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Study on Real-Time Terahertz Imaging and Object Detection System for Soft Foreign Matter in Food Using YOLOv8 with Attention Mechanism

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Abstract— **In this paper, we propose a real-time detection system for identifying soft foreign matter in food, leveraging terahertz imaging technology combined with the YOLOv8 object detection algorithm. Terahertz waves, known for their ability to penetrate non-metallic and non-polar materials, enable non-destructive inspection of internal structures. Focusing on seaweed as the primary food product, we developed a specialized dataset and conducted experiments to detect foreign matter. By integrating several attention mechanism modules, including ECA, CBAM and others, into the YOLOv8 framework, we achieved enhancements in both detection accuracy and processing speed. Our results highlight the system's effectiveness in identifying soft foreign matter, and we anticipate that this approach will significantly improve food safety and quality control within the industry. This study provides significant contributions to the application of terahertz imaging and deep learning in the domain of food safety, expecting a positive impact on future food management systems.**

Keywords— Terahertz Imaging, Attention Mechanisms, Object Detection, Deep Learning, Food Safety

I. INTRODUCTION

Recently, imaging and sensing technologies using electromagnetic waves have gained significant attention across various industrial fields, with the food industry emerging as a particularly important application area. Preventing the inflow of foreign substances during food production is essential, as these products are directly consumed by people. To ensure food safety, surface inspections using vision cameras and internal inspections with X-rays and metal detectors are commonly employed.[1] However, surface inspections alone are often insufficient for detecting foreign substances within food, and X-rays and metal detectors have limitations, including the risk of radiation exposure and the inability to detect soft, non-metallic foreign materials.

However, compared to X-rays, the terahertz(THz) wave is harmless to the human body since the electromagnetic wave in the frequency range of 0.1-10 THz is already known to be safe[2]. While sensitive to moisture, terahertz waves can penetrate non-metallic, non-polar materials such as plastics and wood, allowing for the detection of internal objects. By using terahertz waves, some limitations of traditional inspection methods can be overcome, as they enable non-destructive inspection of food without health risks, making them ideal for foreign object detection systems.

In this study, foreign object detection experiments were conducted on seaweed, a widely consumed food, using terahertz imaging technology, the real-time object detection algorithm YOLOv8, and attention mechanisms. The experiment focused on analyzing performance improvements by comparing YOLOv8 alone to YOLOv8 combined with various attention modules.

II. METHOD

You Only Look Once (YOLO) is a widely used algorithm in object detection, employing a one-stage model that simultaneously performs both object localization and classification. This approach allows YOLO to predict all objects within an image in a single pass, making it highly effective for real-time applications due to its fast detection speed. In this study, we used YOLOv8, developed by Ultralytics, which introduces an object-centered bounding box prediction method, replacing the anchor box-based approach used in previous models. This adjustment reduces computational complexity and improves the speed of Non-Maximum Suppression (NMS), allowing for faster and more efficient detection—a key feature of YOLOv8.[3]

The attention mechanism is a crucial concept in deep learning, initially introduced in natural language processing but now widely applied across various domains, such as image processing and speech recognition. The essence of the attention mechanism lies in guiding the model to focus on important information by learning the significance of each element within the input data and assigning greater weight to key parts.[4] In computer vision, this mechanism highlights important regions within an image, enabling the model to make more accurate predictions. In this study, we apply the attention mechanism to terahertz signal image analysis, aiming to improve foreign object detection performance by concentrating the model's focus more precisely on the locations of foreign objects.

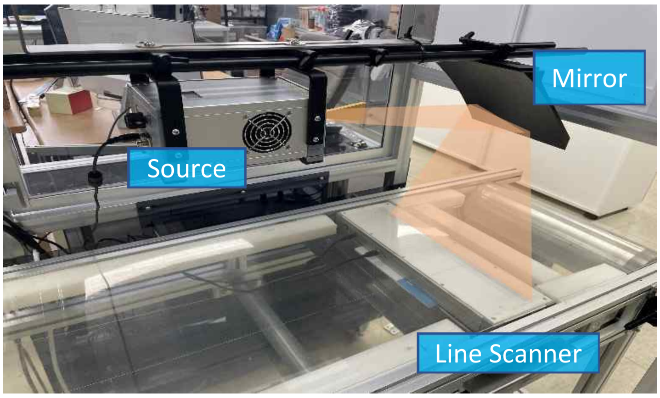

Figure 1. Equipment setup for THz wave signal acquisition

The terahertz detector equipment used in this experiment consists of a transparent conveyor belt to allow signal transmission and components for capturing THz signals, including a source, mirror, and line scanner. As shown in Figure 1, the THz signals are focused through the source and mirror on moving food items placed on the transparent conveyor, capturing information line by line in a line-scan manner. The acquired THz signals contain considerable noise, which is minimized using preprocessing algorithms such as Gaussian filtering. This process enhances the visibility of edges around foreign objects or food items, increasing the data's usability.

