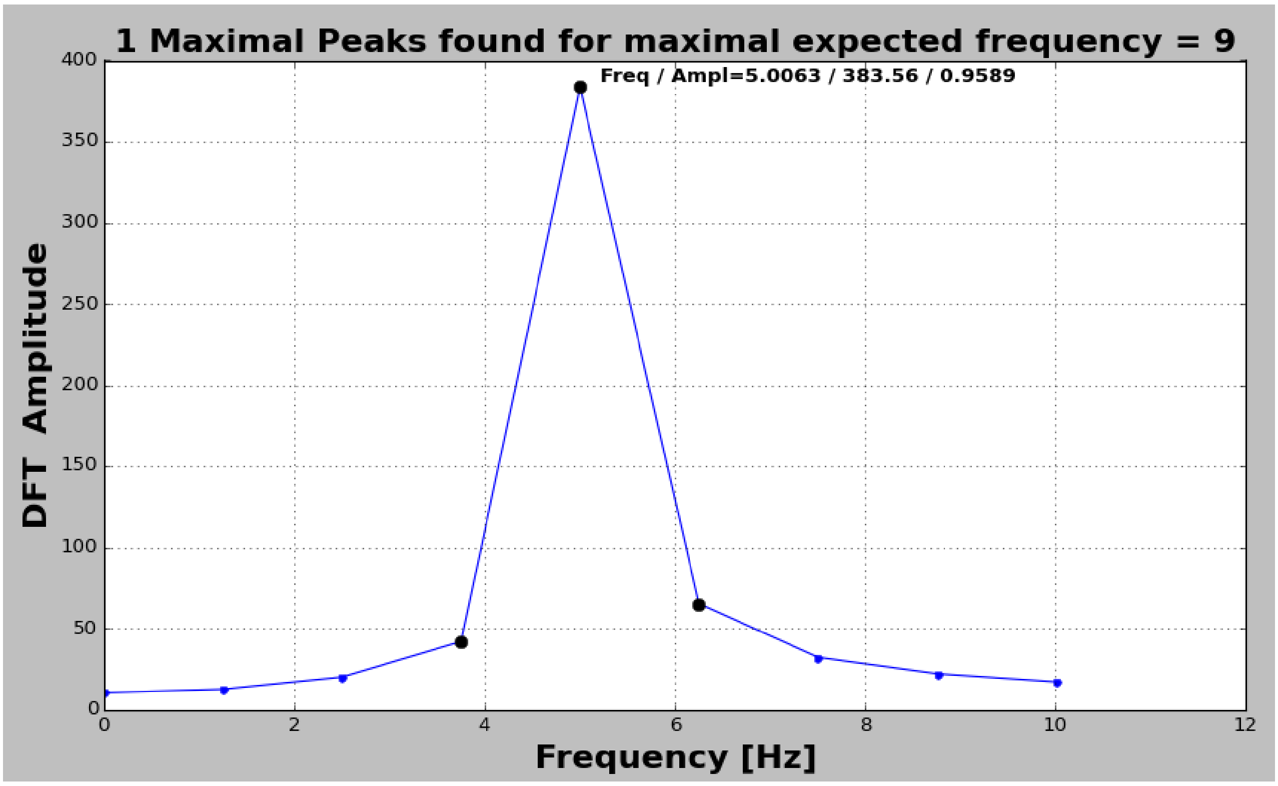

Figure 3. Window displaying the standard DFT. The biggest amplitude and the corresponding frequency are indicated. Note that this frequency is a raw estimation. Right-clicking the bullet at the top of the DFT start the signal processing and the results are displayed in the next opened window.

