Kuo ZHANG, Jianliang HUO, Shengzhe WANG, Xiao ZHANG, Yiting FENG, 2022. Damage quantitative assessment of spacecraft in a large-size inspection. *Frontiers of Information Technology & Electronic Engineering,* 23(4):542-554. https://doi.org/10.1631/FITEE.2000733

Damage quantitative assessment of spacecraft in a large-size inspection

Key words: Hypervelocity impact; Damage information extraction; Image mosaicking; Damage localization; Quantitative assessment

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Motivation

1. Given current non-destructive testing techniques, since impact damage may exist on the subsurface and interior of the nacelle, it is still challenging to realize effective damage information detection.

2. For a huge detection range of spacecraft, up to now, in the face of large-size testing needs, there is a lack of detection solutions combined with non-destructive testing techniques.

3. For safe operation of spacecraft, knowing the location of damage and judging the degree of damage through quantitative evaluation are important prerequisites for impact monitoring, early warning, and timely protection.

Main idea

1. Classify and extract the damage information from the infrared thermal data, and reconstruct it into a two-dimensional image highlighting the damage area.

2. Introduce the idea of image mosaicking, which is suitable for large-size detection. Multiple local detection areas can be spliced and integrated, and global mosaic results can be formed.

3. Segment and extract the damage areas based on image processing, and assess the extent of the damage by localizing the damage area and calculating the quantitative parameters.

Method

1. To achieve damage information extraction, a Gaussian mixture model (GMM) algorithm which can describe the probability distribution of a number of Gaussian components to classify the original thermal data. Furthermore, the image highlighting the damage features is reconstructed by combining the damage information with the pseudo-inverse observation matrix.

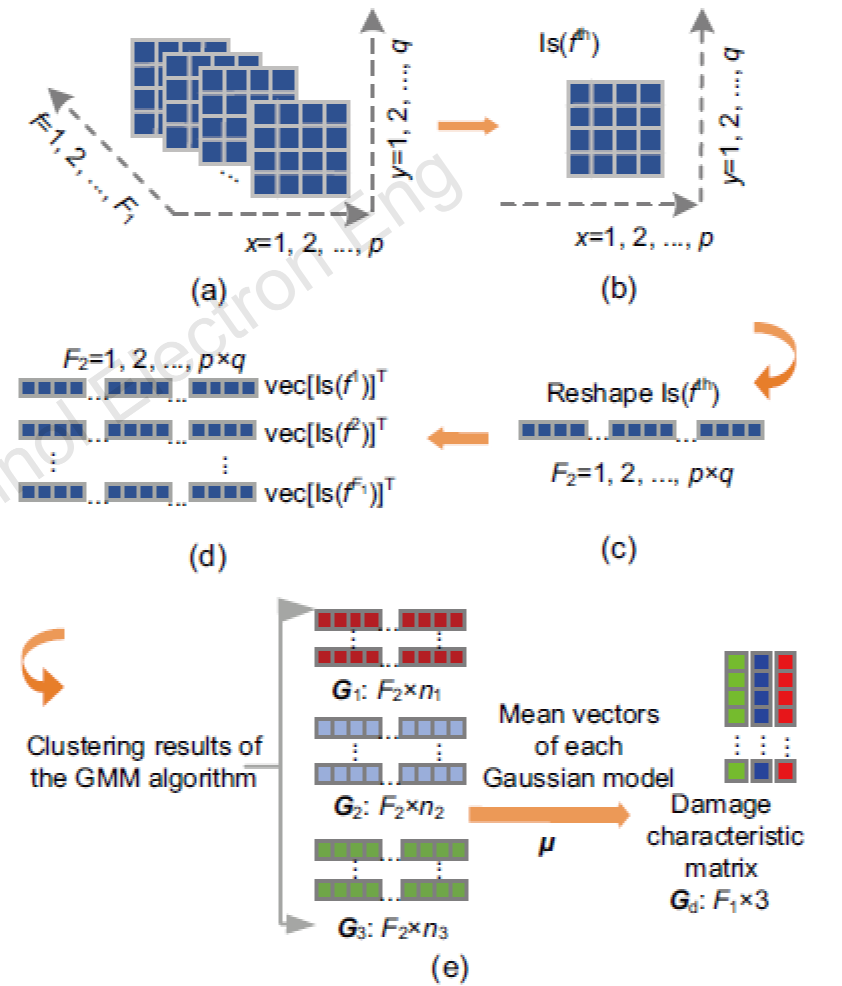


Fig. 2 Schematic of the data conversion and clustering: (a) image sequence Is(f); (b) f^{th} frame of Is(f); (c) vec[Is(f^{th})]^T; (d) reconstruction matrix O_{ttr}; (e) damage characteristic matrix construction

Method (Cont'd)

2. For the large-size detection requirement, a mosaicking scheme is proposed to realize the complete information integration of a global detection result.

