MeetCon conference

Dicoj
Digital Communication Journal
ISSN: 2757-5780 www.dicoj.com

MEETCON-SMART

4th. INTERNATIONAL CONGRESS OF MODERN SCIENTIFIC RESEARCH

August 25-27, 2026

ANKARA TÜRKİYE

Editor:

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Date: 15.09. 2026
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Water Street Corridor New York, NY 10038
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adopted by Mariam Rasulan

ISSUED: 15. 09. 2026
ISBN: ' 979-8-89695-521-4 '

CONGRESS ID

CONGRESS TITLE

MEETCON - SMART
4th. INTERNATIONAL CONGRESS OF MODERN SCIENTIFIC RESEARCH

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Asst. Prof. Dr. Canan TASTIMUR	An Explaınable Lıghtweıght Deep Learnıng Framework For Pharmaceutical Tablet Defect Classıfıcatıon Usıng Espnetv2	Erzincan Binali Yildirim University
Asst. Prof. Dr. Canan TASTIMUR	Brain Tumor Segmentation And Classification With A Lightweight Cnn And U-Net Based Framework	Erzincan Binali Yildirim University
Assist. Prof. Dr. Elçin MUSTAFAYEV	The Theme Of "Karabakh" In The Works Of Altay Hajiyev	Karamanoglu Mehmetbey University
Assist. Prof. Dr. Cemal GÜMÜŞ	Regulation-Enabled Ai Transformation In Digital Identity And Remote Customer Onboarding	Istanbul 29 Mayıs University
Dr. Halil İbrahim OLUCAK Dr. Mehmet KERTMEN Umut FINDIK	The Transformation Of The Textile Industry From The Perspective Of Industry 5.0: A Human-Centric, Sustainable, And Resilient Manufacturing Approach	İskur Tekstil Enerji Tic. ve San. A.Ş.
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AN EXPLAINABLE LIGHTWEIGHT DEEP LEARNING FRAMEWORK FOR PHARMACEUTİCAL TABLET DEFECT CLASSIFICATION USING ESPNETV2

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ABSTRACT

In the pharmaceutical manufacturing industry, the need for AI-supported, autonomous processes for quality control has increased compared to manual diagnostic approaches. Thanks to AI-supported defect detection solutions, issues such as cracks, wear, and discoloration on the drug surface can be quickly detected as the product passes through the conveyor belt, preventing them from reaching the end user. In this study, an ESPNetV2-based deep learning approach is presented for the automatic detection and classification of drug defects. The proposed model classifies five different drug defect conditions. Before training the model, various preprocessing steps were applied to the images in the dataset, thus improving the generalization ability of the model. During the experimental results of the study, the proposed model achieved a training accuracy of 97.54% and a validation accuracy of 98.29%. The proposed model, with 0.5M parameters and 0.2G FLOPs, is significantly faster than the comparatively presented ResNet18, MobileNetV2/V3, and ShuffleNetV2. It is also supported by some visualizations to show how much attention the proposed model pays to the faulty areas.

Keywords: Drug Classification, ESPNetV2, Mild Deep Learning.

INTRODUCTION

Traditional manual fault diagnosis approaches have recently been replaced by intelligent and automated fault diagnosis processes in fields such as healthcare, industrial automation, manufacturing, and agriculture. The recent development of convolutional neural network (CNN) architectures and lightweight deep learning architectures has increased the trend of using them in fault detection approaches, yielding successful results. While traditional image processing-based fault detection approaches require manual feature extraction, including the identification of edge and corner features and the retrieval of morphological features, deep learning-based models used in recent years can successfully perform this process automatically. Furthermore, deep learning models have the ability to process large amounts of image data in addition to automatically extracting features from images.

Traditional quality control processes require a high level of expert oversight. These systems

are susceptible to subjective interpretation and are also highly prone to error due to their reliance on human observation. Long-term operators may overlook defects in the packaging due to poor visual perception. In the pharmaceutical industry, accurate labeling of products passing through high-volume production lines can prevent defective products from being overlooked and reduce costs. Since the pharmaceutical industry directly affects human health, every stage of production is carried out according to high quality standards. Staining, discoloration, breakage, etc., occurring during pharmaceutical production can both reduce product quality and negatively affect human health. Defects on the surface of tablets or capsules can occur during packaging, transportation, or storage. The presence of these defective drugs on the market can both damage the company's image and lead to serious problems such as incorrect dosage and decreased product safety.

