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MOTION MAGNIFICATION TECHNIQUES FOR AEOLIAN VIBRATION MEASUREMENTS

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Introduction

Aeolian vibration of power line conductors is a known phenomenon but damping it properly can still present a challenge in some cases. What sets Norway apart from most other countries is a large number of long spans, some of them having very high every day tension. Eight out of the ten longest spans in the world are in Norway and the everyday stress goes to 40% of the breaking load. Due to the limitation of existing measurement methods the project of evaluating possibilities of using video recordings to determine the amplitude and frequencies of overhead line vibrations and so far, the results are promising.

EXISTING VIBRATION RECORDERS

Existing vibration recorders have some limitations specially when installed on tension clamps. Currently the only commercially available vibration recorder is the Pfisterer-Sefag VIBREC® 500 recorder. The recorder stores the data for conductor bending relative to the clamp end at a distance 89 mm from the clamp end. In addition frequency is stored as well as ambient temperature and wind speed. Attachment of the recorder to the tension clamp is showed on Figure 1.

FIGURE 1 - Movement sensor positioning

One of the problems is that in case that the entire clamp is pivoting around the attachment point to the tower vibrations are not registered correctly because the relative movement between the conductor and clamp does not correspond to the actual vibration occurring. When interpreting the results recorded, it is important to understand how data is stored. Due to memory saving, the recorder uses the so-called classifying approach where the number of cycles that fall it to certain frequency-amplitude range is stored in the frequency amplitude matrix. Prior to every measurement one has to set the frequency and amplitude classes in the recorder, it has a total of 32 amplitude and 32 frequency classes. All the values that have an amplitude or frequency outside the set minimum and maximum limits are discarded and not recorded in the data matrix.

For example one frequency class can be set up to be from 5 to 10 Hz, and one amplitude class can be set up to be from 562 to 625 micrometres. When we are interpreting results, if we see that in this class we have 5 events we do not know the actual frequency and amplitude of those events. We only know that there was 6 vibration cycles with frequencies larger than 5 Hz and smaller or equal to 10 Hz and with amplitudes larger than 562 micrometres and smaller or equal to 625 micrometres. Example of stored data is shown in Figure 2.

FIGURE 2 - Classifying approach to data storage

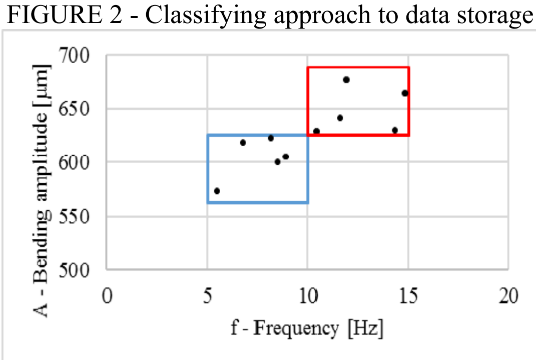


FIGURE 3 - Insulator string failure on Storfjord crossing

FIGURE 4 - Glass insulator pin fatigue fracture surface

Due to possible severity of fjord span vibrations conductor fatigue is not the only fatigue damage that can occur. At least on two occasions, insulator string components failed due to fatigue. Figure 3 and Figure 4 show an example of such a failure where an insulator on Storfjord crossing failed. On spans that are usual for power lines, ranging from 200 m to 800 m, main concern is conductor fatigue. On fjord spans that can have a length op to 5,5 kilometres fatigue and vibration of string components can be of great concern.

