Hyperspectral Imaging and CNN Regression Analysis for Temperature Prediction of Thermal Paints

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Accurate temperature measurement of internal aerospace engine components is essential for ensuring component longevity and engine efficiency. For thermal analysis of inaccessible engine parts, Rolls-Royce PLC has developed thermal paints (TPs), which experience permanent color changes when exposed to elevated temperatures. The resulting color provides an indication of the maximum temperature to which the component surface has been exposed during testing.

Traditionally, temperature estimation relies on visual assessment of the paint color appearance by trained engineers and comparison with calibrated reference samples. However, this approach requires highly specialized training, time, and a carefully controlled working environment to ensure consistent results. Previous studies have investigated automated analysis techniques based on imaging methods to improve the efficiency of the process. Nevertheless, the color changes exhibited by the paints can be extremely subtle, making reliable discrimination and temperature determination challenging. To enhance the reliability and reproducibility of TP-based temperature measurements, this work investigated the use of Hyperspectral Imaging (HSI) in combination with 1D Convolutional Neural Network (1D-CNN) regression.

HSI was explored in the Visible and Near-Infrared range (400 – 1000 nm) for accurate spectral characterization via CNN regression analysis, where the CNN model was trained on a set of color coupons with related ground truth for different types of TPs. The proposed method provides a predicted temperature value for each pixel in the HSI image, including an interval of confidence with upper and lower bounds to indicate the prediction uncertainty. Therefore, HSI allows a fast pixel-wise prediction of temperature, with experiments reporting a performance with mean absolute error (MAE) of around 5°C across the range 500°C - 1280°C, a promising accuracy in comparison with the approaches in current use.

This work demonstrates the way in which HSI combined with advanced data processing can improve temperature prediction accuracy from TPs, enabling automated temperature analysis, which can lead to significant time savings, while reducing reliance on subjective visual assessment. The CNN model was validated internally with diverse samples, and validated externally with real parts of engine components. However, future work includes evaluating the robustness and repeatability of the HSI approach, and the prediction performance for components with complex 3D geometries.