Many studies exist in the literature using deep learning models for drug defect classification. Vijayakumar et al. (2024) proposed a hybrid architecture with the Coordinate Attention and YOLOv8 models for real-time defect diagnosis of tablets in blister packs. In the study, two different drug tablet versions were used in the evaluation phase of the proposed model. A 97.4% mAP rate was achieved by examining tablet defects in the first dataset and detecting the fill rate in drug serum vials in the second dataset. Prajwala (2018) applied classical image processing techniques instead of a deep learning model for drug defect detection. In detecting drug defects, the drugs examined were first evaluated separately in two sections: tablets and capsules. While capsules were grouped according to their colors, segmentation and morphological features were extracted from the images, and the number of missing or defective tablets was determined by comparing it with a reference test image. No performance classification metric results were shared in the study.

Pathak et al. (2025) tested defects in pharmaceutical film tablets using a deep learning model. Four different defect types—spectkling, color non-uniformity, chipping, and breaking—were classified using classical CNN. A special tablet placement apparatus, produced with a 3D printer, was used to create synthetic defects. 25,200 tablet images were generated for training purposes, and data enhancement techniques were applied to ensure robustness under different imaging conditions. The training of their proposed model resulted in 99.7% accuracy. When comparing their proposed CNN model with rule-based classification approaches, the rule-based image processing model produced 70% erroneous results in calculating the drug surface area.

Zhang et al. (2025) proposed an unsupervised anomaly detection approach for drug surface defects. Their diffusion-based model enabled the detection of frequently encountered drug defect types in drug tablet production. However, due to the insufficient number of defective

samples and the resulting inability to accurately locate anomaly regions, a diffusion model was developed. To test the developed model, a total of 4967 tablet images were obtained from the MVTec AD and Pill public versions. The defect types, including scratch, defect, stain, mold, bump, and adhesion, were included in both defective and intact samples, and these defect types are also encountered in real industrial production lines. In the evaluation of the version, which consisted of 3623 intact and 1344 defective tablet images, a 2.55% performance increase was observed when comparing the YOLOv8 model with the proposed model.

Kim and Han (2025) proposed an intelligent tablet press machine for the real-time detection of defective products passing through the pharmaceutical production line. This study, focusing particularly on the separation of the tablet's top layer and unsuitable tablet break strength, utilized random forest and artificial neural networks with data obtained from production line sensors. To test the performance of the developed model, the proposed Process Analytical Technology model was compared. On a dataset of 1482 data points, the results were as follows: Random Forest model (93.7% Accuracy, AUC=0.895), ANN model (92.6% Accuracy, AUC=0.878), and the developed TPM system achieved 99.43% sorting accuracy and 93.71% defective tablet detection success.

Ficzere et al. (2022) utilized the YOLOv5 architecture and image processing techniques to detect coating defects in film-coated pharmaceutical tablets. In this study, an accuracy of 98.2% was achieved in the evaluation of five different coating defects. In addition to classifying coating defects, this study also aimed to measure the thickness of the coating. For this purpose, the pixel count was calculated to measure the thickness of the tablet in the image.

Ma et al. (2020) aimed to detect the internal crack status of orally administered drug tablets using a deep learning-based model. Thousands of 2D cross-sectional images of each tablet were obtained using X-ray computed tomography, and these images were trained on a classical CNN model, achieving an accuracy rate of 94%. To prove the generalizability of the proposed model, it was evaluated on different product types, with different geometries, different bottle types, and different product types.

Varghese and Cetinkaya (2007) aimed to detect defects in pharmaceutical tablets using a contactless and acoustic-based method, targeting cracks and deteriorations on the coating surface during the production process quickly and safely. For this purpose, they proposed two different methods based on the photo-acoustic measurement principle. The time-frequency spectrogram, correlation analysis, and frequency spectra were examined using the vibrating plate and laser-induced plasma methods from the acoustic excitation systems used. They were

successful in detecting even very small and shallow circular holes with this method. The results from the classification metrics were not shared in the study.

Quan et al. (2022) aimed to classify tablets from a pharmaceutical production line as defective and sound. They performed transfer learning on 6000 tablet images obtained from a company's production line using a multi-camera system, employing both image processing and deep learning models. The results obtained separately with ResNet50, ResNet101, DenseNet169, and DenseNet201 from the data, which was divided into 3000/1000/2000 train validation and test modules, were evaluated, and the most successful result was obtained with ResNet50, achieving 96.60 ± 4.9% accuracy.