Source	
Frequency	0.1 THz
Power	100mW
Scanner	
Number of pixels	256
Pixel size	1.5 x 3mm^2
Dimensions of device	450 x 160 x 44 mm^3
Image acquisition rate	5000 fps

Table 1. Specification of the terahertz radar

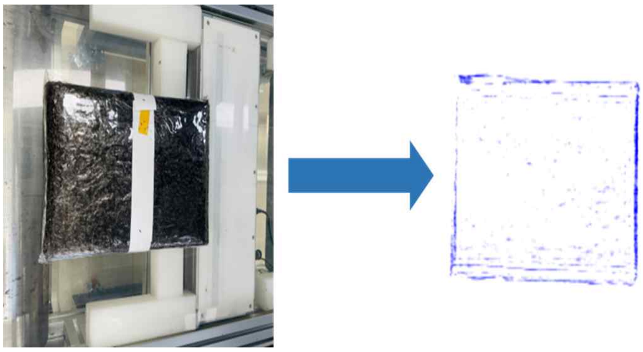

Figure 2. The image of seaweed obtained using terahertz imaging.

III. EXPERIMENTS AND RESULTS

In this experiment, we captured a total of 12,000 THz images of seaweed, varying the position of foreign substances within the samples. Each image was labeled under a single "foreign matter" class to build a dataset for foreign substance detection. For training, we set the learning rate to 0.01, the batch size to 32, and the number of epochs to 60, using YOLOv8n—a lightweight model within the YOLOv8 series—as the base network. Additionally, for performance comparison, we trained networks incorporating various attention modules, Shuffle Attention (SA), Efficient Channel Attention (ECA), Global Attention Mechanism (GAM), ResBlock Convolutional Block Attention Module (ResCBAM), alongside YOLOv8n.[5]

As shown in Table 2, no single module outperformed others across all performance metrics. However, combining attention modules with YOLOv8n resulted in overall improvements in mAP, Precision, Recall, and other metrics compared to using YOLOv8n alone. In particular, the ECA module demonstrated superior performance relative to other modules. This efficient module addresses the limitations of the SE module, a commonly used attention mechanism, by using 1D convolution to reduce computational load while achieving comparable performance with fewer parameters in a simple structure. Additionally, the adaptive kernel size allows dynamic application across various networks, enhancing overall system performance.[6]

$$Precision = \frac{True\ Positive\ (TP)}{True\ Positive\ (TP) + False\ Positive\ (FP)}$$

$$Recall = \frac{True\ Positive\ (TP)}{True\ Positive\ (TP) + False\ Negative\ (FN)}$$

$$mAP = \frac{1}{N}\sum_{i=1}^{N} AP_i$$

$$(AP = \sum_n (Recall_n - Recall_{n-1}) \times Precision_n)$$

*Where N represents the total number of classes

$$F1\ Score = 2 \times \frac{Precision \times Recall}{Precision + Recall}$$

	YOLO v8-n	ECA	GAM	CBAM	SA
mAP$_{50}$^{val}	0.978	**0.988**	0.983	0.978	0.983
mAP$_{50\text{-}95}$^{val}	0.59	0.59	0.588	**0.611**	0.586
Precision	**0.98**	0.95	0.95	0.968	0.951
Recall	0.936	**0.97**	0.97	0.946	0.962
F1 Score	0.95	0.96	0.96	0.96	0.96

Table 2. Equations for Performance metrics and Training results using YOLOv8-n and attention modules.

In this system, which requires real-time detection of foreign substances within food, the use of a lightweight network is crucial. The ECA module meets these requirements well, and as shown in Table 2, it demonstrated relatively higher performance compared to using YOLOv8n alone or with other attention modules. As illustrated in Figure 3, the trained model weights successfully detected soft foreign substances within seaweed in real time.

Figure 3. Result of foreign matter detection within seaweed using the trained model's weight file.

IV. CONCLUSION

This study proposed a method for detecting foreign matters in food by combining the YOLOv8 object detection algorithm with attention modules. The experiment, conducted on seaweed, confirmed the high processing speed and efficiency of foreign object detection systems that integrate YOLOv8 with various attention modules. While no single attention module outperformed across all performance metrics, performance improvements are expected when attention modules are appropriately selected and implemented based on the specific conditions and requirements of the system.

ACKNOWLEDGMENT

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