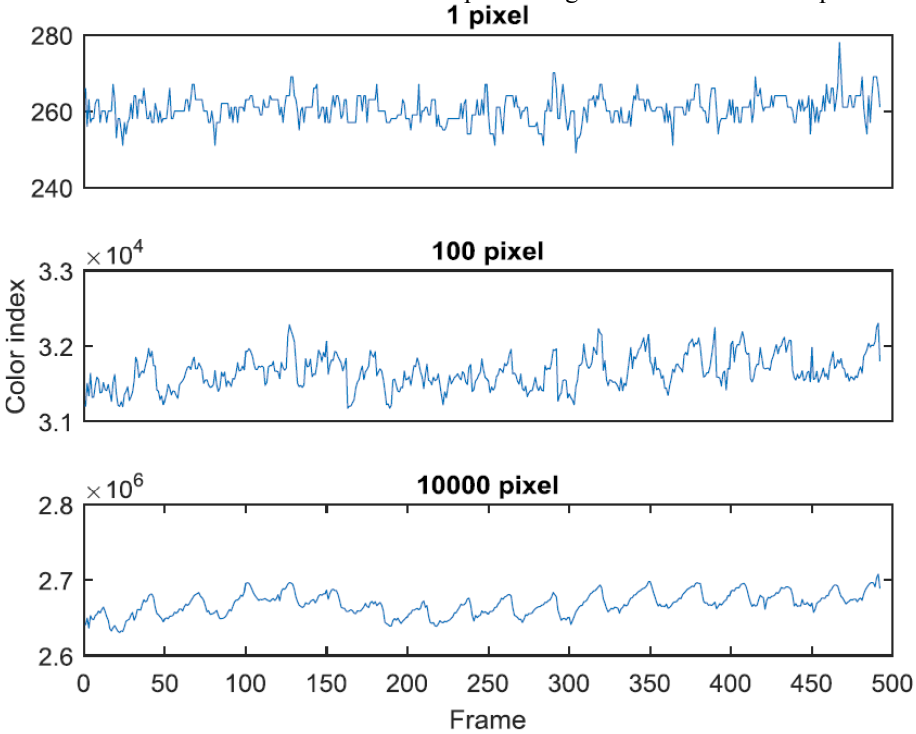
In addition, on some measurements performed on energised power lines there was a very clear predominance of 50 Hz vibrations. Achievable frequency resolution with existing recorders is 1 Hz. One of the obvious thoughts was that the 50 Hz vibrations should be filtered out to eliminate the influence of the power line on measurement electronics. However, measurements were performed on the same span prior to energising and there was a large number of 50 Hz vibrations recorded as well. This raised the question should the 50 Hz vibrations be filtered out or not.

Taking in to account the above-mentioned facts a project that would access the possibilities of measuring vibrations by means of processing videos recordings was started.

DETECTION OF SMALL COLOUR AND MOTION VARIATION

Commercially available vibration recorders have certain limitations specially when used on spans with dead-end clamps since only the relative movement of the conductor compared to the dead-end is registered. Measuring on energised high voltage power lines provides additional challenges and limitations. In cooperation with STRI and other regional utilities (Fingrid, Landsnet and Svenska Kraftnät), Statnett decided to start a project exploring the possibility of vibration measurement by means of processing videos captured with enough frames per second [2]. So far analyses of a series of laboratory-recorded videos of a shaker were performed. Matlab code for the video analysis was written by STRI, and the videos provided by Statnett. The person performing the analysis did not know the amplitude and frequency of the vibrations. The method is based on analysing variations of pixel colour values and extracting frequency and magnitude of the vibrations from the analysis. Each pixel of an RGB image has three colour components (red, green and blue) and each component is saved as an 8-bit digit resulting in a 255^3 possible colours. Small colour variations not visible to humans might contain valuable information; however, the colour variation of pixels due to noise might be stronger than the variation cause by the signal of interest. One possible technique of increasing the signal to noise ratio is to analyse a large population of pixels and the integral of all the small colour variations might come above the noise level. To illustrate this, heart beat rate was extracted from a video taken from a thumb exposed to high intensity. Colour variation of the thumb (due to flow of blood) was extracted when 1, 100 and 10 000 pixels were processed. This is shown in Figure 5. As it can be seen, processing more pixels would reduce the noise contribution to the outcome of the analyses. It is important to notice that the colour variation of the thumb is not visible by naked eyes; however, it would appear in the numerical components of the video's frames.