Diószegi et al. (2024) aimed to detect five different failure classes using YOLOv5 in a real-time system developed for determining tablet fracture strength and disintegration times. In this study, which classified defective tablets with 99.2% accuracy, both surface defect detection and surface texture analysis of defective regions were performed on images obtained from the camera system.

Lin and Xiao (2024) proposed the Biaxial Scanning Slope Symmetry method in this study, where the external appearance integrity of pharmaceutical tablets is checked before packaging. Since pharmaceutical tablets have a symmetrical geometric structure, the need for complex deep learning and image processing techniques is eliminated by performing the analysis based on this assumption regarding tablet deformation. In the tablet image data collection study, the x and y-axis images of the tablets were captured using a data collection image sensor. By digitizing the obtained analog signals, center points are determined, and the slope between consecutive center points is calculated. The variation of all slopes is calculated using the Square Mean Error. Thanks to this calculated value, it is revealed whether there is a deformation in the tablet.

Hu (2026) developed the YOLOv11 architecture for the real-time detection of tablet defects in the pharmaceutical production line, classifying 960 high-resolution drug images into three classes: contamination, crack, and good. The novelty in this study is the use of the Feature Complementary Mapping component. This allows for better integration of semantic and spatial features, enabling the detection of small defects such as microcracks and surface contaminations. The proposed model achieved 94.2% accuracy, 2.1% higher than the classic YOLOv11 model. Furthermore, a real-time processing speed of 85 FPS was achieved.

Daniel et al. (2025) applied Detectron2-based instance segmentation to identify surface defects in drug tablets at the pixel level. Classification was completed on 780 images from the Kaggle public database using crack, chip, coloration, and impurity. High success rates were achieved with 98.5% accuracy and an average mAP of 97.2%.

Lin et al. (2026) used the Gradient Variation Algorithm method for detecting surface defects on pharmaceutical tablets in real time. Analog optical signals were generated by scanning tablet images from the production line with an image sensor and a convex lens. These signals were then converted into binary digital data. A Slew Rate Limiter was used to reduce noise in the data. The method proposed in the study achieved 100% accuracy in six different defect types.

Table 1. Literature review for drug table defect classification

Study	Method	Dataset	Metrics
Pathak et al. (2025)	CNN+ Data augmentation	Good + 4 fault 25,200 images	Accuracy: 99.7%
Zhang et al. (2025)	DTDD (Diffusion Model + AR + SF + Attention)	Normal + 6 fault 4,967 görüntü	AP +2.85%, F1 +2.55%,
Kim & Han (2025)	Random Forest, ANN	Defective / Non-defective 1,482 data	RF: 93.7% Accuracy ANN: 92.6% Accuracy
Quan et al. (2022)	ResNet50/101, DenseNet169/201	Good / Not-Good 6,000 images	ResNet50 Accuracy: 96.60±4.9%, DenseNet169: 94.13%
Hu (2026)	DD-YOLO (YOLOv11 + FCM)	Good, Crack, Contamination 960 images	mAP50: 94.2%, 85 FPS
Daniel et al. (2026)	Detectron2 (Instance Segmentation)	4 fault types 780 images	Accuracy: 98.5%, mAP: 97.2%

METHODOLOGY

In this section, the Extremely Efficient Spatial Pyramid Network (ESPNetV2) transfer learning model was used to train images and perform a classification process for fault classification in drug tablet images. In the proposed method, data preparation, preprocessing, model architecture tuning, model training, and performance evaluation criteria were examined. The dataset used publicly consists of drug images (Tran 2025) divided into five different classes. The ESPNetV2 model used is quite lightweight and suitable for real-time applications.

The ESPNetV2 architecture, developed by Metha et al. (2019), was used in this study with its transfer learning process. This architecture is particularly lightweight and fast enough to be used on edge AI, mobile devices, and embedded systems. Instead of standard convolutions, Depth-wise Dilated Separable Convolution and Group Point-wise Convolution structures are used. Unlike the mobilenet architecture, ESPNetv2 uses Depth-wise Separable Convolution while adding dilation. By combining information from different dilation ratios more efficiently, spatial information loss is prevented by using long-range connections.

