

Angular Frequency Analysis of Wind Turbines by means of Digital Image Processing

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Abstract: This paper proposes a method to calculate the angular frequency of a wind turbine by using Artificial Vision techniques. For a given video in which several wind turbines appear, the set of frames that compose it are taken out. Then, a certain frame is analyzed to determine the wind turbines presented in the image. To deal with that, a preprocessing is carried out in order to improve the image contrast. Applying several filters, main regions of the image are emphasized remaining those ones which present a linear shape. They are identified as potential towers. Next, a rectangular region is defined in the upper area of the rotor. For this region, the number of white pixels is computed for every frame of the video. Maximum values correspond with blade sweeping that allow us to compute the angular frequency.

Key-Words: image processing, wind turbine, angular frequency

1 Introduction

A wind turbine is a machine that converts the kinetic energy in wind into mechanical energy. If the mechanical energy is used directly by machinery, the machine is usually called a windmill. If the mechanical energy is converted to electricity, the machine is called a wind generator, or more commonly a wind turbine.

Fixed-speed wind turbines produce voltage flicker during operations. Some reserchers have tried to predict flicker emission from wind turbines at a certain site previously to installation [7]. Others have analyzed the Doppler spectral content of the wind turbine clutter (WTC) signal and have characterized it, in order to develop specific mitigation schemes [2].

Image processing has been used in many scientific fields, such as in medicine or biology, where researchers represent different types of cells by its texture properties [4], or distinguish between alive or dead cells by analysing their images [6]. In the renewable energy field, it has been also used to develop a field calibration technique for aligning a wind direction sensor to the true north [3], and to monitor the damage of wind turbine blades by measuring its bending [1].

In this work, we have used image processing techniques to calculate automatically the angular frequency of an unknown number of wind turbines from a video. The proposed method allows us to analyse

flicker emission from a wind turbine in such a way that it is unnecessary to obtain the data from the wind farms. This avoids to get permissions and other bureaucracy that is sometimes a tough task.

In section 2 we present the process followed to identify the towers and the blade sweeping. Obtained results are showed in section 3. Section 4 gathers the achieved conclusions.

2 Methods

2.1 Image adquisition

Having a short video with some wind turbines working, what we need to do first is to separate it into frames. Matlab has a function that allows us to obtain the frames of a video, so we use it, and we save those frames in a directory so that we can use them later as independent images. We suppose that the videocamera has not been moving while taking the video. If not, it would not be possible to apply this method. In case that the video is recorded from different points of view, we just need to edit it and save each perspective as an independent record.

2.2 Preprocessing

Once we have obtain the frames, we choose one to locate the towers of the wind turbines. In order to

do that, we have to process the image so that we can distinguish between the wind turbines and the background. The preprocessing consists on turning the color image into greyscale format, and then, mapping the intensity values of the image to a new range by modifying its histogram. To deal with that, the values in the original image are saturated at low and high intensities. This mapping produces a higher-contrast image as it is showed in Fig. 1.

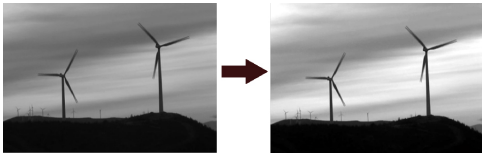


Figure 1: (left) Original imagen. (right) Resulting image after adjusting its histogram.

2.3 Segmentation

Segmentation consists on dividing an image into its different parts. For doing it, we firstly convert the greyscale image to a binary image, using the Otsu's method [5]. So, a threshold that minimizes the intra-class variance of the black and white pixels is chosen. The output binary image has values of 1 (white) for all pixels in the original image whose luminance is greater than such threshold and 0 (black) for all other pixels. For this work, regions to analyze are white on a black background (see Fig. 2).