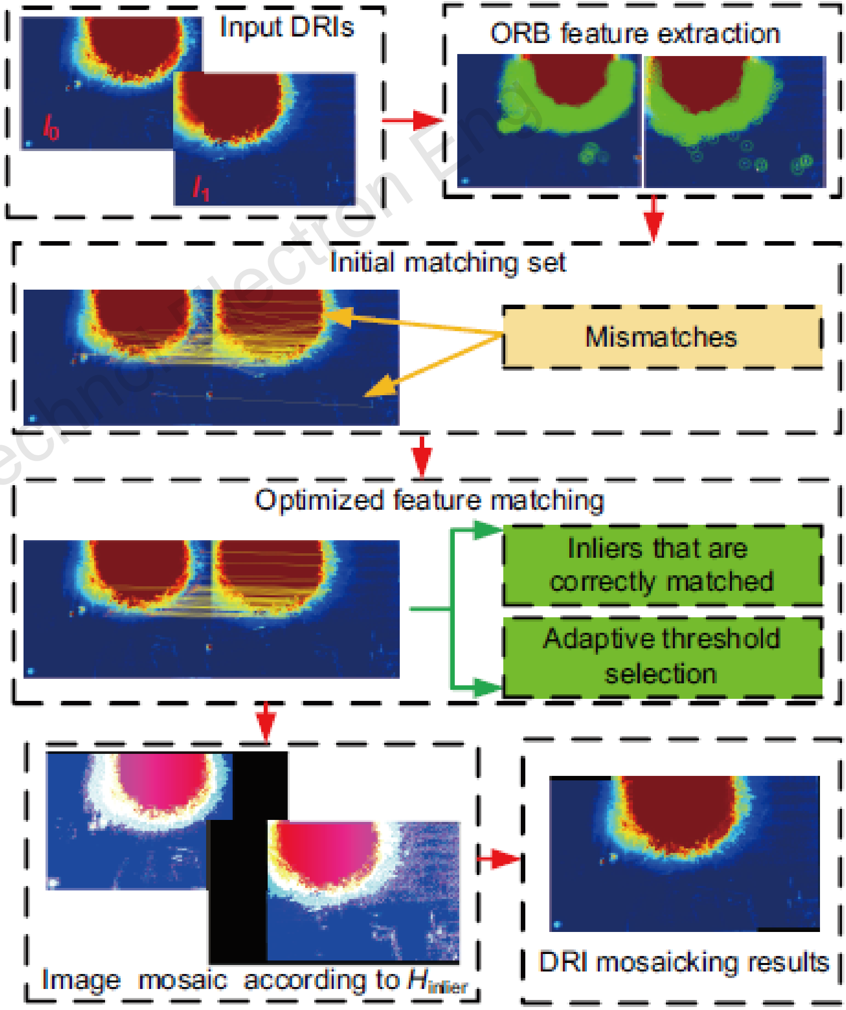


Fig. 4 Schematic of the image mosaicking scheme

Method (Cont'd)

3. With a color feature segmentation based on the clustering method and a binarization segmentation algorithm with dual threshold processing, the damage information localization and quantitative assessment of performance can be achieved.