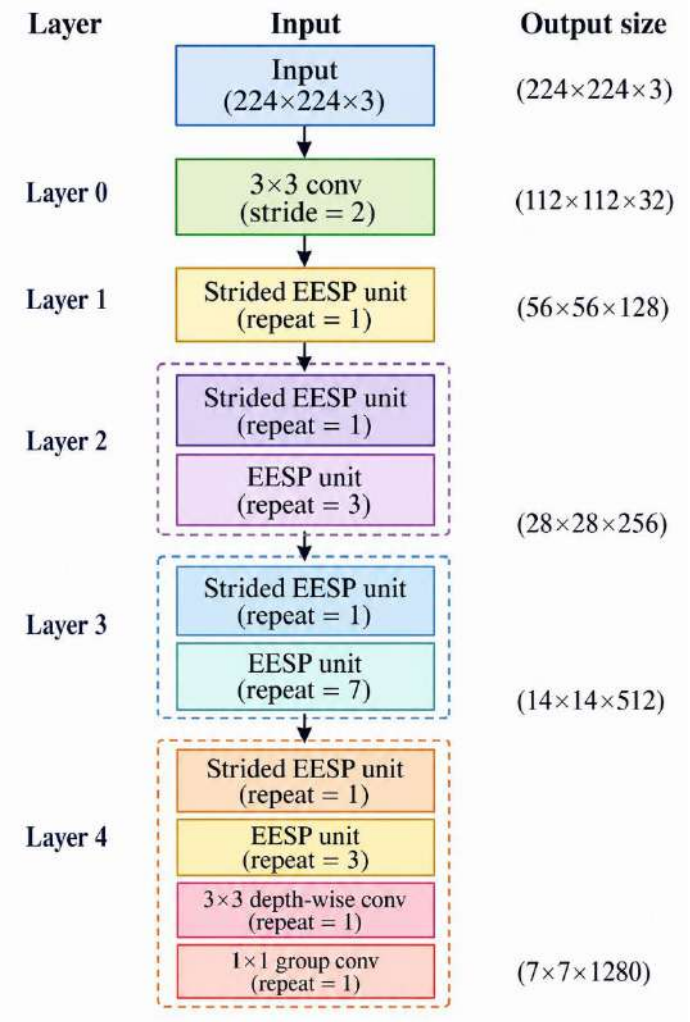


Figure 1. ESPNetV2 overall arcitecture

EXPERIMENTAL RESULTS

In this study, classification metrics, complexity matrix, ROC curve, and classification score for each class were evaluated to assess the performance of the proposed model. To prove that the proposed model is quite lightweight and fast, the MobileNetV3/V2, ShuffleNetV2, and ResNet18 architectures, known for their speed in the literature, were compared in terms of model parameter number, model size, computational complexity, CPU inference latency, GPU inference latency, and CPU throughput. Thus, it was revealed that the proposed model is superior to all other models. This study was conducted on a system with a 13th generation Intel Core i7-13620H central processing unit (CPU) and an NVIDIA GeForce RTX 4060 Laptop GPU graphics processing unit (GPU). Figure 2 shows the comparison of the proposed model with other models in the literature.