FIGURE 5 - Heart rate extraction from processing of colour variation of pixels



Similar approach can be used to detect small vibrations. If motion of an object is larger than a pixel of a video taken from the object, the frequency and the magnitude of the motion can be extracted from the video file. While the frequency can be extracted very accurately, the error of the magnitude estimation would be as large as the distance covered by each pixel of the video. If the object has a different colour than the background colour, the edge of the object can be detected by detecting the colour change. If the camera does not move, the motion of the object is equal to the motion of the edge of the object and the background. This concept is shown in Figure 6. An object (shown with grey colour) is vibrating in a white background environment. In this image, there is a sharp edge between the object and the background. The colour of the image along line 1 (moving upward) starts with white colour which has an equivalent RGB number of (255,255,255). As long as the colour is white the pixels get the same number. When the pixel on line 1 enters to the area of the object, the colour changes to grey with the equivalent RGB number of (128,128,128) for this case. If the object moves up and down, it is possible to detect at which pixel along the line 1, this change of colour occurs. By monitoring position of the colour change over time, and using Fast Fourier Transform (FFT), it is possible to extract frequency and magnitude of the vibration. The transition of colours in Figure 6 happens very sharply in just one pixel, which is because this image is made in a computer. When a picture is taken with a digital camera, the edge between the object and the background would not be as sharp as it is in Figure 6. Due to light scattering, the transition occurs less sharp and can take a few pixels as shown in Figure 7. Therefore, to localize the edge of the object along line 1, a threshold has to be used by which if the colour number changes beyond that threshold, that location would be defined as the location of the edge.

Due to existing of random noise, as it is visible in Figure 7, the pixel's colour of the background and the object may change from one image to another even if there is no motion at all. This would introduce an error in localization of the edge, which may lead to significant error in magnitude and frequency estimation if the real motion is small. A solution to this issue is to use more calculation

lines for analysis of the video. The edge between the object and the background has to be detected along line 1 to line N. Assuming that the object does not bend over this small section, and by taking average position of the edge along the calculation lines, a relatively accurate estimation of location of the edge can be achieved. The analysis would be performed on all frames of the video so to extract the motion of the edge over time. Using FFT, exact frequency and magnitude of the vibration can be calculated.
Using this simple approach and since the location of the edge can be calculated at best with one pixel accuracy, the total accuracy of the vibration magnitude would be equal to the distance covered by one pixel of the image. As an example, a full HD video taken around half a meter away from a vibrating conductor can lead to an accuracy of around 0.5 mm in detection of amplitude of vibration. Frequency of the vibration on the other hand can be calculated very accurately provided that the video is recorded at a frame rate at least twice than the highest vibration frequency. The typical section of the conductor or shield wire needed for the analysis is only a few centimetres and hence our assumption regarding stiffness of the object over this section would be valid.

FIGURE 6 - Edge localization using colour change tracking

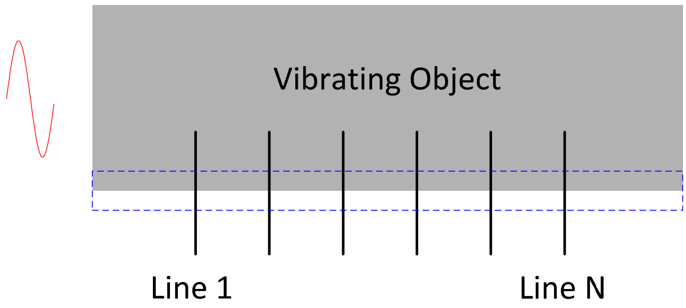
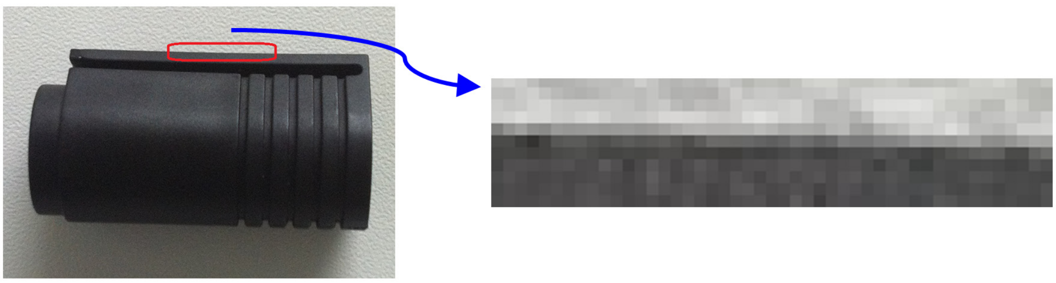