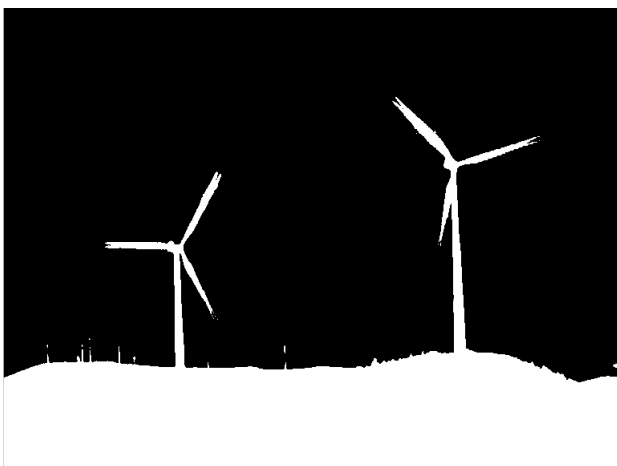


Figure 2: Binary image obtained after segmentation.

Secondly, we create a two-dimensional filter with a 3×3 kernel that emphasizes vertical edges by approximating a horizontal gradient.

$$VerticalPrewittFilter = \begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$$

Then, we apply it to the binary image, obtaining a new image with the zones that better fits to the towers (see Fig. 3).



Figure 3: By applying the Prewitt Filter, the most of the background is removed, keeping vertical regions of the image.

2.4 Tower detection

In the segmented image, we need to find those regions that belong to the towers. As we have just found the regions which better fit, we label them and measure them, computing their areas. We sort them in order to easily find the smaller ones and remove them. After this process, we can see in Fig. 4 how the wind turbine towers are identified.

Finally, we erode the non vertical regions by creating a flat, linear structuring element and applying it to the image. This erosion is more aggressive, such as blades are removed and just the towers (really vertical regions) are left (Fig. 5).

As this erosion may erode bits of some regions, we superimpose the final vertical regions image to the previous one, obtaining this way those regions that determine the wind turbine towers as we can see in Fig. 6.

2.5 Region of interest definition

Once we have identified those wind turbine towers which appear in a frame, we define a rectangular box of $m \times n$ pixels in the upper region of the rotor as it is

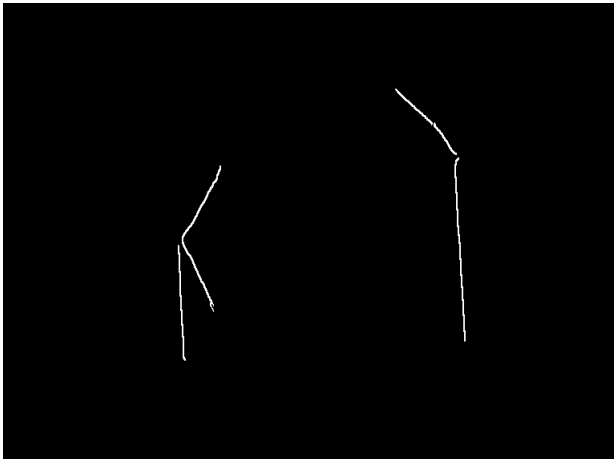


Figure 4: Wind turbine towers correspond with the bigger regions of the image.

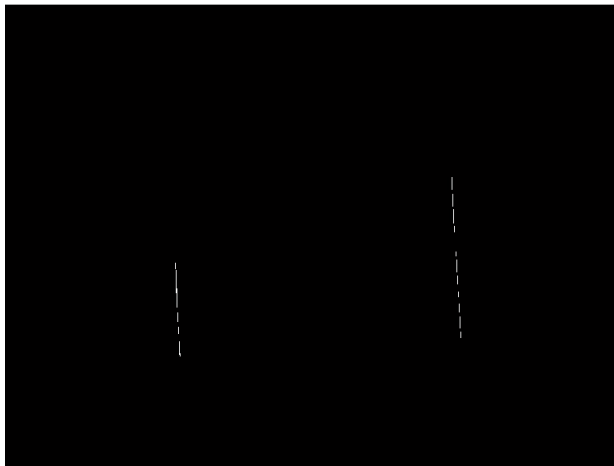


Figure 5: Image obtained after the aggressive erosion.



