

Deep Learning-Based Recognition of Pharmaceutical Pills using Convolutional Neural Networks

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Abstract—Drug identification technology is a critical step that pharmacies take to ensure they are dispensing the correct drug. Photos of pills can be used to determine what medication it is, and which manufacturer produced it. Elderly patients are more likely to lose or misplace their medicines, especially if they are using a pill organizer. With the proper technology, patients will be able to determine which drugs are which. Convolutional Neural Networks identified medications from images with over 90% accuracy. This algorithm allows for better verification processes in the pharmacy and provides a tool for patients and global supply chain professionals with practical decision-support. Existing safeguards such as barcoding and electronic prescribing reduce, but do not eliminate, the risk of administering the wrong medication, particularly in environments complicated by polypharmacy and globalized supply chains. The need for reliable, scalable verification at the pill level has therefore become a pressing concern in pharmacovigilance.

Keywords—Computer Vision, Deep Learning, Drug Authentication, Healthcare Technology, Patient Safety, Pharmacovigilance, Pill Recognition, Supply Chain Management.

I. INTRODUCTION

Medication safety remains a central concern for healthcare systems worldwide. Despite advancements in digital health and regulation, errors in prescribing, dispensing, and administration continue to cause avoidable harm to patients and strain healthcare resources. The World Health Organization estimates that one in twenty patients experiences medication-related harm, a significant portion of which is preventable [3]. These risks are heightened by polypharmacy, high-alert medications, and complex supply chains that place pharmacists under increasing pressure to ensure accuracy [1]. Dispensing and labeling errors, particularly those involving look-alike or sound-alike drugs, remain a major contributor to patient morbidity [4]. Even with safeguards such as barcoding and electronic prescribing, lapses in verification can lead to wrong-patient or wrong-drug events. In parallel, the scale and globalization of pharmaceutical supply chains demand solutions that enhance reliability at the pill level, supporting both pharmacists and patients in safe medication use [3]. Recent advances in computer vision and deep learning offer promising avenues to address this challenge. Convolutional Neural Networks (CNNs) are a type of deep learning architecture that can automatically extract and learn layered patterns from images, capturing both low-level details and

higher-level visual structures. By capturing visual attributes such as color, edges, contours, and texture, CNNs excel at distinguishing objects that appear superficially similar. Their ability to generalize across diverse imaging conditions makes them especially relevant to pill recognition, where subtle differences in shape, imprint, or hue can separate one medication from another [2] [6].

II. LITERATURE REVIEW

Dispensing errors remain a significant source of preventable harm in pharmacy and hospital workflows, with systematic reviews linking them directly to adverse events, hospitalizations, and patient mortality [9]. Wrong-patient incidents are frequently triggered by adjacency of similar drug names in records, inadequate confirmation, and heavy workloads, which create opportunities for the administration of the wrong medication. Labeling deficiencies, particularly in high-alert medications, further exacerbate risk as incomplete or misleading information on packaging has been shown to precipitate harmful substitutions [4].

Medication errors are multifactorial, arising from patient-level vulnerabilities such as polypharmacy and impaired cognition, provider-level issues including cognitive bias and miscommunication, and drug-level characteristics such as look-alike packaging or sound-alike names [1]. These overlapping factors demonstrate the limitations of existing safeguards and underscore the need for technological support to strengthen accuracy in real-world dispensing and administration.

Computer vision and deep learning have emerged as promising approach to address these vulnerabilities. CNNs applied to blister-pack recognition have demonstrated the ability to distinguish visually similar medications and reduce look-alike/sound-alike dispensing errors in clinical environments [6]. Integration of imprint recognition with CNN-based classifiers has been shown to enable robust real-time identification of pills, supporting pharmacists and patients with accessible decision-support systems [5]. Comparative surveys confirm that deep learning consistently outperforms traditional feature-based methods for pill recognition, while also identifying challenges in dataset diversity, imprint legibility, and generalizability across markets [2].

