Can We Detect Physical Hazards in Meat Before They Reach the Consumer?

Exploring Spectral–Spatial Detection of Physical Hazards in Meat by Hyperspectral Imaging

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Abstract

Physical hazards such as bone, stone, wood, metal and polymeric materials can present important food-safety risks in meat products. Rapid and reliable detection of foreign materials is therefore important for food safety and quality control. Hyperspectral imaging (HSI), which combines spatial and spectral information, has shown potential for detecting bone fragments and diverse foreign materials, including polymers, wood and metal, in meat and poultry products [1,2]. More recently, deep learning and spatial-spectral approaches have been investigated for pixel and object level detection and localisation of foreign materials on poultry meat [3,4]. However, reliable localisation within heterogeneous meat backgrounds remains an important challenge for practical application.

This study investigates visible and near-infrared (VNIR) HSI for detecting and identifying physical hazards on meat surfaces. HSI datacubes were acquired using a Specim IQ camera covering approximately 400-1000 nm with 204 spectral bands. Five hazard classes were investigated: wood, stone, bone, nitrile and metal. A support vector machine (SVM) was used as a spectral classification baseline, followed by evaluation of a multiclass U-Net segmentation framework for direct spatial localisation and classification.

The dataset comprised clean meat scenes, single hazard scenes and scenes containing multiple hazard types. Preliminary spectral analysis included 180 regions of interest from 10 independent meat specimens, representing the five hazard materials together with meat and fat backgrounds. Analysis was restricted to approximately 452-948 nm and evaluated using leave-one-specimen-out validation to minimise information leakage. A class balanced linear SVM applied to raw spectra achieved 99.4% overall accuracy, 99.5% balanced accuracy and a class averaged F1 score of 0.997. A more conservative cube level analysis, using a single mean spectrum for each class within each cube, correctly classified all evaluated cube class observations following standard normal variate (SNV) preprocessing, demonstrating strong spectral separability under specimen independent validation.

Spatial modelling was subsequently performed using full object boundary annotations with specimen independent separation of training, validation and test data. Although spectral classification showed high separability among hazard materials and meat backgrounds, full scene multiclass localisation was substantially more challenging. Heterogeneous meat regions produced false positive hazard responses, highlighting a clear distinction between spectral separability and spatial generalisation. These findings emphasise the importance of specimen independent validation, clean scene evaluation and explicit false positive analysis when assessing HIS based physical hazard detection, and provide a basis for developing more robust spectral spatial localisation strategies.

References

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