DIRECT NEURAL NETWORK CALCULATION OF RESIDUAL STRESSES FROM WRAPPED SPECKLE INTERFEROMETRY PHASE PATTERNS

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The speckle interferometry hole drilling method for residual stress determination demands expert manual phase analysis. The developed 1D-CNN, trained on synthetic data, automates stress calculation directly from noisy wrapped phase data, bypassing manual steps like unwrapping and filtering. Validation on independent test data shows strong agreement. This approach eliminates operator variability and ensures reproducible stress determination

Keywords: neural networks; speckle interferometry; phase unwrapping; residual stresses; automation; noise-aware training

Introduction. Speckle interferometry combined with blind hole drilling offers several advantages over standard strain-gauge approaches (standard ASTM E837) for determination of residual stresses. However, it requires skilled operators to process the measurement results and calculate the stresses.

Under a uniaxial stress state, the displacements u_x measured by speckle interferometry are related to the stresses σ_{xx} by the formula:

$$u_x(r = 2.5r_0, \theta) = \big((\mathrm{A} + Bcos2\theta)cos\theta - \mathrm{C}sin2\theta sin\theta\big)\sigma_{xx}, \qquad (1)$$

where the constants A, B and C are precomputed using the finite element method and depend on the material's mechanical properties, the hole size and the ratio of hole depth to its diameter [1, 2].

However, the phase-stepping method used in the analysis of speckle interferograms determines only the phase of the interference fringes. Modern speckle interferometry workflows for residual stress determination rely on a multi-stage manual pipeline: reference selection, phase unwrapping, masking of decorrelation/fringe artifacts, optional filtering and further analysis. These steps are labor-intensive, subjective, and difficult to scale across large experimental series. Variability in acquisition (illumination, fringe saturation, blur) increases operator effort and inconsistency. The practical need is to eliminate manual post-processing while preserving accuracy and robustness on real, noisy data.

The main idea of the work is to apply AI methods to automatically compute residual stresses from the phase interferometric pattern obtained after drilling blind holes in the stressed material, thereby avoiding phase unwrapping, filtering and other operator-dependent post-processing steps.

To train the neural network a synthetic dataset was created, that simulates various possible noisy distributions of displacements $u_x(\theta)$ as a function of the stress state σ_{xx}. The dataset includes the corresponding distributions of wrapped interferometric phase as the data and the stress values as the labels. The main task is the simultaneous execution of the phase-unwrapping procedure transforming the noisy green wrapped-phase curve (Fig.1) into the blue curve that represents displacement values and the computation of stress values according to Eq. (1).

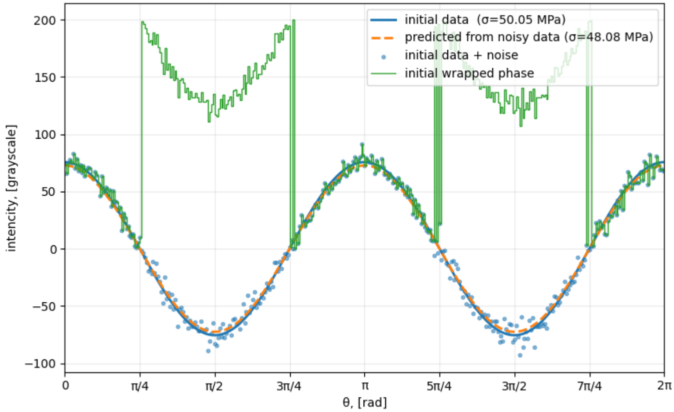

Fig. 1. Residual stresses prediction based on noisy wrapped phase data.

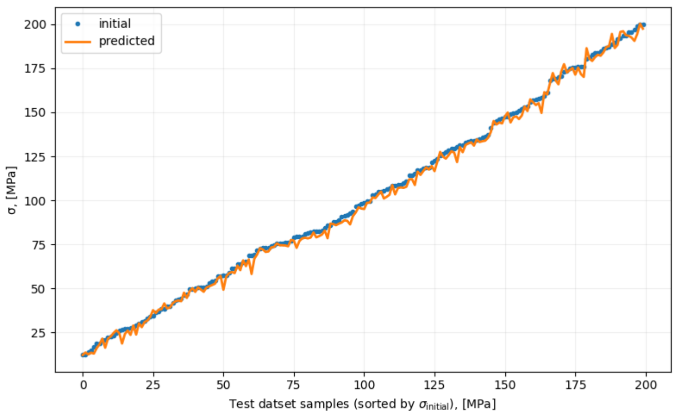

Fig. 2. Initial σ_{xx} vs. 1D-CNN prediction on test data.

The validation of our AI-driven speckle-interferometry approach, performed on completely independent test data (i.e., data excluded from the neural network training process), demonstrates strong predictive performance. As illustrated in Fig. 2, the stress estimates generated by the model show excellent agreement with the actual values, quantified by a low Mean Absolute Error of 2.274. This compelling result robustly confirms the effectiveness of the proposed methodology and underscores its significant potential for the accurate, AI-powered determination of residual stresses based on speckle-interferometry data analysis.

Conclusions. A fully automatic numeric-stage for residual-stress (σ_{xx}) calculation is demonstrated: a 1D-CNN with convolutional layers replaces manual post-processing on noise phase data produced by the current speckle-interferometry pipeline. This reduces operator effort and variability, preserves reproducibility.

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