Figure 6: Final image where towers are white regions on a black background.

showed in Fig. 7. We define n as the tower width and $m = L/3$, being L the tower height. We focus on this region to determine when a blade sweeping happens.

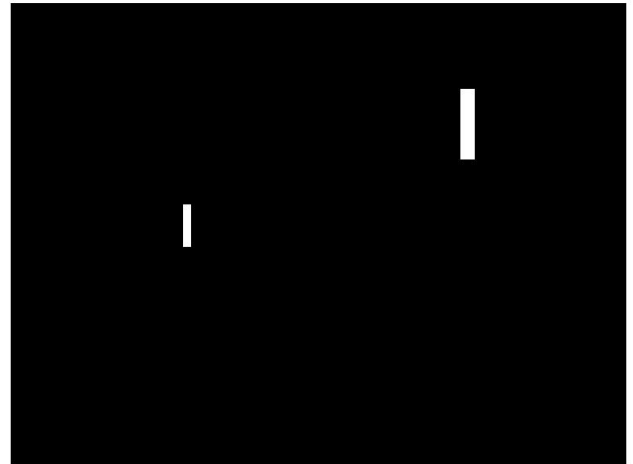


Figure 7: For each wind turbine, a region of interest is defined.

2.6 Blade sweeping identification

For all the frames that comprise the video, we apply the preprocessing and segmentation procedures obtaining a binary image that keeps mostly the wind turbine structures (see Fig. 3). For those images, we compute the number of white pixels in the region of interest previously defined. So, we can see how such number varies across frames (Fig. 8). Maximum values indicate when the blade is passing, so we can calculate the period T .

Let be f_i and f_j two consecutive frames where maximum values are achieved. As the wind turbine presents three blades, the period T is computed as:

$$T = \frac{1}{n}(f_i - f_j) * 3 \tag{1}$$

being n the number of frames per second.

Finally we compute the angular frequency for each wind turbine of the image as:

$$\omega = \frac{2\pi}{T} \tag{2}$$

3 Experimental Results

Experiments have been carried out considering three videos of wind turbines. They have been captured by using a digital video camera. The frame size is 768×576 pixels and is a true color image. Video

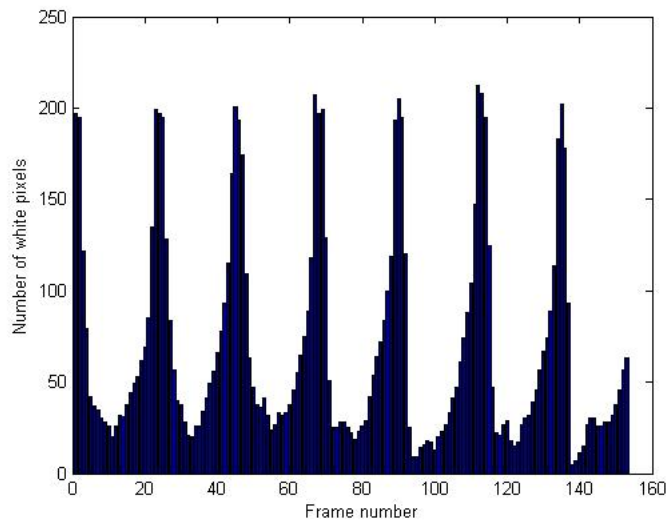


Figure 8: White pixel variation in the region of interest across the frames of the video.



Figure 9: Examples of videos considered for experiments.

compression used is FMP4 and the frame rate, 1/25. Videos present several wind turbines, at different distances and from different points of view. Examples of frames of such videos are showed in Fig. 9.

For the considered videos, we compute the angular frequency of the wind turbines that appear in the images following the proposed procedure. Obtained results are showed in Table 1.

