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Spacecraft damage infrared detection algorithm for hypervelocity impact based on double-layer multi-target segmentation

Key words: Hypervelocity impact damage; Defect detection; Gaussian mixture model; Image segmentation

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Motivation

It is well known that there is a large amount of debris in space [1-3]. With the systematic development of human space activities, this volume will continue to increase sharply. The harm it causes to spacecraft in hypervelocity collisions seriously threatens on-orbit operation, reusability, and safety of the spacecraft used[4][5].

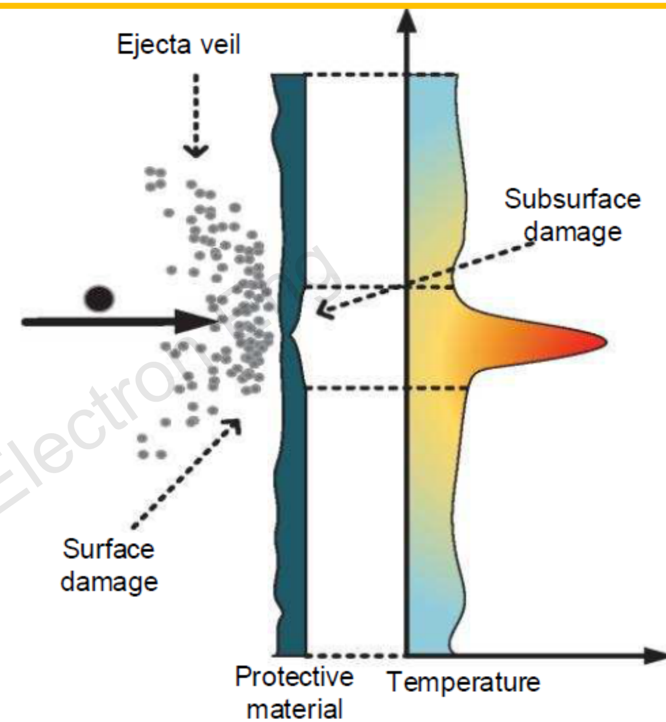

Fig. 1 Schematic of hypervelocity impact damage

Fig. 2 Hypervelocity impact damage

To improve spacecraft damage detection, retain details, and remove noise interference, we propose a novel multi-objective optimization damage detection algorithm for spacecraft hypervelocity impact evaluation.

Main idea

- The algorithm is designed for data processing of a damage detection infrared video stream to obtain an infrared reconstructed image (IRRI) using the transient thermal response (TTR) curve.
- We also propose a defect segmentation algorithm that achieves the best noise suppression and the best details of IRRI through multi-objective optimization. In the segmentation process, the detailed information of the damaged area should be segmented from the material background area as much as possible to ensure complete defect detection. Simultaneously, it is correctly divided into noise areas to ensure the accuracy of damage detection.