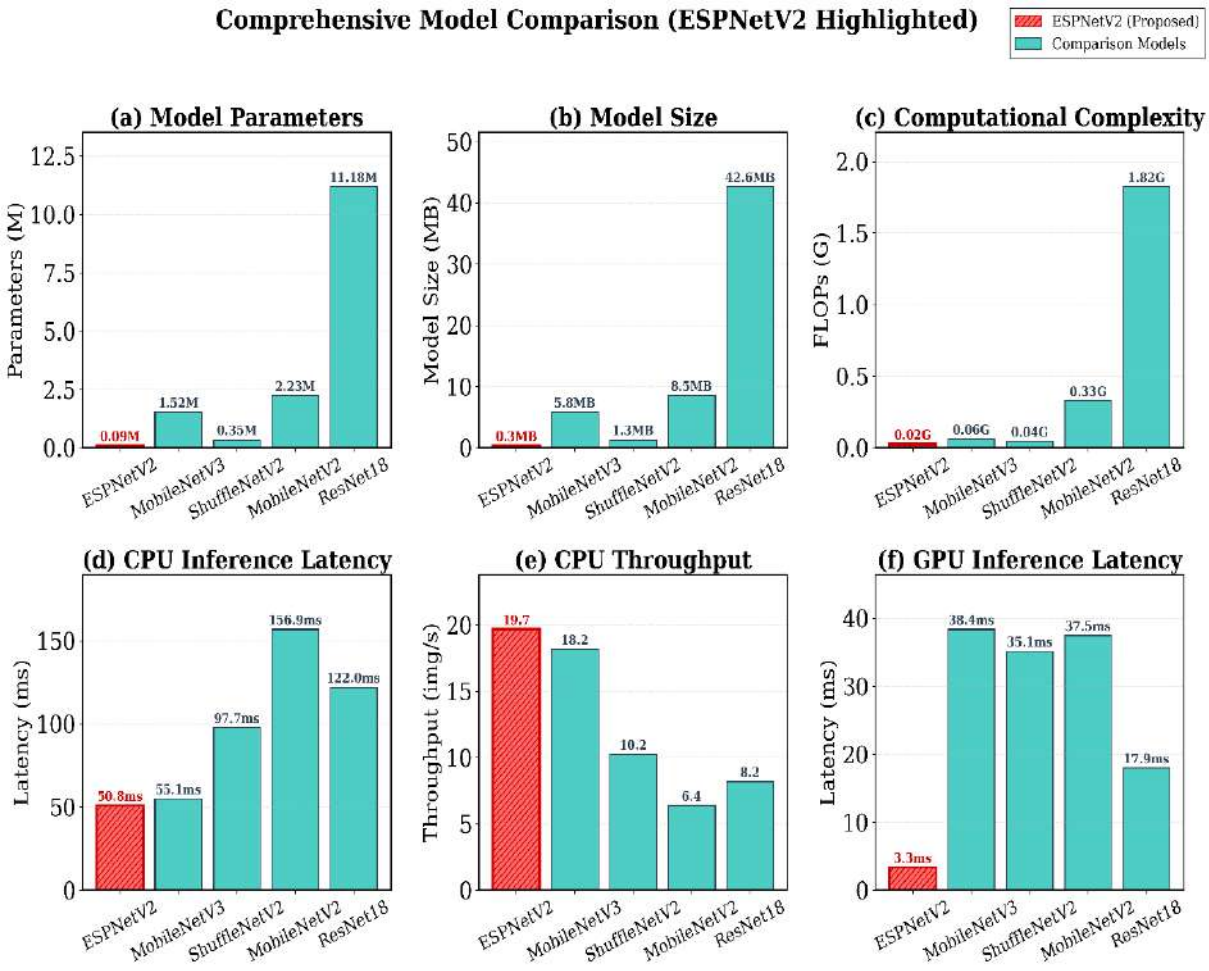


Figure 2. Comprehensive model comparsion

Table 2. Computational cost and inference performance of ESPNetV2 and comparison models

Model	Params (M)	Size (MB)	FLOPs (G)	CPU Latency (ms)	Throughput
MobileNetV3	1.52	5.81	61.459M	71.82	13.9
ShuffleNetV2	0.35	1.32	43.553M	87.23	11.5
MobileNetV2	2.23	8.51	326.213M	105.56	9.5
ResNet18	11.18	42.64	1.824G	76.96	13.0
ESPNetV2	0.09	0.33	24.701M	21.02	47.6



(a) (b) (c) (d) (e)

Figure 3. Sample drug images belonging to the categories (a) Broken, (b) Colored, (c) Normal, (d) Stained, and (e) Unknown.

Figure 3 shows an example visualization of the public drug tablet dataset used in this study. The training and validation accuracy curves and loss curves of the proposed model are shown in Figure 4. It is clear that the model successfully completed the training and did not experience overfitting. The ROC curve presented in Figure 5 supports this. In the confusion matrix in Figure 6, only 6 test samples were mislabeled, while all other classes were correctly labeled. The t-SNE visualization space presented in Figure 7 shows how well the model differentiated and grouped the sample test images. Figure 8 visualizes where the model focuses its attention on each layer, thus showing how it concentrates on faulty areas.

Table 3. Class-wise performance analysisof the proposed model

Classes	Precision	Recall	F1-Score
Broken	0.9571	0.9571	0.9571
Colored	0.9589	1.0000	0.9790
Normal	0.9853	0.9571	0.9710
Stained	1.0000	0.9857	0.9928
Unknow	1.0000	1.0000	1.000