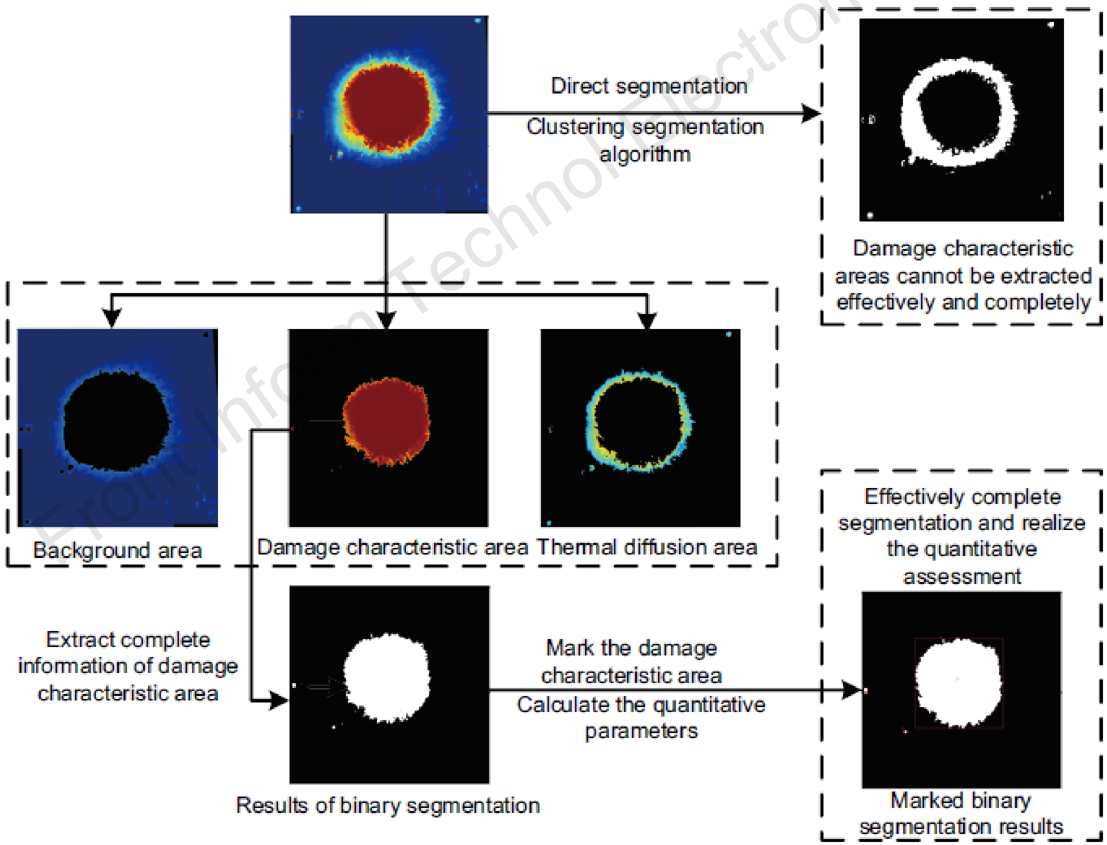
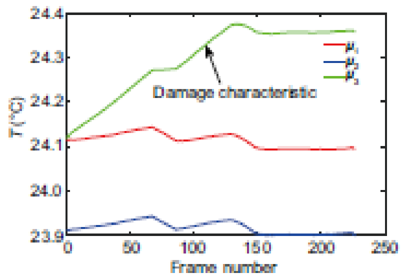
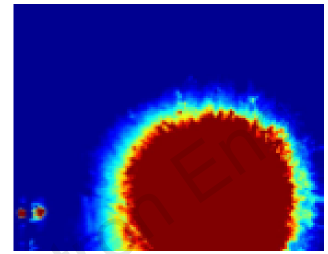
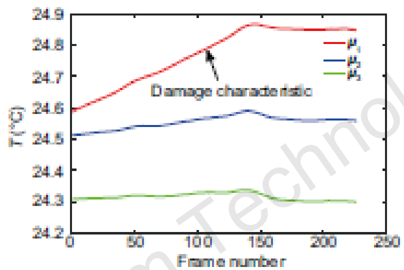
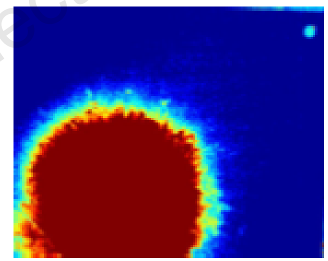
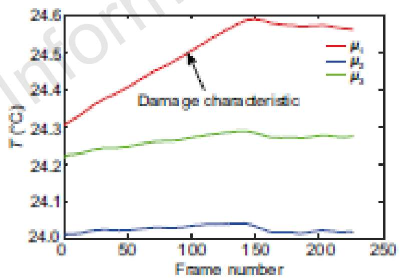
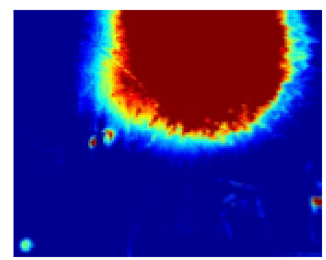
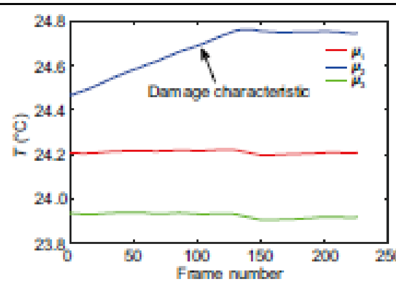
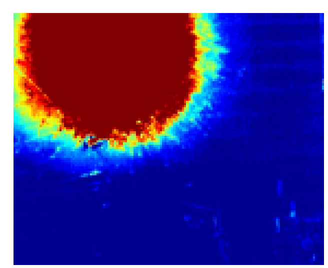


