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A noise-tolerant method for section parameter extraction in cast blade inspection

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Abstract
The automated optical inspection of casting blades is a promising technology for manual replacement. The inspection quality of section parameters is seriously affected by the surface roughness and the accuracy of a laser scanner. This paper proposes a new noise-tolerant method for section parameter extraction of aero-engine cast blades. An inspection process from automatic scanning to feature parameter extraction is designed. The mean-camber curve, a key parameter in blade inspection, is extracted using mathematical morphology and the theory of medial axis. Then, leading/trailing edges are calculated using fast iterative optimization. In addition, the chord length and maximum thickness are extracted too. Distinct from the final CMM inspection, this proposed in-process inspection method is non-contact, fast and robust to noise. Based on the method, an automated optical system Hust-Scan I is developed for inspection of aero-engine cast blades. After clamping the blade, this system can scan the given 2D sections and generate inspection report automatically. Finally, experiments tested in the system show the efficiency and stability of the proposed method.

Keywords: parameter extraction, cast blade inspection, leading/trailing edge, mean-camber curve

1. Introduction

As a critical part in blade machining, in–process inspection of section parameters is a complicated and tough work. Currently, most of the inspection is performed manually, as shown in Fig 1. But they are labour intensive, time consuming and accuracy low. Furthermore, final-process inspection of section parameters is mainly carried out by CMM, as shown in Fig 2, which is accurate but inefficient. And traditional research [1-3] on section parameters extraction of blades is mainly aimed at the high-quality section point cloud obtained by CMM. However, it's different from the uneven and noisy point cloud obtained by the optical inspection system that is a promising technology. In this paper, a new noise-tolerant method for section parameter extraction is proposed. In addition, for in-process parameter extraction, we developed an automated optical inspection system Hust-Scan II, which is stable and fast.

The remainder of the paper is organized as follows. Section 2 introduces the parameter extraction method. Section 3 presents the developed inspection system and experiment. Finally, section 4 draws the conclusion.

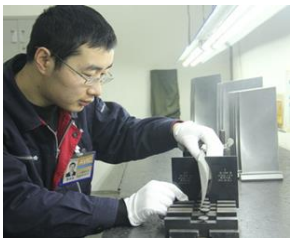

Figure 1. In-process inspection using manual method

Figure 2. Final-process inspection using CMM

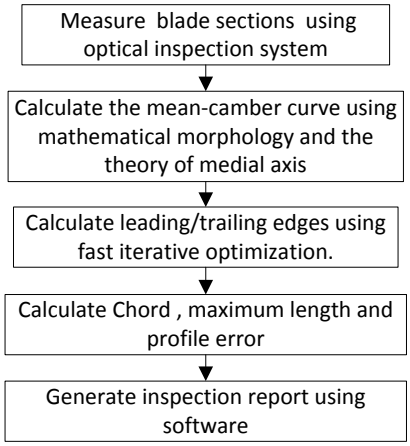

Figure 3. The overall flow chart of parameters extraction

2. Parameters extraction of blade sections

Featured parameters of the blade section include mean-camber curve, leading/trailing edge, chord, maximum thickness, profile error, etc [1-3]. The overall flowchart of the proposed parameters extraction process is shown in Fig. 3.

Sections measurement: A blade is fixed by a clamp to make sure that the 2D laser scanner measures the correct sections that can be expressed as point cloud *P*

$$\boldsymbol{P} = \left\{ \boldsymbol{p}_{ij}\left(x_{ij}, y_{ij}, z_{ij}\right), 1 \le i \le M, 1 \le j \le N_i \right\}$$

Where symbol *M* is the total number of measured sections, symbol N_i is the number of measured points in the section i.

Extraction of the mean-camber curve: We use a mathematical morphology operation to the point cloud of a section to extract the initial mean-camber curve [4].

1) Interpret the section point cloud into 3D grids.

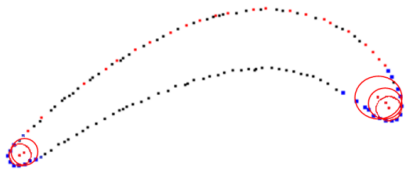

Figure 4. Schematic diagram extracting leading/trailing edges where blue and bold points denote initial leading/trailing points

2) If there is a point in the grid, the value of this grid is defined as "1", otherwise, it is defined as "0". So the 3D grids can be described using a binary image.
3) Execute dilation and erosion operations to the image. Both operations are simple adding and subtracting operations based on an image, and can reduce the noise of the image.
4) Extract the initial mean-camber curve using morphological skeleton operation.