The global burden of medication-related harm highlights the urgency of scalable solutions that extend beyond manual verification. Systematic reviews and international reports emphasize that preventable harm is concentrated in prescribing and dispensing stages, where image-based decision-support systems can provide the greatest impact [3] [7].

III. METHODOLOGY

This study employed a structured methodology spanning dataset preparation, model development, evaluation, and deployment into a user-facing application.

The dataset was sourced from Kaggle and contains images of ten popular pharmaceutical drugs and vitamins commonly used in the Philippines. Each class originally included 1,000 pill images, and two additional images per class were incorporated, resulting in a total of 10,020 images. This design improves generalization by exposing the model to non-uniform surfaces and lighting contexts. Images were preprocessed through resizing to 128×128 pixels, pixel normalization, and augmentation techniques such as rotation, flipping, shifting, zooming, and brightness adjustment. A supplementary metadata file was curated with drug names, active ingredients, and therapeutic applications, enabling recognition outputs to be paired with contextual information for pharmacists, supply chain professionals, and patients.

The recognition engine was built on a CNN architecture, with EfficientNetB0 serving as the backbone model. CNNs are designed for image classification tasks, using convolutional layers to extract hierarchical features such as pill edges, contours, and imprints. In this study, EfficientNetB0 was fine-tuned across four stages to adapt the CNN to pill-specific features, enabling accurate recognition across ten classes, leveraging transfer learning from ImageNet weights. To adapt the backbone to pill-specific features, the model was trained in four progressive stages: (i) Stage 1 froze the base layers while training only the classification head, (ii) Stage 2 partially unfroze deeper layers with a reduced learning rate, (iii) Stage 3 unfroze all layers for full fine-tuning, and (iv) Stage 4 conducted final fine-tuning with very low learning rates to stabilize convergence. Each stage applied the Adam optimizer with categorical cross-entropy loss, accompanied by callbacks such as early stopping and learning rate reduction.

The dataset was split into training, validation, and test sets in an 80:10:10 ratio. Performance was assessed using accuracy, precision, recall, F1-score, and confusion matrices.

Streamlit-based web app operationalized the trained model. Users, including pharmacists, supply chain professionals, and patients can upload pill images and receive Top-3 predictions with confidence scores, supported by retrieved metadata.

IV. RESULTS

The CNN model achieved 91.2% Top-1 accuracy, meaning the correct pill was the highest-ranked prediction in more than nine out of ten cases. Top-3 accuracy reached 98.2%, showing that the correct pill was almost always within the top three predictions. Minor misclassifications occurred only among visually similar analgesics, highlighting the practical value of Top-3 prediction.

Overall Accuracy: 91.22%				
Top-3 Accuracy: 98.20%				
Classification Report:				
	precision	recall	f1-score	support
Decolgen	0.96	0.93	0.94	100
Fish Oil	0.86	0.95	0.90	100
Bactidol	0.94	0.83	0.88	100
Kremil S	0.98	0.97	0.97	100
Biogesic	0.91	0.89	0.90	100
DayZinc	0.94	0.97	0.96	101
Bioflu	0.91	0.88	0.89	100
Neozep	0.89	0.85	0.87	101
Alaxan	0.79	0.88	0.83	100
Medicol	0.96	0.97	0.97	100
accuracy			0.91	1002
macro avg	0.91	0.91	0.91	1002
weighted avg	0.91	0.91	0.91	1002

Fig. 1. Classification report showing precision, recall, and F1-score.

V. CONCLUSION

This study highlights the potential of deep learning-based pill recognition as a decision-support tool for medication safety. By analyzing pill images directly, the system reduces reliance on packaging or labeling, offering verification where human error, labeling inconsistencies, and polypharmacy risks persist. The integration of a Streamlit application extends practical utility by providing top-3 predictions with drug metadata, enabling pharmacists, patients, and supply chain professionals to confirm medication identity efficiently. Positioned as a complementary safeguard, such recognition systems strengthen pharmacovigilance, reduce dispensing errors, and improve patient trust. Future work should enhance dataset diversity and enable seamless integration into clinical workflows.

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