Fig. 6 Flowchart of the quantitative assessment method (References to color refer to the online version of this figure)

Major results

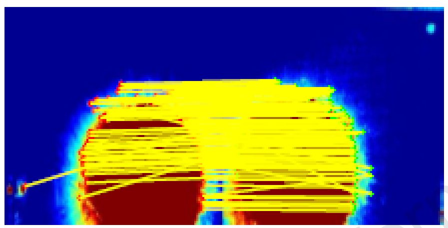
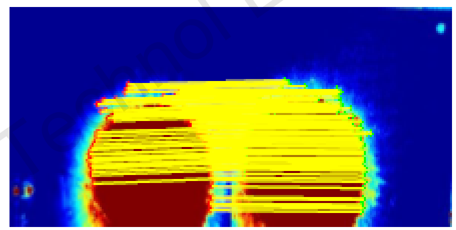
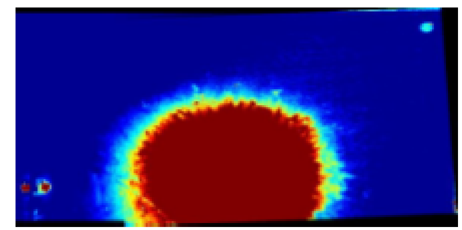
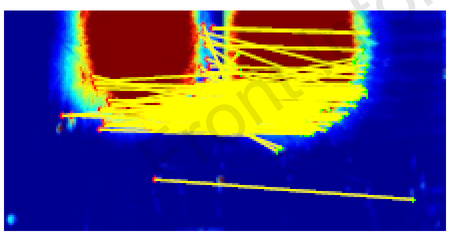
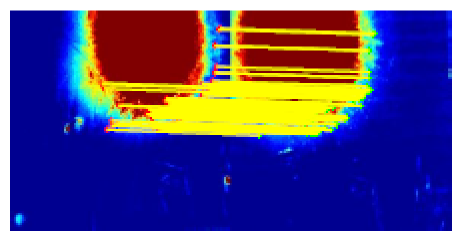
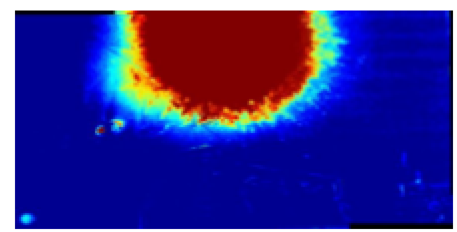
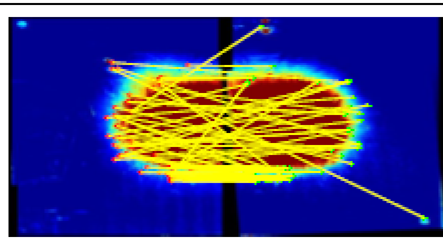
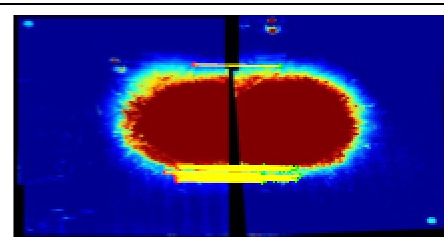
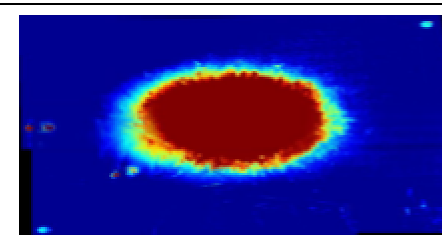
Table 1 Damage characteristic mean vector curves and the corresponding DRIs of sample *A*

