

Study on visual detection method for wind turbine blade failure

Jianping Chen and Zhenteng Shen¹

College of Mechanical Engineering, Tianjin University of Science & Technology,
Tianjin 300222, China.

¹ sztcmx@126.com

Abstract. Start your abstract here...At present, the non-destructive testing methods of the wind turbine blades has fiber bragg grating, sound emission and vibration detection, but there are all kinds of defects, and the engineering application is difficult. In this regard, three-point slope deviation method, which is a kind of visual inspection method, is proposed for monitoring the running status of wind turbine blade based on the image processing technology. A better blade image can be got through calibration, image splicing, pretreatment and threshold segmentation algorithm. Design of the early warning system to monitor wind turbine blade running condition, recognition rate, stability and impact factors of the method were statistically analysed. The experimental results shown showed that it has highly accurate and good monitoring effect.

1. Introduction

As an important part of wind turbine, operating condition of wind turbine blade seriously affect the overall performance of wind turbine. According to statistics, the wind farm accident caused by the blade failure accounted for about 30% of the total accident rate. As the work environment of wind turbine is relatively poor, it is very inconvenience and difficult to maintain it. Once blade broke down, the staff could not found and handle it in time.

The technology of monitoring condition and diagnosing fault of wind turbine blade in on-line way can reduce maintenance operations and help to find the wind machine mechanical and electrical initial failure, which can effectively curb major accidents and prevent the occurrence of joint failure [1]. At present, many non-destructive testing methods of blade quality, such as X-ray, ultrasonic, acoustic emission, optical fiber sensor and infrared thermal imaging detection, but acoustic emission detection is most suitable than others for real-time monitoring active blades[2]. Some people used acoustic emission technology to monitor the load damage process of composite material through the honeycomb sandwich composite static compression failure test [3]. A set of wind turbine blade crack wireless monitoring system was designed by using the acoustic emission in the laboratory environment [4]. There are some new monitoring methods in recent years. Someone made a non-contact detection method based on leaf time difference prediction blade fault to address the shortcomings of contact monitoring of existing fan blades [5]. From the video image to start, the blade state extraction and diagnosis methods were studied in depth by using the digital image processing technology [6], but it could not achieve on-line monitor. There are some companies to begin to try ebbing fiber gratings inside the blades on the time of producing wind turbine blades. Except acoustic and fiber grating detection have had some tests in the actual small wind turbine, other methods are still in the theoretical or experimental study stage. Although the acoustic emission method can realize the



on-line damage detection for the blade and detect the initial failure and track its expansion process, its signal is weak and fastly attenuate [7]. It is difficult to extract the signal in the complex background noise. Moreover, it is extremely sensitive to environment factors. FBG(Fiber Bragg Grating) is light weight and high sensitivity and has wide detection range, but it is more brittle and easy damaged. Once damaged, it would not be replaced. Besides, FBG has some problems on performance stability and price, which leads to its application being limited [8]. In short, there is not yet relatively perfect and mature technology program for detecting defects and damage of wind turbine blade [8-9].

In view of the shortcomings of current study for monitoring wind turbine blade fault on-line, we put forward a three-point slope deviation method based on image processing theory and technology. The method needs to make three markers on the blade. Then the blade operating state could be determined by detecting the slope deviation between the centers. The fault diagnosis effect was tested through designing the experiment.

2. Image processing

2.1. Calibration

Due to manufacturing errors, lens surface error and the axial spacing between lens, the optical camera lens used in the machine vision will have a certain degree of distortion. Distortion affects the accuracy of the parameters extracted from the image feature. Therefore, calibration is necessary before the image processing, the main principle of which is to use of distortion images to reverse the camera internal parameters. The experimental device uses a short focal length CCD lens, which mainly affected by radial distortion.

The lens distortion occurs during the transformation of the camera coordinate system to the imaging plane coordinate system, the relationship is:

$$\begin{bmatrix} u \\ v \end{bmatrix} = \frac{f}{Z_c} \begin{bmatrix} x_c \\ y_c \end{bmatrix} \quad (1)$$

As in equation (1), f is the main distance of the camera.

