Delaunay-Based Aircraft Engine Casing Strain Reconstruction and Data Processing

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Abstract. In structural health monitoring, we focus on some critical parts to ensure safety. However, we are unable to install detection components in those parts, due to the structure or the working condition. In order to obtain the strain information of the entire detection area for the engine receiver, we propose a strain reconstruction method based on Delaunay. Besides, we visualize the data for manual processing. In this article, we take the engine fan case as an example. Firstly, we get data from pre-arranged sensors. Next, use EMD (empirically modal decomposition) to process data. Finally, with position data of the detection area, we accomplish strain reconstruction and data visualization. In the end, the validity of the result is analyzed.

1. Introduction
During the service of the aircraft, the harsh working environment is likely to cause damage to the structural components, which can result in the faults, mission failure, and even crashes. As an essential part of the aero engine, the engine casing is the base of the entire engine. It bears most of the external load. The engine casing mainly bears pneumatic load and mass inertial force under working conditions, and also, it can withstand the thermal load, acoustic load, and some assembly stress [1]. The state of the casing reflects the working state of the engine. Health monitoring of the engine casing can significantly improve flight safety.

The strain reconstruction refers to the discrete field information of the finite point obtained by the detection, and the strain field information of the detected portion is obtained by calculation. There are two common ways to achieve. One is to interpolate based on discrete information, and the other is to combine mechanical models for mechanical analysis. However, due to the complexity of the structure and the variability of the load in the working condition. We choose to use the interpolation method to perform strain reconstruction, using Delaunay triangulation interpolation.

2. Delaunay Triangulation
Delaunay triangulation plays a significant role in computational geometry and has considerable value in many fields. Delaunay triangulation algorithm is used to solve problems in many applications, such as the finite mesh generation, robust boundary simulation, image processing, and 3D solid geometry modeling [2].

In this paper, we choose the Triangulation growth method [3]. Using a spatial data point as a starting point, it gradually expands to form a triangulation covering all the point sets, forming a tetrahedral geometric network composed of only scattered points. After the entire area is tetrahedral, we can interpolate the entire scatter set \( (x_i, y_i, z_i, t_i) \) [4]. The data set \( (x_i, y_i, z_i, t_i) \) consists of two parts, one part of its position \( (x_i, y_i, z_i) \) and the other part of its measured value \( t_i \).

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Suppose a tetrahedron $p_1p_2p_3p_4$. Given the four vertices $p_1, p_2, p_3, p_4$, namely: the locations $(x_i, y_i, z_i)$ of four vertices and their values $t_i$. The value $t$ at any arbitrary point $p(x, y, z)$ within this tetrahedron can be found by barycentric interpolation as a weighted average of the values $t_i$.

$$ t = a_1t_1 + a_2t_2 + a_3t_3 + a_4t_4 $$

(1)

Where $a_1 + a_2 + a_3 + a_4 = 1$. The weights $a_1, a_2, a_3, a_4$ are the barycentric coordinates of the point $p$ in the tetrahedron. It can be shown that $a_1, a_2, a_3, a_4$ are given by,

$$
\begin{bmatrix}
    a_1 \\
    a_2 \\
    a_3 \\
    a_4 \\
\end{bmatrix}
= \begin{bmatrix}
    x_1 & x_2 & x_3 & x_4 \\
    y_1 & y_2 & y_3 & y_4 \\
    z_1 & z_2 & z_3 & z_4 \\
    1 & 1 & 1 & 1 \\
\end{bmatrix}^{-1}
\begin{bmatrix}
    x \\
    y \\
    z \\
    1 \\
\end{bmatrix}
$$

(2)

3. Strain Reconstruction

Human brains process visual information much more easily than written information. When we analyze data, using graphs to summarize complex data ensures that the data is understood faster than disturbing reports or spreadsheets. Therefore, we transform the data into a graphical display in a visual form to enhance understanding.

The entire refactoring process is shown in Figure 2. First, we acquire the scatter coordinates from the monitoring area, and generate the grid coordinates and the surface of the detection area. Then, process the strain data acquired by the sensor. Finally, combined with the mesh surface, based on the tetrahedral interpolation, the strain reconstruction result is obtained.
We take the engine fan case as an example, as shown in Figure 3, for the selected surface in the figure to test.

**Figure 3.** Engine casing and the selected surface

### 3.1. Entity Visualization

In order to realize the visualization of the detection area, the first step is to obtain the spatial coordinate information of the surface. Through the three-coordinate detection or the digital model, we can obtain the discrete coordinates of a large number of detection areas. According to the Delaunay triangulation, we can visualize the selected surface. In this paper, the spatial data of the monitoring surface is obtained by the digital model. The result is shown in Figure 4.
3.2. Data Visualization

The data collected by the sensor contains the noise interference of the working environment. To this end, we also need to filter the collected signal. We use EMD filtering to process the data. The empirical mode decomposition (EMD) method is a signal analysis method proposed by Huang et al. in 1998. Breaking down signals into various components, EMD can be compared with other analysis methods such as Fourier transform and Wavelet transform. Using the EMD method, any complicated data set can be decomposed into a finite and often small number of components. These components form a complete and nearly orthogonal basis for the original signal. Without leaving the time domain, EMD is adaptive and highly efficient [5]. Based on these characteristics, we process the data at first.

Next, we combine the strain information obtained with the spatial mesh obtained in the previous. Finally, strain reconstruction is performed according to the Delaunay interpolation method. The result is shown in Figure 5.

We select 10 points from the result to compare with the preset control points. The results are shown in Figure 6. The cross is the actual detected value, and the circle is the calculated value. From the relative error table in Table 1, we can see that the measured values are similar to the calculated values, and the difference is small.
4. Conclusions
For the strain reconstruction of the engine casing, a strain field reconstruction method based on Delaunay triangulation is proposed, taking the surface of the casing as an example. The result shows that the method is in a great performance. However, at the end of the detection area, data accuracy gets worse, which is due to the characteristics of interpolation algorithms. Subsequent work is focused on the optimization of the measurement point layout and the processing of the endpoint data in order to obtain a more accurate spatial strain field.

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