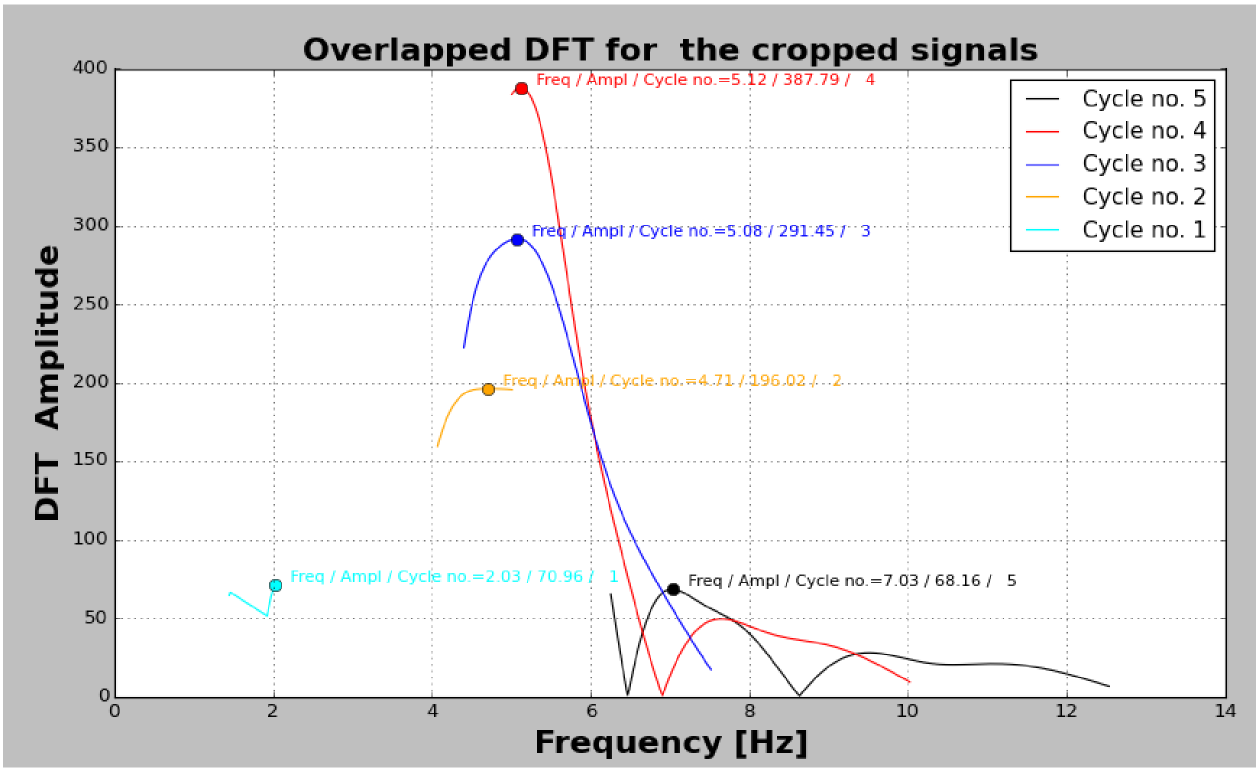

Figure 4. Window displaying the overlapped DFT. The calculated peaks are displayed by different colors in function of the number of cycles contained in the truncated signal. The maximum found for each cycle is marked with a bullet. By right-clicking the desired bullet the interpolation is performed and the results are displayed in the next window.

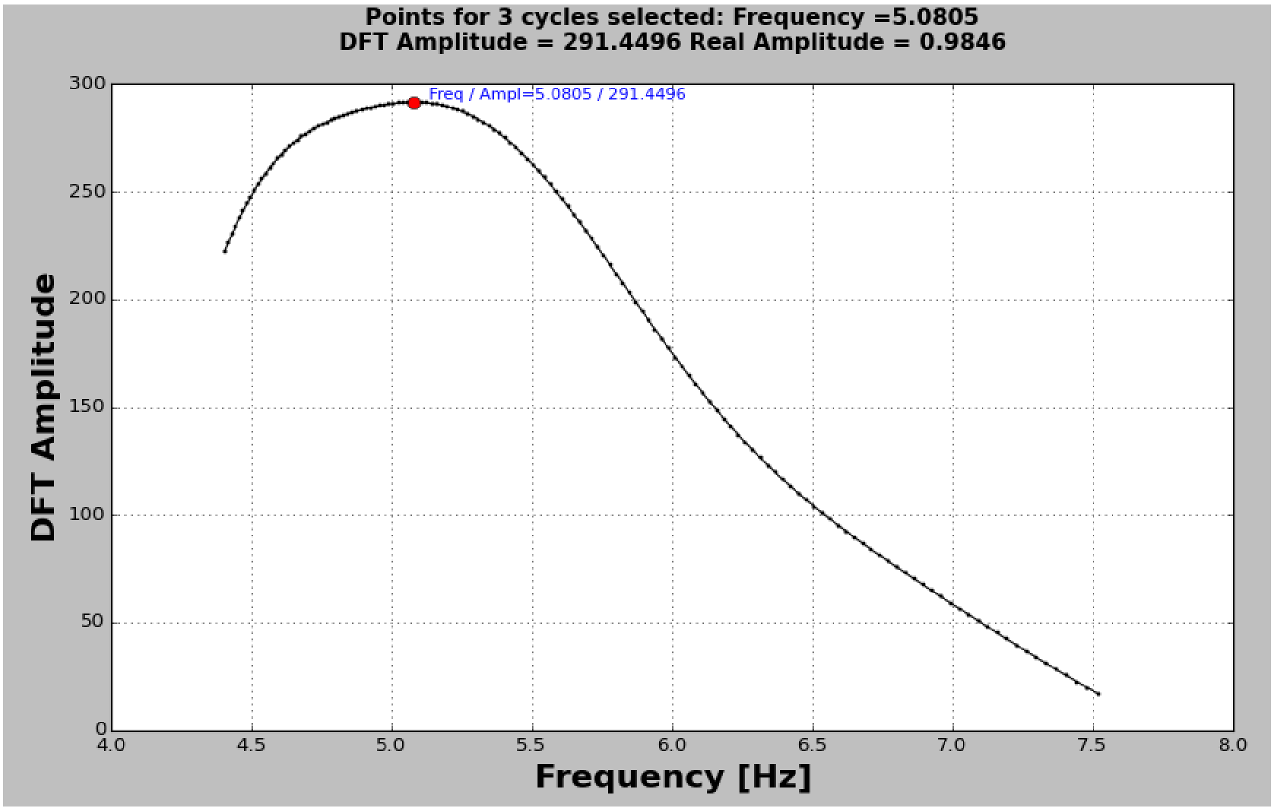

Figure 5. Window displaying the amplitudes calculated for the selected number of cycles and the maximum derived from the regression curve. The estimated frequency, the amplitude and the real amplitude calculated in function of the number of samples contained in the signal are displayed.