FIGURE 7 - Slow transition of colours near the edge and presence of noise in the image



EXPERIMENTAL VERIFICATION

In order to test the functionality of the proposed method, a shaker capable of producing vibrations with frequency and magnitude similar to what usually occurs at overhead lines was used. Stattnet has provided STRI two sets of seven and eight videos taken from the shaker vibrating at a known frequency and magnitude (not known to STRI). The videos of each set were taken at a different phase angle (α) and at different distance (d) from the shaker. This was done to test the sensitivity of the method with respect to the recording angel and the distance between the camera and the test object. This is important since in the real application distance between camera and overhead line conductor would be in the range of tens of meters and recording angel might vary from case to case. Schematic of the video recording system is shown in Figure 8. Photos of the experimental setup are shown in Figure 9. The videos were processed using the introduced method. Frequency and magnitude of the vibrations extracted from the video files together with real values are shown in Table 1 and Table 2.

FIGURE 8 – Schematics of the video recording system and the vibrating wire

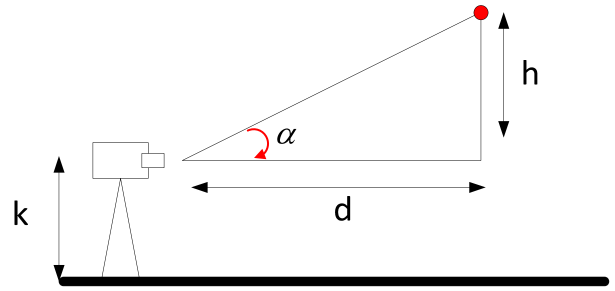


FIGURE 9 - Photos of experimental setup (red circle in the right image is the processing region)

TABLE 1 - Videos recorded at an angle of 20 degrees and 40 cm away from the shaker

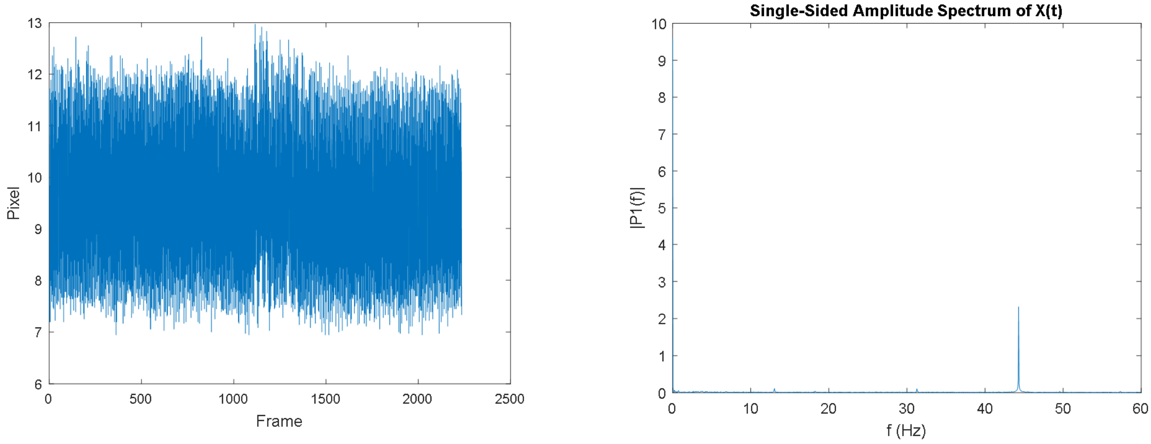
	Frequency [Hz] (error [Hz]) /Actual frequency [Hz]	Magnitude peak–peak [mm] (error [mm]) /Actual magnitude [mm]
Vid1	12.8 (±0.02) / 12.8	0.38 (±0.53) / 0.35
Vid2	12.8 (±0.02) / 12.8	1.17 (±0.53) / 1.25
Vid3	23.7 (±0.02) / 23.7	0.44 (±0.53) / 0.46
Vid4	23.7 (±0.02) / 23.7	2.10 (±0.53) / 2.16
Vid5	44.3 (±0.02) / 44.3	0.61 (±0.53) / 0.64
Vid6	44.3 (±0.02) / 44.3	2.41 (±0.53) / 2.44
Vid7	80.3 (±0.02) / 80.3	0.55 (±0.27) / 0.62