Based on the initial mean-camber curve, the accurate mean-camber curve is extracted by applying the theory of the medial axis [5] to every section, which makes the extracted mean-camber points evenly distributed.

Extraction of leading/trailing edges: The beginning and ending part of the mean-camber curve is used to find the initial leading and trailing edge points, respectively, as shown in fig 4. Here, taking the initial leading edge points $\boldsymbol{P}_l = \{ \boldsymbol{p}_{lj}, 1 \le j \le k \}$ as an example.

1) Circular fitting the points P_l that have been sorted along the direction of the section curve.
2) Find the beginning and ending leading points that are outside the circle and remove them.
3) Calculate the distance deviation ε that can be expressed as

$$\varepsilon = \frac{\sum_{i=1}^{k} \left| \left\| \boldsymbol{p}_{li} - \boldsymbol{o}_l \right\| - r \right|}{k}$$

Where symbol $\boldsymbol{O}_l$ and r represent the center and radius of the fitted circle, respectively.

4) Repeat the process of 1) to 3) until the deviation ε is less than the given threshold.

Extraction of other parameters: Chord can be obtained as the common tangent of the leading and trailing circles. Maximum thickness is calculated as the diameter of the maximum medial circle when extracting the mean-camber curve. Profile error is calculated as the distance from every measured point $\mathbf{p}_{ij}$ to the CAD model after 3D registration using ADF (adaptive distance function) algorithm [6].

3. Experiment

Figure 5 illustrates the developed automated optical inspection system. The 2D laser scanner is made by a linear laser generator and an IMAVISION DHMER-125-30UM/UC-L camera that has 1292 x 964 pixel resolution. The scanner and blade are respectively mounted on a guideway and a turntable to reconstruct the whole 3D section point cloud. Measurement accuracy of the scanner and system is 0.02mm and 0.04mm, respectively. laser generator and an IMAVISION DHMER-125-30UM/UC-L camera that has 1292 x 964 pixel resolution. The scanner and blade are respectively mounted on a guideway and a turntable to reconstruct the whole 3D section point cloud. Measurement accuracy of the scanner and system is 0.02mm and 0.04mm, respectively. The developed software iCloud3D of motion planning, point clouds reconstruction and processing, 3D registration, error profile map generation, parameter extraction and report generation are all programmed using C++. The process of parameter extraction takes about 2s and the extracted result of sixth section are shown in Fig7. Figure 6 illustrates the profile error map that shows the distance deviation of every measured point compared with the CAD model. The entire inspection process from scanning to report generation is automatically executed and needs about 94s.

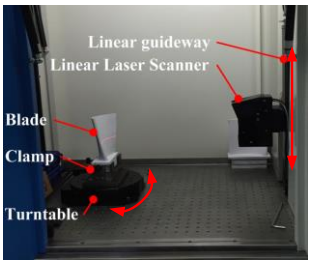

Figure 5. Optical inspection system

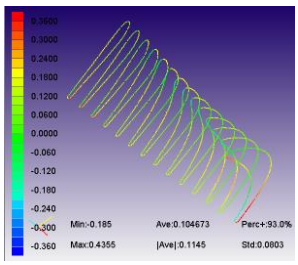

Figure 6. Profile error map

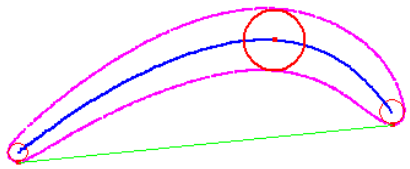

Figure 7. Extracted parameters

4. Conclusion

It has been a challenge to apply the optical technology in the in-process inspection of casting blades for manual replacement. Aiming at this goal, this paper introduces an automated optical inspection system, whose inspection accuracy and efficiency are significantly improved than the manual method. Based on the section point cloud acquired from 2D laser scanner, this paper presents a novel parameter extraction method that is different from that in the final process inspection using CMM. For reducing the noise, mean-camber curve is extracted using mathematical morphology and the theory of the medial axis. The leading/trailing edge is extracted using fast iterative optimization. The experiments show the potential of the automated inspection method and system for a real application.

Acknowledge

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