Detection area	Damage characteristic curves	Damage reconstructed image
A1		
A2		
A3		
A4		

Major results (Cont'd)

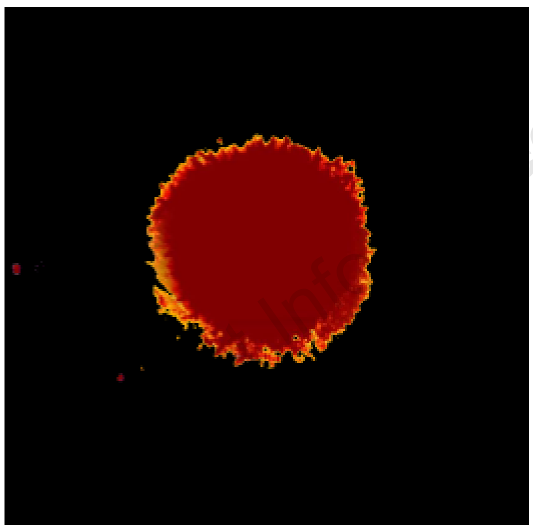
Damage reconstructed image mosaicking scheme

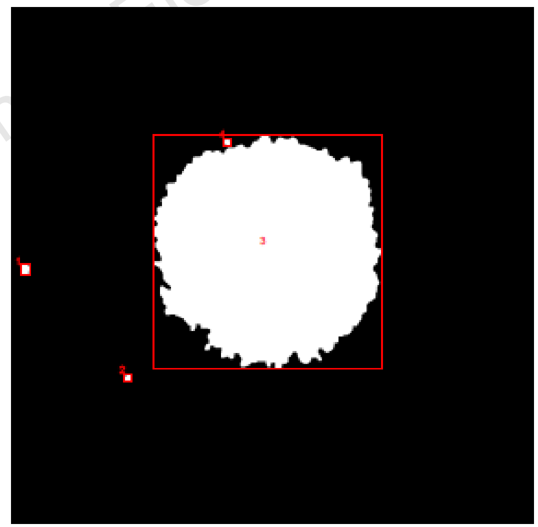
Table 5 Specific display of image mosaicking of sample *A*

Process	Initial feature matching	Optimized matching	Image mosaicking results
A1-A2			
A3-A4			
A1A2-A3A4			

Major results (Cont'd)

Segmentation and extraction of damage information from panoramic mosaicing results





Major results (Cont'd)

Summary of damage location information and quantitative parameters

Table 6 Quantitative parameter statistics for damage characteristic regions of sample *A*

Area	ul(x, y)	ul(x', y')	lr(x, y)	lr(x', y')	$\mathrm{Pm}_{\mathrm{p\_d}}$ (mm)	$\mathrm{Pm}_{\mathrm{r\_d}}$ (mm)
A1	(13.5, 419.5)	(15.8, 495.0)	(28.5, 438.5)	(33.4, 517.4)	54.07	44.34
A2	(184.5, 600.5)	(215.9, 708.6)	(196.5, 613.5)	(229.9, 723.9)	38.27	31.38
A3	(232.5, 208.5)	(272.0, 246.0)	(608.5, 591.5)	(712.0, 698.0)	1573.30	1290.11
A4	(348.5, 214.5)	(407.8, 253.1)	(358.5, 225.5)	(419.5, 266.1)	31.81	26.08

Conclusions

1. Based on the GMM clustering algorithm, the damage characteristics are extracted from the infrared thermal data to reconstruct the image.

2. An improved mosaicking scheme is proposed and it can realize fast and accurate mosaicking of damage reconstructed images. The mosaicking results are explicit, without deformation and distortion, reflecting the global damage characteristic distribution.

3. With the damage region segmentation method proposed, the actual regional spatial position coordinates and the actual damage perimeter value of each damage characteristic region can be obtained, reflecting the distribution and degree of the damage .