But there are some gaps between the ideal imaging plane coordinates and the real imaging plane coordinates. If only radial distortion is considered, the corrected coordinates is as follows [10]:

$$\begin{bmatrix} \tilde{u} \\ \tilde{v} \end{bmatrix} = \frac{2}{1 + \sqrt{1 - 4k(u^2 + v^2)}} \begin{bmatrix} u \\ v \end{bmatrix} \quad (2)$$

As in equation (2), k is the radial distortion coefficient. If it was negative, it is barrel distortion, otherwise pincushion distortion.

The corrected imaging plane coordinates is converted to the image coordinate system, and the conversion relationship is as follows:

$$\begin{bmatrix} r \\ c \end{bmatrix} = \begin{bmatrix} \frac{\tilde{v}}{S_y} + C_y \\ \frac{\tilde{u}}{S_x} + C_x \end{bmatrix} \quad (3)$$

As in equation (3), r and c are the coordinates of the image coordinate system, S_x and S_y are the distance between the adjacent pixels in the horizontal and vertical directions of the image sensor, C_x and C_y are the vertical projection coordinates of the projection center on the imaging plane.

$(f, k, S_x, S_y, C_x, C_y)$ is the internal parameters of the camera, and calibration is a process to solve the parameters of camera. It is necessary for solving the problem to use the standard calibration plate. The results is as follows:

$$\begin{cases} f = 3.35981 \times 10^{-3} \text{ m} \\ k = -43039.7 \frac{1}{\text{m}^2} \\ S_x = 4.71095 \times 10^{-6} \text{ m} \\ S_y = 5 \times 10^{-6} \text{ m} \\ C_x = 380.57 \\ C_y = 260.928 \end{cases} \quad (4)$$

The size of the collected image is 768×576 .

The images corrected before and after are shown in figure 1. The bend of the front door and wall in figure 1(a) is very clear, but this is almost eliminated after calibration. The calibration can improve the accuracy of later image processing.

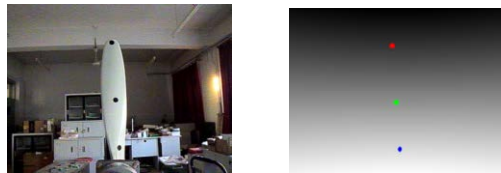


a. Before calibration b. After calibration

Figure 1. Calibration.

2.2. Image segmentation

Due to wind machine working in the wild environment, the background information of the blade image is complicated and mixed with a variety of noise. The pretreatment seriously affects the accuracy of the regional parameters of the blade image extracted and also had great influence on the system reliability. Considering the speed and time of filter, binomial filter is used to reduce the surrounding noise interference. Then the regional area, similar elliptic coefficient and first-order moments of triple selection are used to ensure the accuracy and integrity of the blade segmentation, as shown in figure 2.



a. Three-point position b. Threshold segmentation

Figure 2. Image segmentation.

3. Principle of three-point slop deviation method

The factors, such as the strong wind load, the sand erosion, the atmospheric oxidation and humid air corrosion, would inevitably lead to pores, cracks, wear and corrosion, accumulating to a certain extent of which would cause the blade bending or fracture [11]. Bending and fracture are the most common form of blade failure.

The method that the ribbon is added on the edge of the blade can increase the gray gradient between the blade and the surrounding environment in order to get the better image of wind turbine blade from the background [8]. Likewise, if three points were marked on the blade, the operating status of the blade could be monitored by detecting the possible relative change in the three-point position in real time.