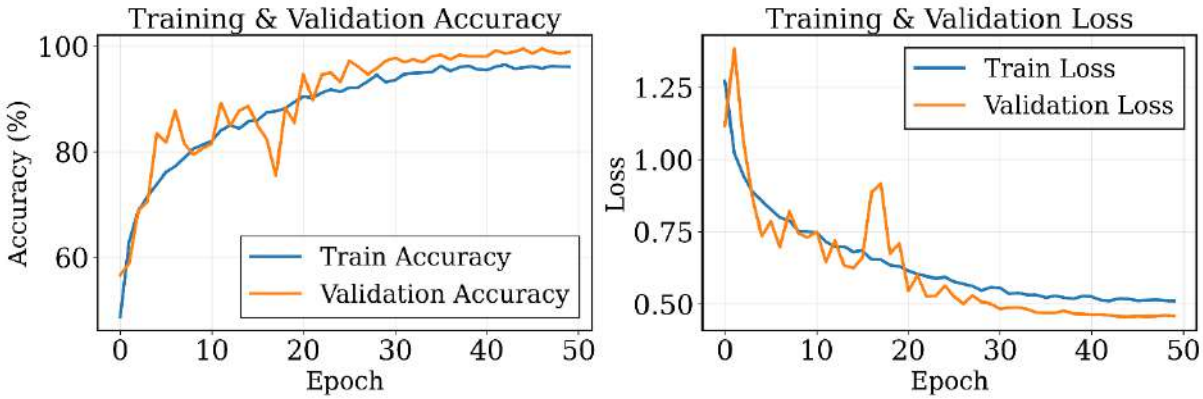


Figure 4. Training and validation curve of the proposed model

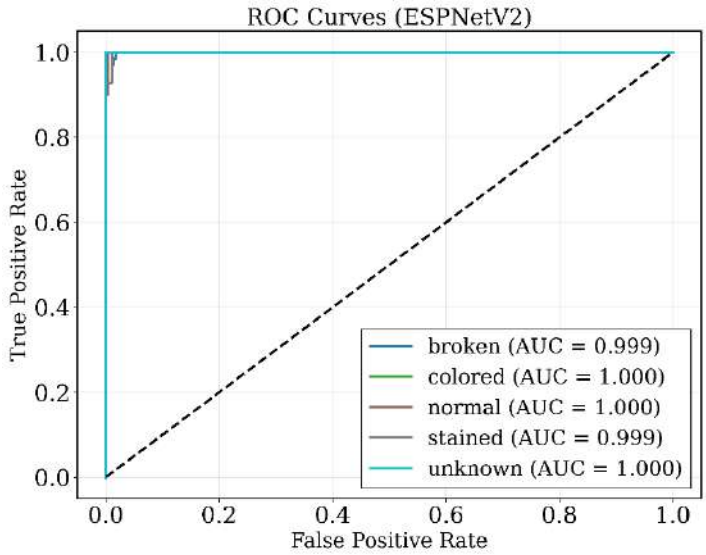


Figure 5. ROC curve of the proposed model