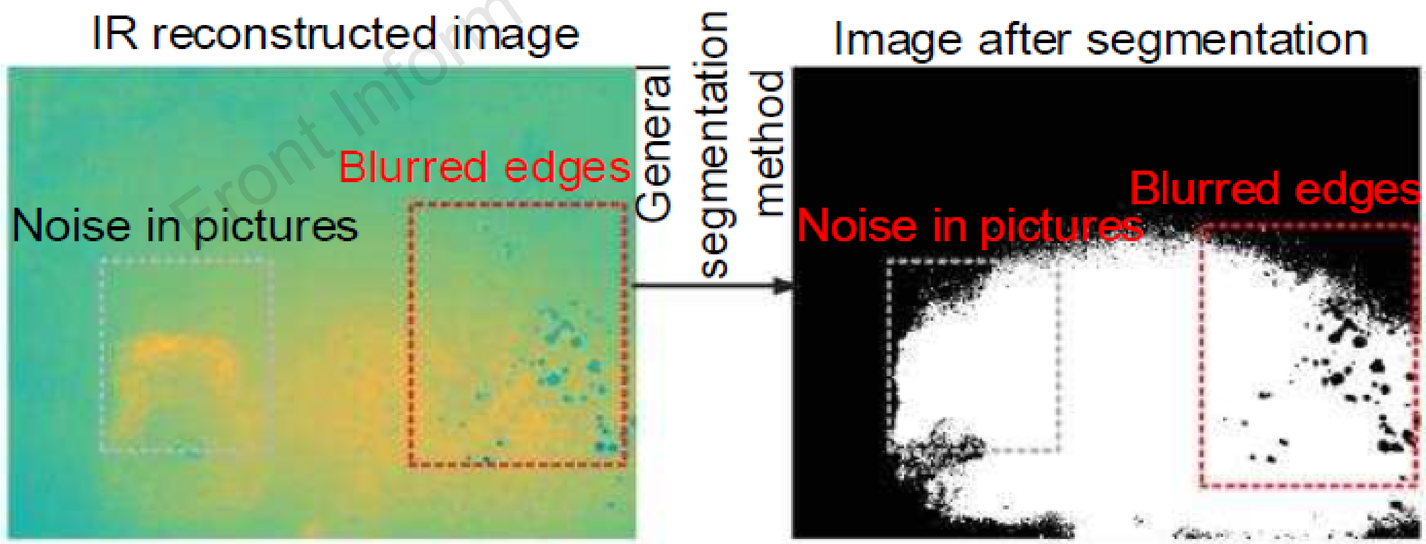

Fig. 3 MOP for image segmentation purposes

Method

The designed segmentation objective function $\min f_3(v) = f_1(v) + f_2(v)$ is used to ensure the effectiveness of image segmentation for noise removal and detail preservation, while considering the complexity and variability of IRRI. A multi-objective optimization algorithm is introduced to achieve a balanced relationship between detail preservation and noise removal. At the same time, the MOEA/D algorithm is used to optimize the solution to ensure the accuracy of damage segmentation.