3. RESULTS AND DISCUSSION

We performed numerous tests to find out if the algorithm and the application developed on it work properly. In this section we present estimation results achieved for a signal generated with the frequency $f = 6.33\,\text{Hz}$ and the amplitude $A = 1$. The number of samples used to generate the signal varies between $N_{\min} = 278$ and $N_{\max} = 1269$. This number of samples is selected in order to cover a time length that corresponds to a range of cycles between 4 and 20. The sampling frequency $r = 1000\,\text{Hz}$ is used in all analyzed cases.

The results are presented in a concentrated form in Fig. 6. One can observe that the results and consequently the errors are similar if we involve in the analysis signals constructed with different number of samples. This happens because by truncation the final signal length is the same for all original signals that contain initially samples in a given range. Based on the comparison of the estimates made with the standard DFT, shown in Fig. 3, and that made by involving the original algorithm, shown in Fig 5, we can certainly conclude that the latter method is more precise.

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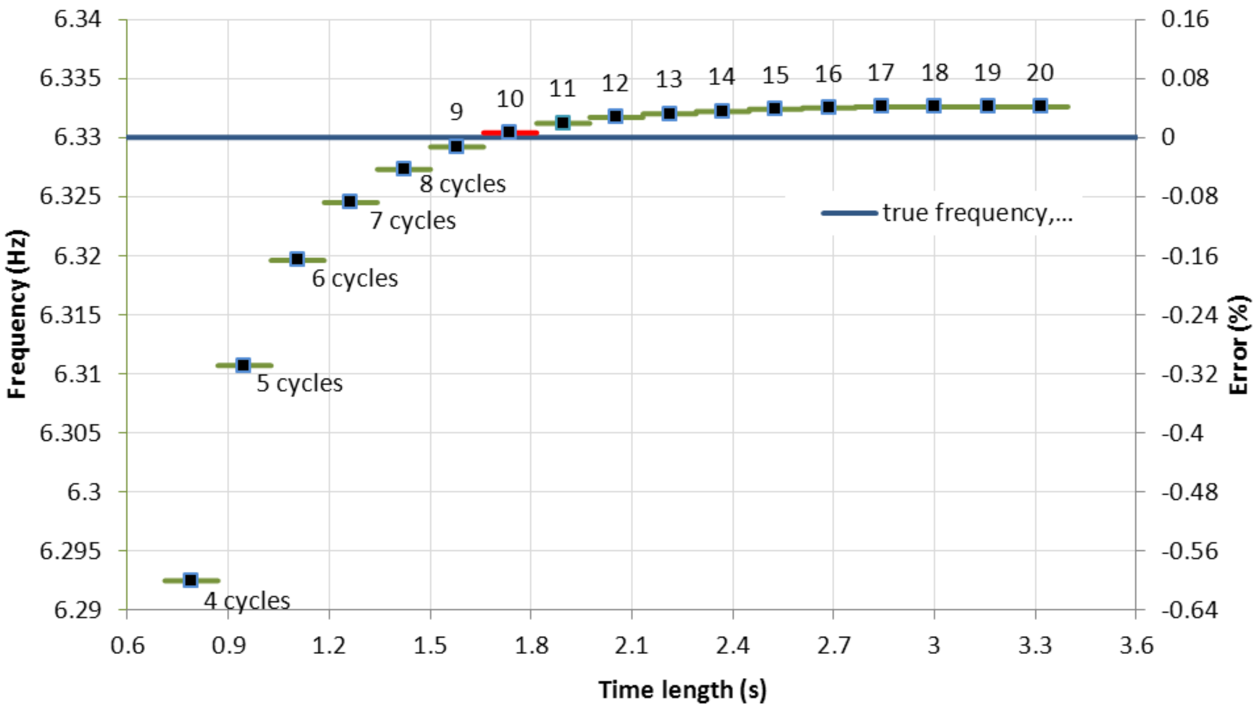

Figure 6. Frequency evolution and the resulted error in function of the number of cycles taken into consideration in the analysis

It can be observed from Fig. 6 that the precision increases with the number of analyzed cycles, i.e. with the time length. For the signal containing few cycles the error is up to 0.6%, while for more than 15 cycles the error is stabilized and predictable (around 0.04%). This accurate estimation permitted observing very small frequency changes. A domain for which this application was developed is damage detection. For real systems, we succeed to detect the occurrence of cracks in very early stage [18,19].

4. CONCLUSION

The paper present an algorithm, implemented in an application, written in the Python programming language, which permits an easy and extremely accurate estimation of the harmonic components of a signal. Tests made for signals with known frequency have shown that the accuracy depends on the number of cycles contained in the final signal, which should be bigger than eight to achieve an error less than 0.1%.

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