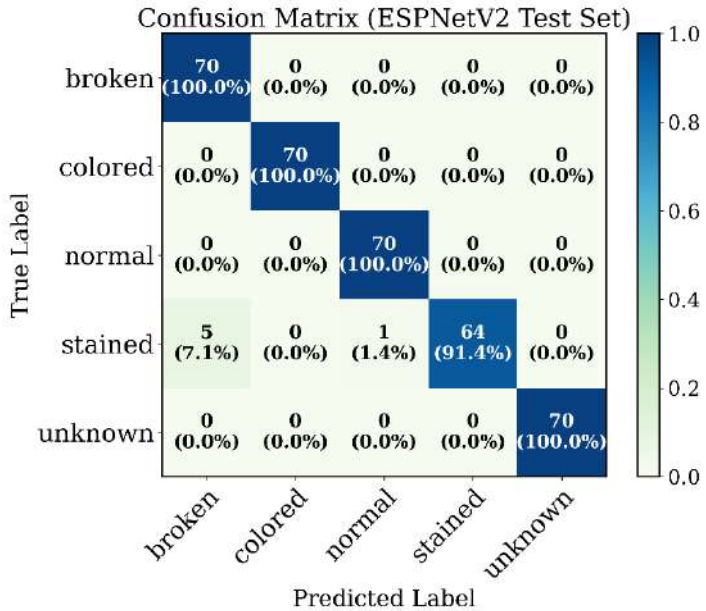


Figure 6. Confusion matrix of the proposed model

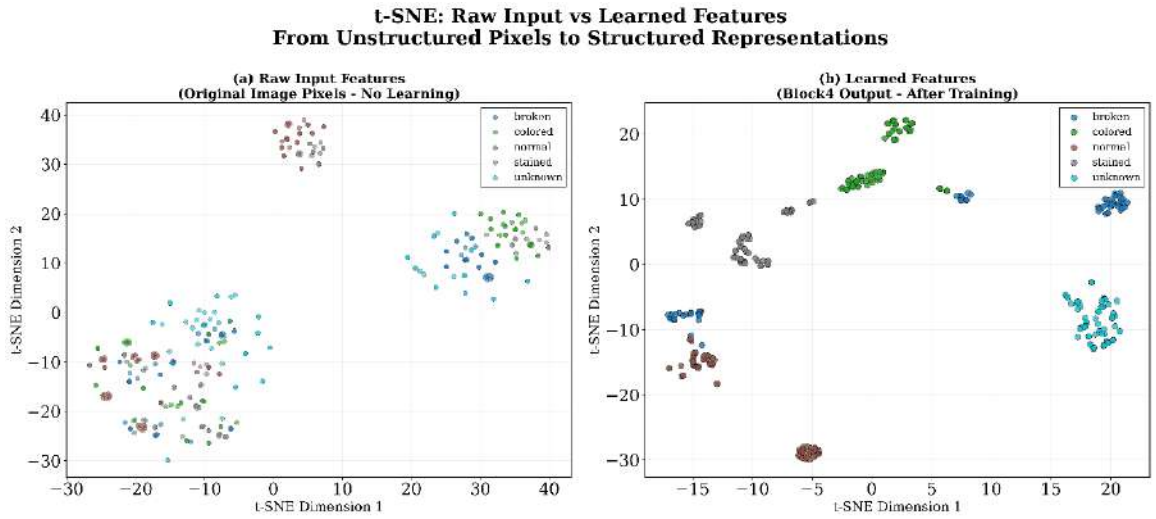
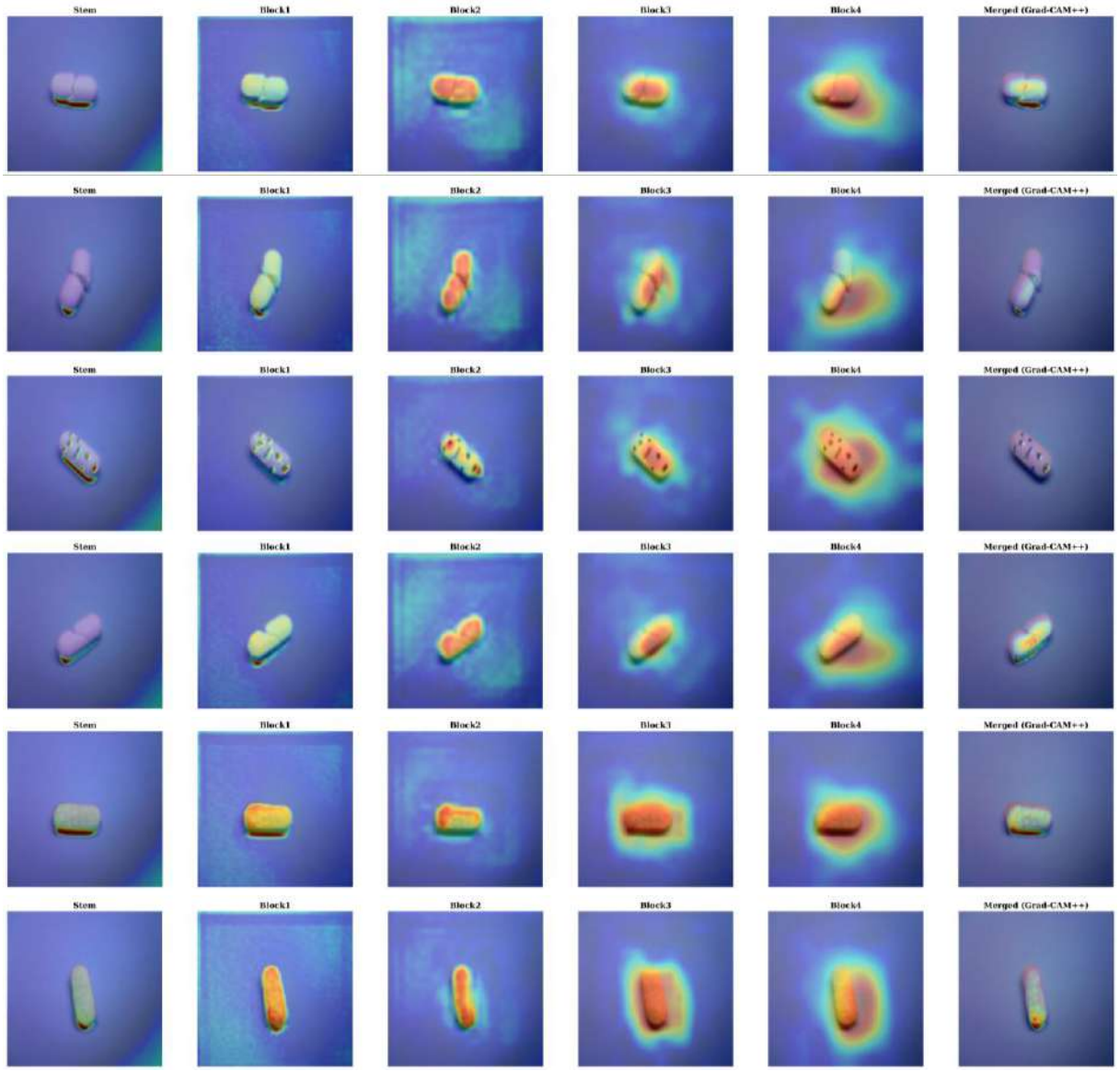