However, the points A , B and C is composed of a number of pixels in image processing, as shown in figure 3. The three regional centers are A_{cp} , B_{cp} and C_{cp} , the coordinates of which are

$(rowA_{cp}, colA_{cp})$, $(rowB_{cp}, colB_{cp})$ and $(rowC_{cp}, colC_{cp})$. The area of blades are $areaA$, $areaB$ and $areaC$, which have i , j and k pixels, then:

$$\begin{cases} rowA_{cp} = \frac{rowA_1 + rowA_2 + \dots + rowA_i}{areaA} \\ colA_{cp} = \frac{colA_1 + colA_2 + \dots + colA_i}{areaA} \end{cases} \quad (5)$$

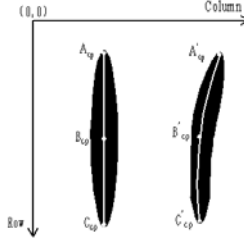


Figure 3. Three-point slope deviation in image coordinate system

The solution of $(rowB_{cp}, colB_{cp})$ and $(rowC_{cp}, colC_{cp})$ is similar to equation (5). In order to make the measurement more accurate, i , j and k should be as equal as possible. The best shape of the three markers should be circular, which helps to extract the center point and improve accuracy.

When blade is normal,

$$\frac{rowB_{cp} - rowA_{cp}}{colB_{cp} - colA_{cp}} = \frac{rowC_{cp} - rowB_{cp}}{colC_{cp} - colB_{cp}} \quad (6)$$

When blade is bent,

$$\frac{rowB_{cp} - rowA_{cp}}{colB_{cp} - colA_{cp}} \neq \frac{rowC_{cp} - rowB_{cp}}{colC_{cp} - colB_{cp}} \quad (7)$$

When blade is bent, a number of mark points are less than three.

Assume that the slope between any two points in the three points is Sv_1 and Sv_2 , then the three-point slope deviation Sv_d is:

$$Sv_d = |Sv_2 - Sv_1|^{-1} \quad (8)$$

In theory, when the blade state is normal $Sv_d = 0$, but due to manual marking errors and feature area segmentation errors, it is always not equal to zero.

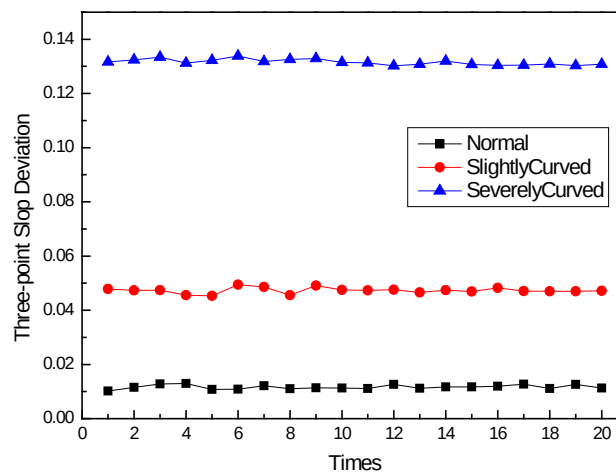
4. Experiment analysis

Twenty consecutive randomized experiments on normal, slightly curved and severely curved blades were performed, as shown in table 1. Each value in table 1 takes the average of ten values, which were obtained in the case of blade rotation. The data of Sv_d was statistically analyzed by using MINITAB, which is a tool dedicated to experimental data analysis, as shown in figure 4. The results of data analysis are given in table 2.

From figure 4, even under normal condition, Sv_d is not zero. Although Sv_d measured through the experiment under normal condition, slightly curved condition and severely curved condition is floating, the distinction is also obvious. Therefore, the operating state of the blade can be judged by setting a suitable three-point slope deviation threshold. At the same time, if the multiple thresholds were set, the classification of the curved degree could be achieved. table 2 shows the specific data of the average, the standard deviation and other information.

Table 1. Experimental data of three-point slope deviation Sv_d

Times	Three-point slope deviation Sv_d		
	Normal	Slightly Curved	Severely Curved
1	0.0102	0.0478	0.1316
2	0.0115	0.0473	0.1324
3	0.0128	0.0474	0.1334
4	0.0130	0.0456	0.1312
5	0.0108	0.0453	0.1322
6	0.0109	0.0494	0.1338
7	0.0121	0.0486	0.1318
8	0.0110	0.0456	0.1326
9	0.0114	0.0491	0.1329
10	0.0113	0.0475	0.1315
11	0.0111	0.0473	0.1313
12	0.0126	0.0476	0.1302
13	0.0112	0.0466	0.1308
14	0.0117	0.0474	0.1320
15	0.0117	0.0469	0.1307
16	0.0120	0.0483	0.1304
17	0.0127	0.0471	0.1305
18	0.0111	0.0470	0.1309
19	0.0126	0.0470	0.1303
20	0.0113	0.0472	0.1308

**Figure 4.** Three-point slope deviation in three different states.**Table 2.** Experimental data analysis results of Sv_d .