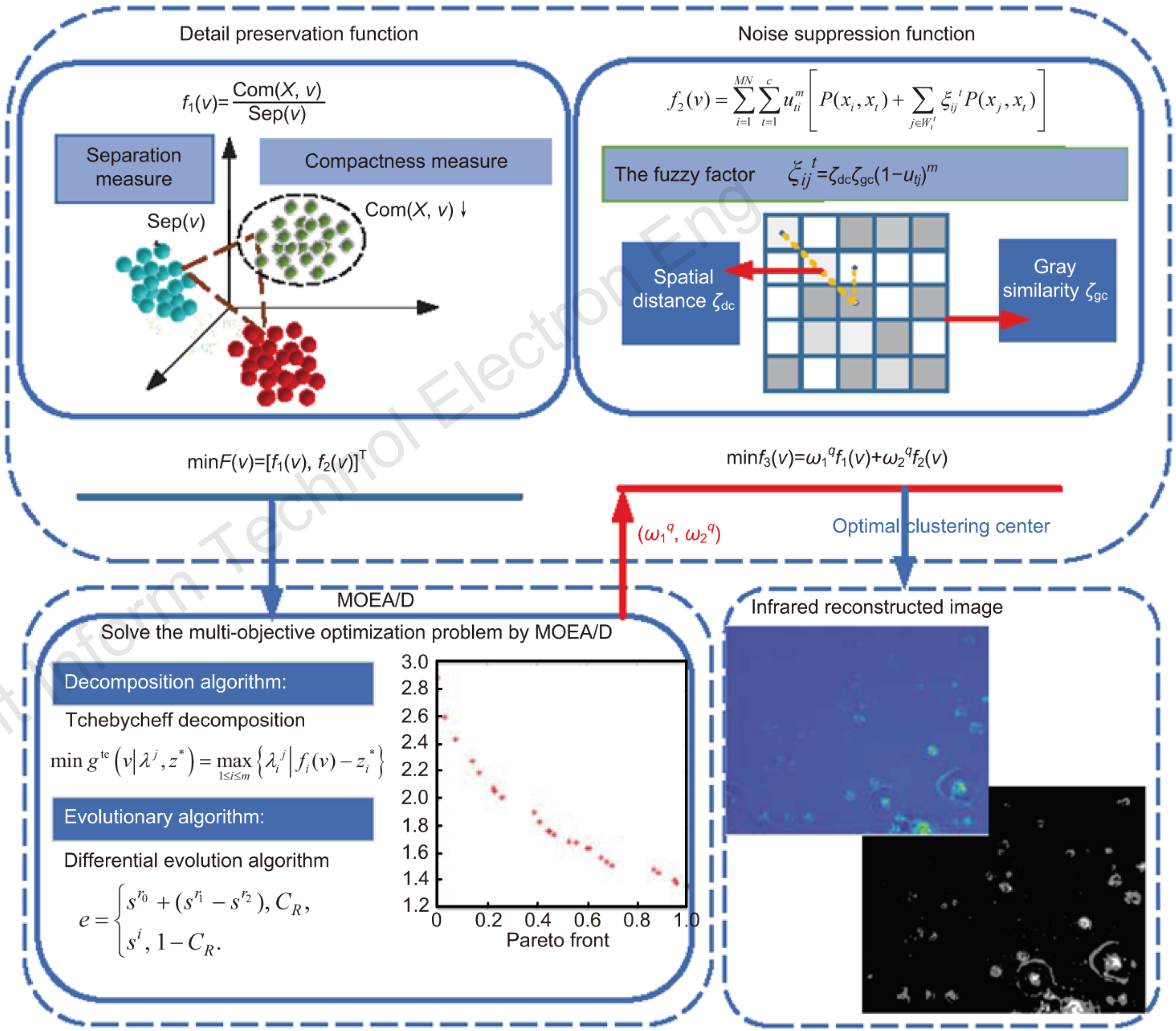

Fig. 4 Image segmentation method based on the multi-objective problem

Method (Cont’d)

The IRRI as the segmentation object uses the temperature change characteristics that correspond to different defects in the tested sample to display the defects. We want to use the infrared video stream composed of multiple infrared images to identify the main defect characteristics. The specific steps are as shown in Fig. 5.

