Graphical User Interface for Ultrasound Guided Wave Imaging

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Abstract. In order to more accurately grasp the exact shape, contour size and distribution of defects in the plate-like structures material and other detailed feature information, this paper designed the graphical user interface GUIGWT0.1, which is specifically used for ultrasonic guided wave imaging. This software integrates filtering back projection algorithm, damage probability reconstruction algorithm and diffraction tomography algorithm, which can image the plate-like structures structure as required, and develop the defect detection results to the visual direction. To investigate the validity of the interface, the projection data of lamb wave in the plate-like with a partial-thickness notch are numerically simulated by three-dimensional elastodynamic finite integration technique (EFIT). The resulting projected data is imported into the graphical user interface for imaging. For each existing reconstruction imaging, the result can be represented in terms of grayscale image of projected data, defect imaging, image color inversion and false color defect recognition. Through simple operation, reconstruction of image with defect of plate-like structure are obtained in the user interface.

1. Introduction

Ultrasonic guided wave based plate-like structures damage detection has been widely studied in structural health monitoring (SHM) and nondestructive testing (NDT) [1]. The traditional method of ultrasonic detection that by observing the spectrum, amplitude and time of the signal to judge the location and size of the defect is inconvenient. With the increasingly strict requirements on the safety of plate-like structures, the detection results are no longer satisfied with the determination of the presence or absence of defects. The quantitative reconstruction of defects and visualization of defect location and size have become the hot spots in the research field of guided wave monitoring [2]. Ultrasound guided wave imaging is a new method developed in recent years, which has shown great potential due to the feature that inspects large structural area and their sensitivity to small defects in the structure[3].

Damage imaging technique is an attractive tool to provide an intuitive visualization that effectively localizes damages in a plate-like structures[4]. Damage imaging algorithms based on fan beam array projection is probably the most well-known damage localization techniques utilizing sparse array of shot point. Fan-beam inverse projection imaging technology is a straightforward approach to represent the accumulated error weighting factor of direct signals onto the spatial domain according to appropriate definition of wave-paths.

The imaging algorithm based on fan beam array projection is very promising from an application point of view, but they are completely lacking a user-friendly interface that would make their application easier, faster, and more reliable, hence sidespread uses is limited. This paper presents
graphical user interface GUIGWT0.1, a newly developed GUI for imaging algorithm based on fan beam array projection. It can be used to manage the projection data import phase in a more efficient way[5], because it allows the user to visually and interactively check the data. Moreover, it runs the core program and postprocesses the results, presenting the outputs in the same graphical environment. Therefore, users can quickly run their preliminary computation[6].

Software operation results show that the shape, size and distribution of defects in the plate-like structure can be accurately detected by importing the projection data of the plate-like structure into the graphical user interface. In the following article, the principle of ultrasonic guided wave detection and imaging, the operation process and matters needing attention of the graphical user interface will be shown in detail.

2. Basic principles of guided wave imaging
The fan-beam backprojection filtering algorithms of the lowest-order antisymmetric(A0) mode which was emitted and received in once more receive mode. For the path of wave propagation[7], in order to avoid reflections from boundaries generally make it hard to localize damages due to many overlaps between the primary scattered and the second arrival, the directly arrived form sensor is been investigated.

The defect reconstruction imaging of the plate-like structure model with imaging algorithm should be done as follows. In order to facilitate the explanation of the principle, in addition to fixed (x-y) coordinate system and polar coordinate system(r,∅), the rotation coordinate system (t-s) is introduced as shown figure2 in this paper. The coordinate system (t-s) coincides with the origin of the coordinate system (x-y), the included angle is θ, so the projection path position can be uniquely determined by the coordinate(t-s), and (t-s) also corresponds to a projection value, and the path(r,∅) through (t-s) satisfies the following equation(1):

\[ t = r \cos(\phi - \theta) \]  

(1)

To projection data collected in the shortest possible time, adopting isometric fan beam scanning reconstruction algorithm. For the fan-beam geometry(Fig3), the relationship between the coordinate system and the associated parameters has been indicated. The M point in the figure is expressed in polar coordinates as (r,∅), line segment SE is an ultrasonic guided wave propagation path through point M, opening angle is γ, the length of the line so as detection area radius of D. The parametric relationship satisfies the Equation (2)

\[ \begin{align*}
\theta &= \beta + \gamma \\
t &= D \sin \gamma
\end{align*} \]  

(2)

According to the relationship in the figure3, the projected value through point M is expressed by the rotating coordinate system:

\[ p(t,\theta) = p(D \sin \gamma, \beta + \gamma) \]  

(3)