Variable	N	Mean	StDev	SE Mean	98% CI	Z	P
Normal	20	0.01165	0.000772	0.000157	(0.011290, 0.012014)	0.32	0.749
Slightly curved	20	0.04730	0.001061	0.000224	(0.046780, 0.047820)	0.45	0.655
Severely curved	20	0.13156	0.001053	0.000312	(0.131045, 0.132085)	0.29	0.771

Double thresholds were designed for fault diagnosis and bent classification. In the case of different speed of the wind turbine blade, the recognition rate of the monitoring system is obtained as shown in figure 5.

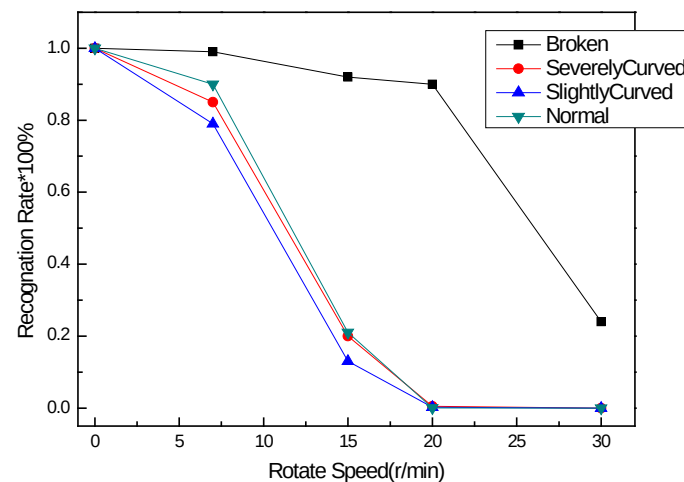


Figure 5. The effect of rotate speed on recognition rate.

From the figure 5, when the blade speed is low, the system has a better recognition for the blade state, low false positives and good reliability. When the blade speed gradually increase, the recognition rate begin to decline, but the diagnosis for blade fracture malfunction is relatively more stable. Through observation, it is the main reason whether the top marker of the blade could be extracted.

When the blade rotates, the line speed of the top mark is the greatest than others. When the exposure is constant, the faster the subject is, the more blurred the image is. As shown in figure 6, when the blade speed is increasing, the impact of the rotational speed for the lower mark is minimal, and the tip mark of blade is rapidly blurred with the increase of the speed, and even the "ghost" will appear.

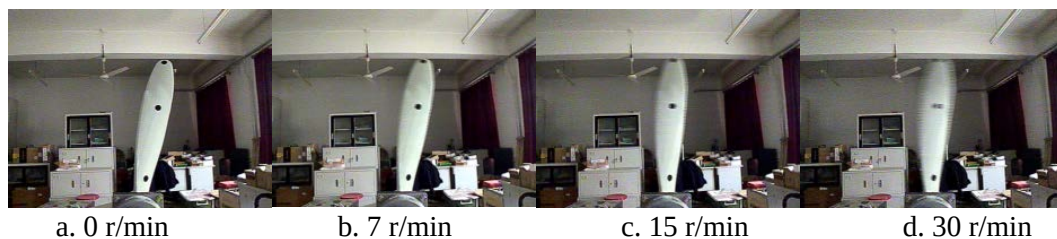


Figure 6. Mark status at different speeds.