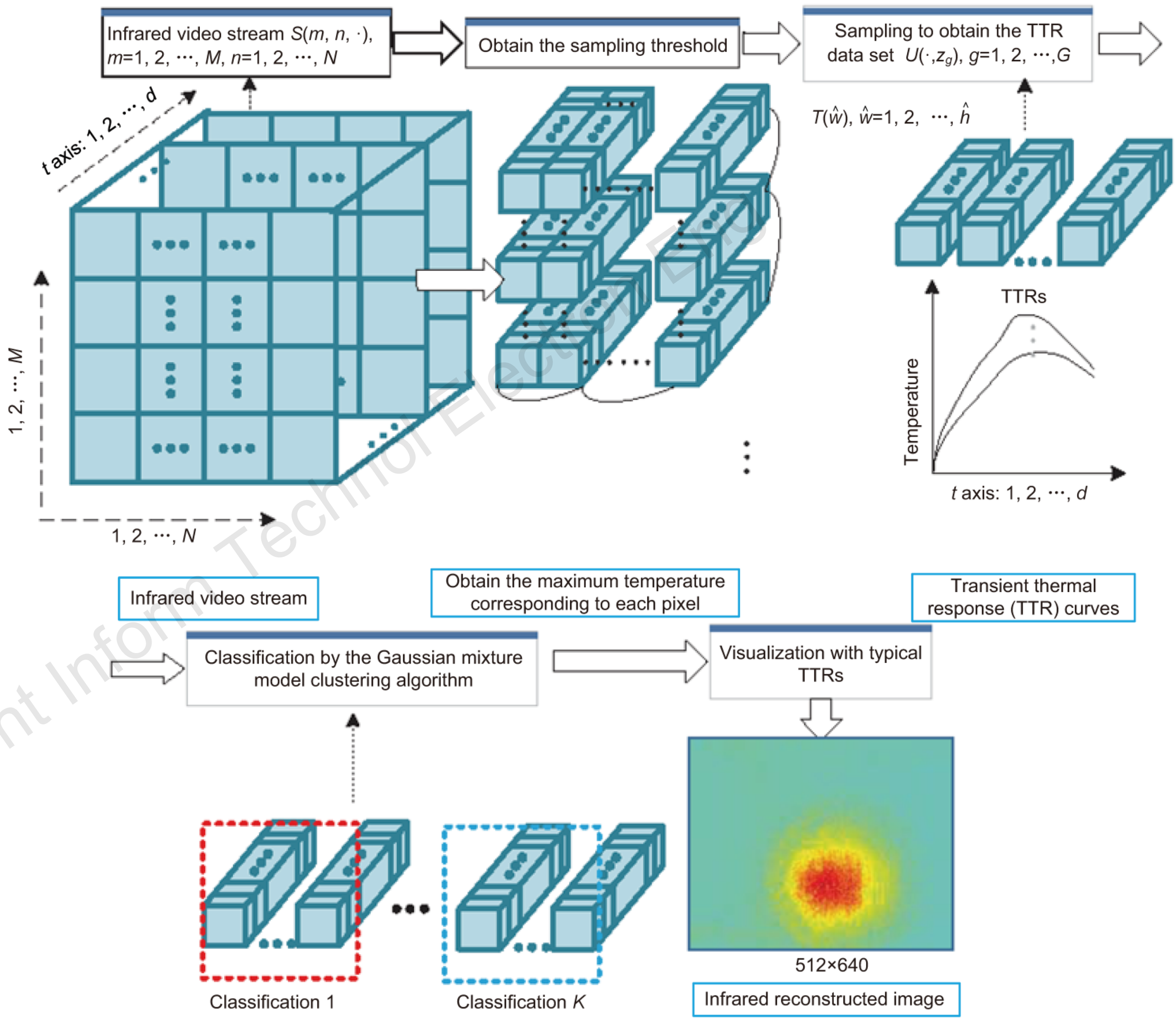

Fig. 5 Schematic of infrared reconstructed image generation

Major results

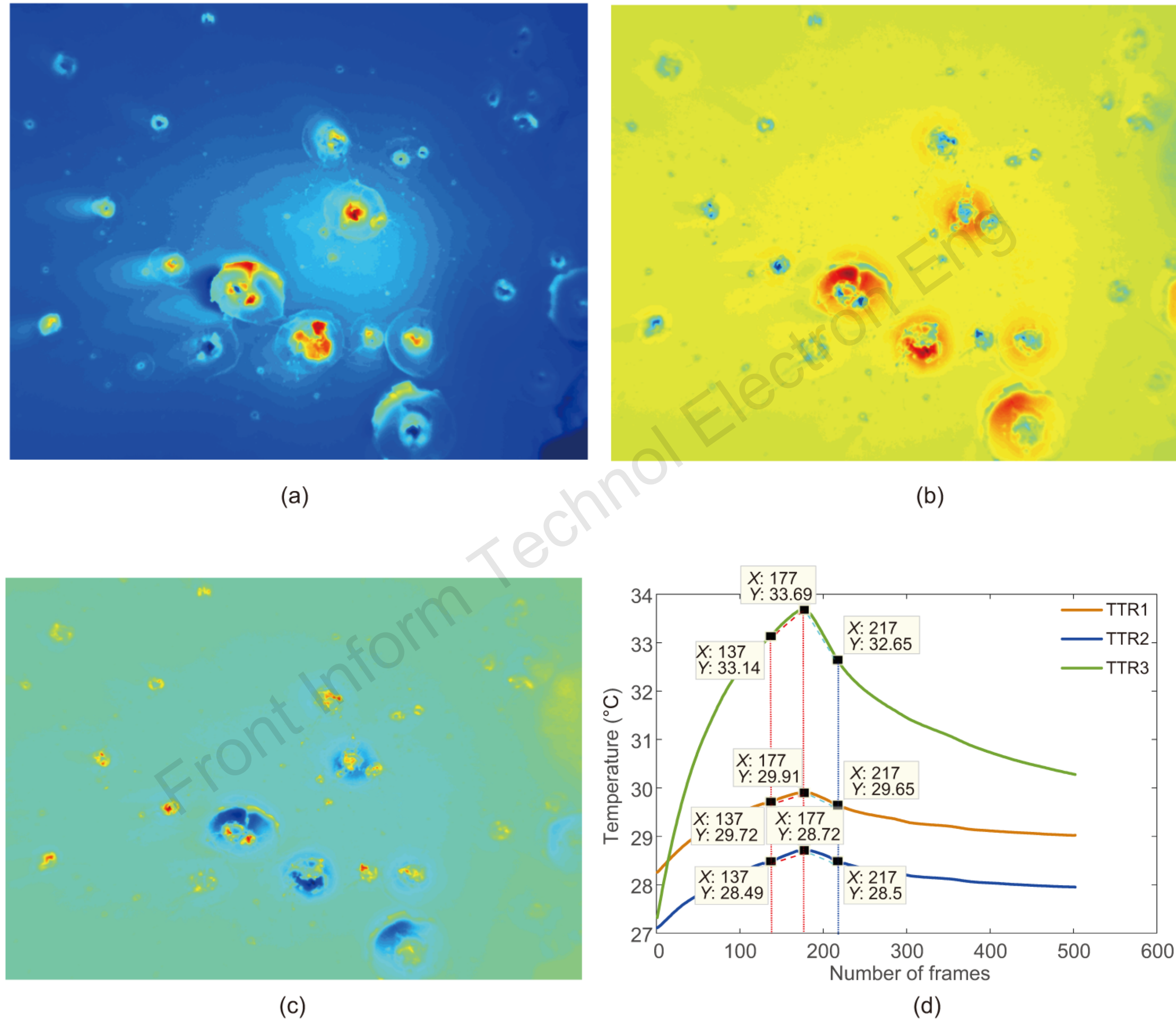

Fig. 9 IRRI acquisition results for the sample: (a) stress damage around the perforation defect; (b) drum kit; (c) perforation damage; (d) TTR for damage