TABLE 2 - Videos recorded at an angle of 35 degrees and 120 cm away from the shaker

	Frequency [Hz] (error [Hz]) /Actual frequency [Hz]	Magnitude peak–peak [mm] (error [mm]) /Actual magnitude [mm]
Vid1	6.5 (±0.02) / 6.5	0.59 (±0.85) / 0.62
Vid2	6.5 (±0.02) / 6.5	2.12 (±0.85) / 2.22
Vid3	13.1 (±0.02) / 13.1	1.09 (±0.85) / 0.89
Vid4	13.1 (±0.02) / 13.1	1.85 (±0.85) / 1.84
Vid5	35.2 (±0.02) / 35.2	0.68 (±0.85) / 0.58
Vid6	35.2 (±0.02) / 35.2	1.01 (±0.85) / 1.35
Vid7	41.1 (±0.02) / 41.1	0.68 (±0.85) / 0.95
Vid8	41.1 (±0.02) / 41.1	1.31 (±0.85) / 1.81

As it can be seen from the results shown in Table 1 and Table 2, frequency of the vibrations can be retrieved very accurately while the accuracy of amplitude of the vibrations depends on the special resolution of the video file. In fact, even if the vibrations are very small (less than a pixel), still the frequency of vibrations can be extracted from the video file. Using advanced filtering techniques (not used in this paper) it is possible to extract amplitude of the motion even when the motion travels less than a pixel [3]. As it is shown in Table 2 the error of magnitude evaluation is 0.85 mm which is very large. This is due to the fact that the distance between the camera and the shaker was larger than the first set of experiments and since the camera was not zoomed on the shaker, each pixel of the video covered a larger area, which resulted in a lower accuracy. This issue can be solved if camera is zoomed on the shaking wire. Example of the data and FFT of the data is shown in Figure 10. In this example, the amplitude can be calculated from RMS of the left image or using FFT magnitude from the right image. To achieve a better accuracy, each video file was processed on several sections of the shaking wire and the average of all calculations was used as the final frequency and amplitude estimation. In the example shown in Figure 10 using RMS the amplitude of the vibrations turned out to be 2.45 mm and using FFT it was 2.31 mm. That gave an average of 2.38 mm. By using the other sections of the same video file for the processing purpose, and taking average of the all calculations lead to a value of 2.41 mm for amplitude and 44.32 Hz for frequency of the vibrations.

FIGURE 10 - Left: variation of the conductor edge position. Right: FFT of the edge position



CONCLUSION

The analyses of laboratory made videos of a vibrating shaker have shown that, given a high enough video frame rate and a stable camera, the frequency can be obtained with a high accuracy while the amplitude with a moderate accuracy. The amplitude accuracy is dependent on the number of pixels across the object of interest, i.e. the resolution. Because of the high FPS and high resolution required for recording the videos, at the moment the method is only considered for short term monitoring (recordings) of high voltage power lines or other structures that are difficult to access.

If used on power line vibration measurements, two clear advantages would be no need for an outage on a power line for installing the measurement equipment and the possibility to perform measurements with relatively inexpensive commercially available equipment. As mentioned, at the present stage the frequency can be determined with a sufficient accuracy, given a high enough frame rate of the videos taken, while the amplitude is highly dependent on the resolution of the videos and size of the object filmed. The project will be taken further; more comparisons and field experiments will be conducted. Furthermore, possibility of improving accuracy of magnitude estimation will be studied by using different filtering methods.

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