However, if the quality of the camera in the experiment can be improved, the impact of speed on system identification will be effectively reduced. Therefore, the camera quality is a key factor affecting the stability and reliability of the system. The selection of it should be strictly based on the actual operating conditions, type and parameters of the wind turbine blade. The location of the camera is shown in figure 7. As the blade is too long, if a camera can not meet the actual shooting requirements, we can use the approach of two cameras real-time mosaic or three cameras fixed-point shooting. The encoder in the wind turbine chassis provides the signal of making camera capture blade picture. You can use fiber or 4G LTE network to transfer image data. The control signal is access to the safety chain circuit, if a fault is detected, the system will automatically make the blade shutdown.

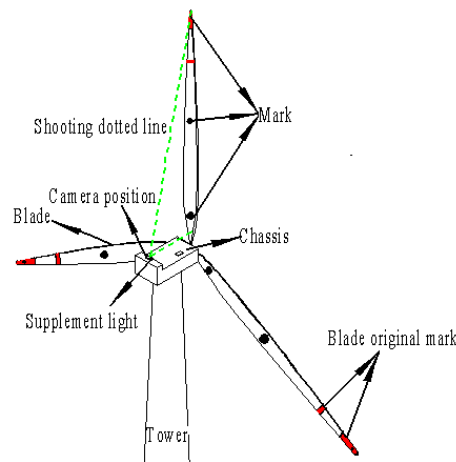


Figure 7. The way of camera and marker arrangement.

5. Conclusions

According to the actual working situation of the wind turbine blade, the three-point slope deviation method based on machine vision is proposed to monitor the running state of the blade. Major conclusions are as follows:

The visual inspection theory of three-point slope deviation is proposed, and the model system is designed. The experiment results proved that the method is effective and reliable. It could effectively monitor the running state of the blade and timely warning in the event of failure.

The system is simple, low cost and good reliability, which is worthy of being promoted and applied.

The impact of blade pitch, non-fault deformation or bad weather on monitoring system need to be further studied. The engineering test will be carried out on the actual wind turbine blade to improve the on-line monitoring and fault diagnosis method.

References

- [1] Jiang D X, Hong L Y, Huang Q, Ding R S 2008 Research on Condition Monitoring and Fault Diagnosis Technology of Wind Turbine J. Grid and Clean Energy **24**(3) 41-44
- [2] Xu Y, Liu W S, Qiao G H 2013 Nondestructive Testing of Large-scale Wind Turbine Blades J. Fiberglass/Composites **3** 76-79
- [3] Wu G H, Liu S Y, Wu W, Zhong J L 2013 Compression Damage Acoustic Emission Characteristics of Honeycomb Sandwich Composites J. Nondestructive Testing **35**(12) 42-45
- [4] Han J Y 2010 Research on Wireless Monitoring System of Wind Power Blade Crack Based on Acoustic Emission Technology D. Beijing Beijing University of Chemical Technology
- [5] Chen J P, Li X, Zhao C X, Wang Y L 2014 Research on wind turbine blades in real-time fault monitoring warning system J. Mechanical Design and Manufacture **8** 161-163
- [6] Zhang L 2013 Research on Blade Defect Diagnosis of Wind Turbine Based on Computer Vision D. Wuhan Huazhong University of Science and Technology
- [7] Zhu Y F, Pan R Q, Chen S P 2010 Health Monitoring Method of Wind Turbine Blade Structure Based on Acoustic Emission Sensor Array J. Nondestructive Testing **32**(10) 753-761
- [8] Liu S, Hu B, Hu Z, Hu Z, Li Y T 2015 Comparison and Evaluation of Nondestructive Testing Methods for Wind Turbine Blade Defects J. Nondestructive Testing **37**(3) 47-51
- [9] Hu Y P, Dai J H, Liu D S 2013 Research Status and Development Trend of Large Wind Turbine Blades J. Journal of Mechanical Engineering **49**(20) 141- 150
- [10] Sonka M, Hlavac V, Boyle R 2011 Image Processing, Analysis, and Machine Vision M. Beijing Tsing hua University Press
- [11] Harris C, Stephens M J 1988 A combined corner and edge detector C//Proceedings of Fourth Alvey Vision Conference Manchester UK IEEE 147-151