Major results (Cont'd)

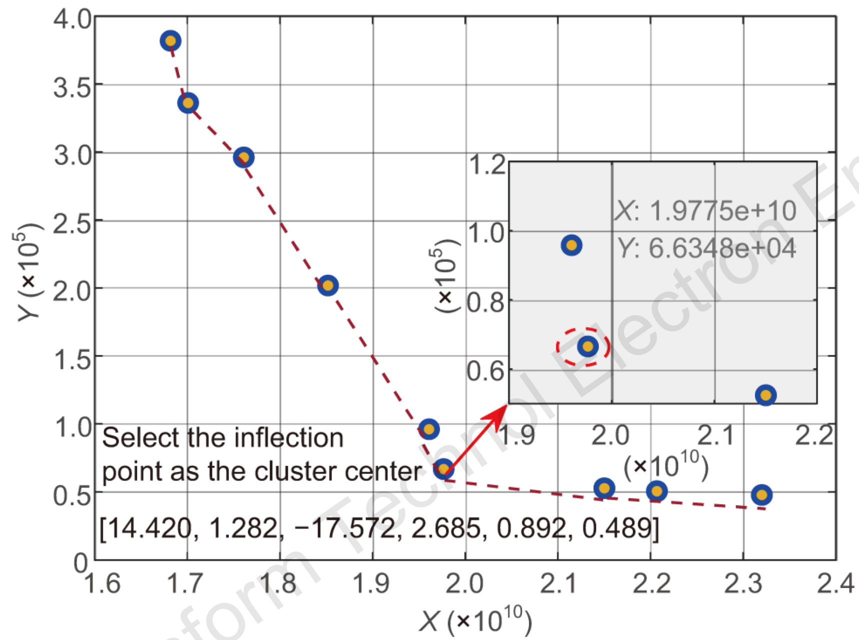

Fig. 11 Pareto front

The Pareto front (PF) corresponding to the design objective function is obtained by the proposed algorithm, and the inflection point in the PF solution is used for image segmentation corresponding to the cluster center.