For a fan-beam geometry, the original function f can be reconstructed by applying fan-beam backprojection filtering algorithms. According to the above fan beam projection parameter relations, the final obtained fan beam reconstruction formula is:

\[ f(r,\phi) = \frac{1}{2} \int_{\gamma_m}^{\gamma_a} \int_{\gamma_m}^\gamma P(D \sin \gamma, \beta + \gamma)h(r \cos(\beta + \gamma) - r \sin \gamma)D \cos \gamma d\gamma d\beta \]  

(4)

Generally speaking, it is difficult to solve for f in Eq.(4). Therefore, it is suggested to use the imaging algorithm in the actual projection data processing is needed by the discretization of the digital signal. Because the projection data is in the actual process of translation, rotation angle increment step, if a total of M projection data are collected at a 360° angle, namely the sector as the rotation of the step for ∆β=2\pi/M, projection angle for the first time i as \( \beta_i = i \times \beta \), the imaging algorithm with discrete mathematical language expression as shown in the following equation (5):

\[ f(r,\phi) = \sum_{i=1}^{M} \frac{1}{D^2 + r^2 + 2Dr \sin(\beta_i - \phi)} p_h(n \Delta \gamma) D \cos(n \Delta \gamma)|_{\Delta \gamma = \gamma} \]  

(5)
Figure 1. Schematic diagram of projected suspected distribution of fan beam structure

Figure 2. Schematic diagram of three coordinate system relations

Figure 3. Parameters of isogonal fan beam

3. Graphical user interface

3.1 Interface operation flow
The operation process of tomographic imaging of the plate-like structure is introduced in detail. This paper shows the process of projecting data from import to tomography. The graphical user interface first imports the projected data internally, and then the interface visually verifies the imported data to minimize errors. Then, set the corresponding parameters in the parameter settings panel according to the imported projected data of plate-like structure. Finally, the final image structure is displayed in the corresponding position in the display area by pressing the relevant button.

3.2 Graphical interface imaging
Once the program has been launched, the GUIGWT0.1 appears on the screen, as shown in figure 5. In the left button control area, the user can perform corresponding operations on the graphical user interface according to their own needs. The parameter setting area needs to be assigned by projecting the model shown in figure 4 below according to the method mentioned in section 2. The circle surrounded by red points is the detection area, and each point represents a detection coordinate point. On the right side of the interface is the display area, where the user can check the imported projection data and view the tomography results.

(a) central defect model  (b) center-right defect model  (c) defect model at the upper right
Figure 4. Three-dimensional finite element model
4. Image reconstruction results

The defect localization for the numerical model shown in Fig. 4, including the central defect model and the local defect model. Detailed defect feature information is listed in Table 1. Numerical analysis software was used to conduct simulation experiments on circular defects of the same size at different positions, and the original data about them were obtained respectively. The three numerical models were reconstructed using graphical user interface GUIGWTO.1, and the imaging results were shown in the figure 6 below.

Table 1. Simulation Model Defect Information

|                        | Model (a) | Model (b) | Model (c) |
|------------------------|-----------|-----------|-----------|
| Detection area diameter (mm) | 100       | 100       | 100       |
| Defect types           | Center for defect | Center-right defect | Upper right defect |
| Defect diameter and thickness (mm) | 18.75*2   | 18.75*2   | 18.75*2   |
| Defect center location coordinates | (0,0)     | (0,25)    | (25,25)   |

Figure 5. Main GUIGWTO.1 panel output result
Figure 6. Reconstruction results of plate-like model

GUIGWT0.1, a graphical user interface, was used to image the original data detected under the fan-beam structure. As can be seen in FIG. 6, the reconstructed results obtained the defect related information consistent with the simulation model in the plate-like structure with different defect locations. Compared with the original defect model, the defect location is clearly visible, with high identification, good reconstruction effect and no excessive noise. The defect imaging results obtained by the two image segmentation methods established in this paper are more clearly visible and more recognisable than those obtained by direct imaging, which makes the reconstruction results more optimized.

The graphical user interface by importing original data plate-like structure, realizes the tomography of all kinds of models for various defects detection and imaging effect under the contrast, the results show that using this software to faults slab structure internal defects is feasible, the result is not only accurate, reliable, and very intuitive.

5. Conclusion
This paper proposes a graphical user interface (GUI) GUIGWT0.1, by simply working with the GUI users can easily obtain the defect reconstruction images of the plate-like structure. The original data about the plate-like like structure input in the interface can be visually checked in the display panel, which improves the interaction between the user and the interface and facilitates the setting of relevant parameters, so as to minimize the occurrence of misoperation. This software realizes the defect image reconstruction of models with different plate-like structures, and the reconstruction results are one-to-one corresponding to the defects in the plate-like model, which strongly proves the feasibility, reliability and accuracy of ultrasonic guided wave tomography detection technology.

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