Figure 7. t-SNE visualization of the proposed model



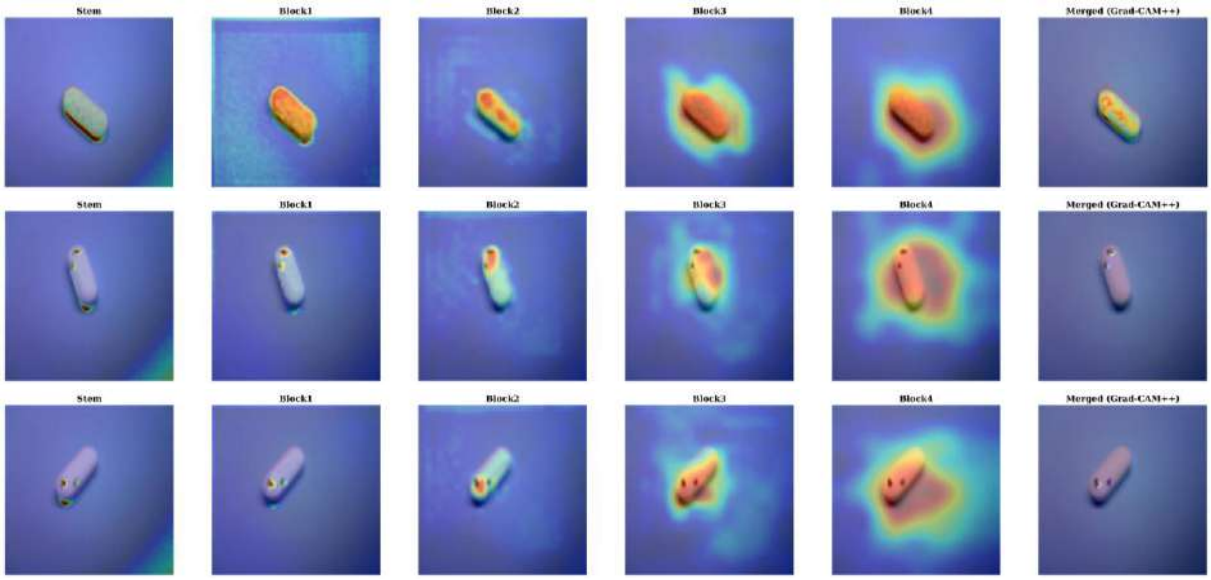


Figure 8. Grad-CAM visualization of the proposed model

CONCLUSIONS

In this study, a lightweight and explainable deep learning model based on ESPNetV2 was developed for the automatic classification of drug defects. The proposed model was evaluated on five classes: Broken, Colored, Normal, Stained, and Unknown, achieving 97.57% training accuracy and 98.57% validation accuracy. These results demonstrate that ESPNetV2 has a high discrimination capacity in the drug defect classification problem. Model comparisons revealed that ESPNetV2 offers significant advantages not only in terms of accuracy but also in terms of computational efficiency. With approximately 0.09M parameters, a model size of 0.33 MB, and 24.701M FLOPs, ESPNetV2 presented a more compact structure than the compared MobileNetV2, MobileNetV3, ShuffleNetV2, and ResNet18 models. Furthermore, a CPU latency of 21.02 ms and a throughput of 47.6 images/s indicate that the model is suitable for applications requiring fast image analysis. Grad-CAM analyses showed that the model focused on distinctive regions representing defects in the deep layers, while t-SNE results revealed that the learned features successfully separated between classes. Therefore, ESPNetV2 offers a balanced solution in terms of classification performance, computational cost, and explainability. In the future, it is planned to test the method on larger datasets from different production conditions and to validate it in real-time production lines.

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Date: 15.09.2026

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adopted by Mariam Rasulan

ISSUED: 15.09.2026
ISBN: ' 979-8-89695-521-4 '



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