Major results (Cont'd)

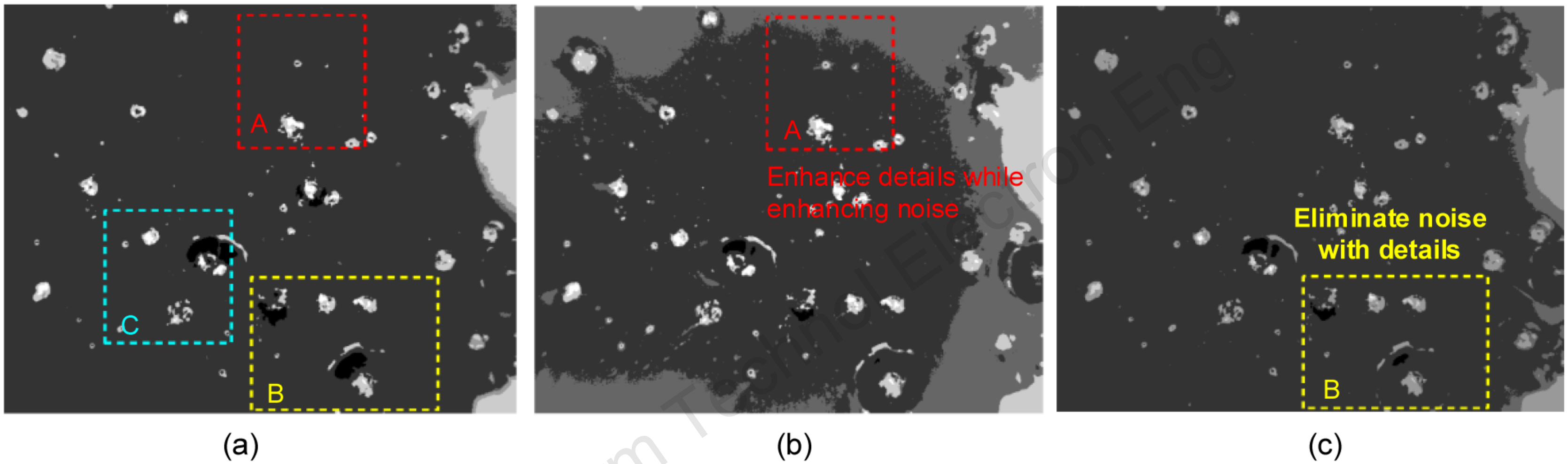

Fig. 12 Comparison of the image segmentation results of our proposed algorithm with those of the single segmentation function involved in the algorithm: (a) image segmentation object in this study; (b) detail preservation function (DEPF) $f_1(v)$ segmentation result; (c) noise suppression function (NOSF) $f_2(v)$ segmentation result

Conclusions

- We designed a defect detection algorithm using infrared video streams to detect defects in spacecraft specimens impacted at hypervelocity.

- First, we obtained the IRRI that highlights different defect features using GMM to extract different temperature change information, that is, TTRs. To separate the damaged part from the background, and to avoid the possible noise interference and blurring of details in IRRI, an adapted objective segmentation function was designed.

- To obtain more accurate segmentation, we used the idea in solving multi-objective optimization problems to obtain segmentation weights that adapt to each IRRI by constructing a two-layer multi-objective optimization segmentation algorithm. Experimental results verified the effectiveness of the algorithm.

References

[1] Lamb H, 2018. Space agencies turn focus on small space debris. *Eng Technol*, 13(1):48-49.

[2] Adushkin VV, Aksenov OY, Veniaminov SS, et al., 2020. The small orbital debris population and its impact on space activities and ecological safety. *Acta Astronaut*, 176:591-597.

[3] Murtaza A, Pirzada SJH, Xu TG, et al., 2020. Orbital debris threat for space sustainability and way forward. *IEEE Access*, 8:61000-61019.

[4] Aglietti GS, Taylor B, Fellowes S, et al., 2020. The active space debris removal mission RemoveDebris. Part 2: in orbit operations. *Acta Astronaut*, 168:310-322..

[5] Huang XG, Yin C, Ru HQ, et al., 2020. Hypervelocity impact damage behavior of B4C/Al composite for MMOD shielding application. *Mater Des*, 186:108323.