We can also know if the wind turbines that appear in the video are in phase. For doing this, we compute in which second of the video the blade passes for the defined zone from the number of frame:

$$s = \frac{f_i}{25} \quad (3)$$

Table 2 gathers information about the phase.

4 Conclusions

In this work we present a method based on image processing to analyze the angular frequency of a wind

turbine. From a video that presents one or more wind turbines, towers are firstly identified by applying several filters and morphological operators. Then an area is defined in order to determine the blade passing. For all the frames that comprise the video, the number of white pixels in such region is computed. Maximum values correspond with the blade sweeping so angular frequency can be calculated. This is an useful parameter in flicker analysis for those cases where data are not provided by the companies.

References:

- [1] L. Fournier. Wind turbine blades video-based monitoring system. In *EWEC, Business, Science and Technology*, 2006.
- [2] B. Gallardo, F. Pérez, and F. Aguado. Characterization approach of wind turbine clutter in the spanish weather radar network. In *ERAD 2008 - THE FIFTH EUROPEAN CONFERENCE ON RADAR IN METEOROLOGY AND HYDROLOGY*, 2008.
- [3] Jeong Wan Lee. Field calibration of wind direction sensor to the true north and its application to the daegwanryung wind turbine test sites. *Sensors*, pages 7783–7791, 2008.
- [4] T. Markiewicz, S. Osowski, L. Moszczynski, and R. Salat. Myelogenous leukemia cell image pre-processing for feature generation. In *V International Workshop Computational Problems of Electrical Engineering*, 2003.
- [5] N. Otsu. A threshold selection method from gray-level histograms. *IEEE Transactions on Systems, Man, and Cybernetics*, 9(1):62–66, 1979.
- [6] A. Santos, C. Ramiro, M. Desco, N. Malpica, A. Tejedor, A. Torres, M.J. Ledesma-Carbayo, M. Castilla, and P. Garca-Barreno. Automatic detection of cellular necrosis in epithelial cell cultures. In *Medical Imaging 2001: Image Processing*, volume 4322, 2001.
- [7] C. Vilar, H. Amarís, and J. Usaola. Assessment of flicker limits compliance for wind energy conversion system in the frequency domain. *Renewable Energy*, 31:1089–1106, 2006.

<i>Video</i>	<i>Wind turbine</i>	ω during the video											
1	1	2.38	2.28	2.38	2.28	2.38	2.28						
	2	2.38	2.38	2.38	2.28	2.38	2.28						
2	1	2.38	2.28	2.38	2.28	2.38	2.28	2.49	2.28	2.09	2.49	2.49	
	2	2.28	2.38	2.28	2.28	2.38	2.38	2.62	2.09	2.18	2.38	2.28	
3	1	2.49	2.18	2.76	2.28	2.38	2.38	2.01	2.38	2.38	2.62	2.01	3.08
	2	2.49	2.28	2.38	2.38	2.28	2.62	1.94	2.76	2.38	2.28	2.18	2.62

Table 1: Angular frequencies computed by using the proposed method for the wind turbines that appear in the considered videos.

<i>Video</i>	<i>Wind turbine</i>	<i>s</i> of the video when the blade sweeping happens												
1	1	0.60	1.48	2.40	3.28	4.20	5.08	6.00						
	2	0.04	0.92	1.80	2.68	3.60	4.48	5.40						
2	1	0.32	1.20	2.12	3.00	3.92	4.80	5.72	6.56	7.48	8.48	9.32	10.16	
	2	0.56	1.48	2.36	3.28	4.20	5.08	5.96	6.76	7.76	8.72	9.60	10.52	
3	1	0.60	1.44	2.40	3.16	4.08	4.96	5.84	6.88	7.76	8.64	9.44	10.48	11.16
	2	0.04	0.88	1.80	2.68	3.56	4.48	5.28	6.36	7.12	8.00	8.92	9.88	10.68

Table 2: For each wind turbine, we compute when the blade sweeping happens.