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Convolutional Neural Network in Exclusive Approaches to Coffee Beans: A Literature Review

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Abstract:

The review presents a comprehensive evaluation of 15 published systems centred on the application of Convolutional Neural Network (CNN) in exclusive exhibitions on coffee beans via utilizing Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA). The assessment displayed the accuracy rate, methodical procedure, and relevance of CNN as a tool. Furthermore, an extensive analysis was performed to determine the effectiveness and reliability of CNN which yielded a high-rating accuracy ranging from 90 to 100 percent from chosen studies. The findings highlight CNN's superiority over traditional methods, emphasizing its potential as a pioneering neural network architecture for coffee quality assessment. Nonetheless, limitations of the CNN model are also highlighted alongside the recorded data.

Keywords **—Convolutional Neural Network, Coffee Beans,CNN model**

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I. INTRODUCTION

A. Contextualizing Convolutional Neural Network in Coffee Bean Analysis

Convolutional Neural Networks (CNNs) have been investigated in various types of studies for applications related to coffee bean analysis. [18][7] It is collective methods to attain high accuracy in their quality-based coffee bean classifications, whereas Hsia developed a lightweight CNN model. With the goal to achieve a high and efficient classification, an industrial robot arm has been combined with a CNN-based classifier for autonomous coffee bean selection. All this research show how CNNs can be used for several types of coffee bean analysis, like automatic selection and quality grading [3]. Coffee is next in terms of worldwide agricultural production followed by petroleum. For exporting nations, maintaining the quality of coffee beans is important, but because of the volume of trade, this can be difficult. Automating quality control requires the use of digital technology. Using Deep Learning for image classifiers is an efficient way. Deep Learning takes the place of traditional methods that rely on feature extraction algorithms [9].

B. Specific focus on coffee bean quality assessment

Several methods to determine the quality of coffee beans have been explored in recent research. Color descriptors play an important part in [16] demonstration of the effectiveness of computer vision and machine learning algorithms in detecting and categorizing problems in coffee beans. [11]The potential of spectroscopic methods for assessing several aspects of coffee quality, which includes Raman, fluorescence, near infrared, and mid-

infrared spectroscopy. [1] An image processing method that yields 100% classification accuracy in identifying and eliminating black beans. [4] The viability of coffee embryos in which the obtained test results on their study were positively correlated with the final sensory analysis score for the coffee beans. [5] The several advanced analytical techniques that allow the determination of several compounds such as volatile chemicals, caffeine, trigonelline, phenolic compounds, carbohydrate, and lipid constituents. All these studies highlight how important it is to assess coffee bean quality using modern equipment and an all-encompassing strategy.

C. Objectives

This literature review aims to investigate the recent advancements of Convolutional Neural Network (CNN) applications in the classification of coffee bean quality. It may include:

- To review the most recent and previous studies of CNN-based applications and methods, specifically relating to coffee bean quality to provide insight into their approaches, performance indicators, and potential areas of advancement.
- To analysea number of parameters, including dataset size, image processing techniques, and model frameworks, that affect CNN performance in classifying coffee bean quality.
- To identify the obstacles and limitations of traditional methods for grading the quality of coffee beans and how CNNs may be able to help.
- To analyse exclusive studies about classification, verification, and detection of defects and quality of coffee beans.

D. Significance

Convolutional Neural Network exhibits the following characteristics:

- *Upgraded Accuracy:* CNNs have demonstrated exceptional performance in image classification, including the ability to recognize small variations in the appearance of the image.
- *Automation and Productivity:* The process of manual inspection by skilled professionals is typically necessary for traditional ways of classifying coffee bean quality, which can be laborious and imprecise. Without requiring human participation, CNN-based techniques automate the process with less time and greater efficiency.
- *Reliability:* CNNs minimize inconsistency that may result from human judgment by providing reliable and consistent assessments of coffee bean quality.
- *Ability to scale:* Scalable quality control approaches are necessary as the world's demand for coffee continues to grow. CNN-based techniques are appropriate for both small- and large-scale production because they can easily handle massive quantities of coffee beans.
- *Cost efficiency:* CNN-based techniques are less costly than human inspection techniques in the long run. Automated quality monitoring lowers expenses and boosts output.

II. METHOD

The sets of literature have compressed to narrow down the selection through the deployed referencing approach of PRISMA—Preferred Reporting Items for Systematic Review and Meta-Analysis [10].

A. Literature Search

The literature evaluation was progressed via following the framed format.

B. Principles for CNN-based systems selection on Coffee Beans

The reviewed studies were subjected to in-depth research, focusing on the facilitation of Convolutional Neural Networks for the verification, classification, and detection (of defects etc.) of coffee beans. The process was adhered to within a systematic outline for consistent evaluation. Published sets of literature between 2018 and 2023 were regarded as part of the review.

The inputs were searched for under ResearchGate, IEEE Xplore, and Google Scholar to ensure an authentic developed system. Associated relevant terms, such as 'CNN' (Convolutional Neural Network), 'Coffee Beans', and 'Image Processing' were used as the reference point for direct results in the titles and abstract of published studies. Other linked words— 'Roast Degree', 'Coffee Beans Quality', 'Defect Assessment', and 'Coffee Beans Identification' were also entered and considered to minimize the screened outputs in each database.

Studies that incorporated uncommon neural network-based systems other than CNN, albeit indirectly related, were considered foundational for further analysis and thorough conceptual digestion. However, studies with disparate methods, contrasting the discourse embedded within CNN, were excluded. Additionally, objectives independent of the review's aims were also disregarded.

The researchers conducted the following steps as preliminaries to assess the integrity of the searched studies:

1. *Identification:*The search emphasized the main scope through directly employing specific key terms such as 'CNN on Coffee Beans', 'Image Processing on Coffee Beans', and 'Classification on Coffee Beans' in the database. A Comprehensive review of the titles, keywords, and abstracts was applied to efficiently integrate the relevance of the studies to CNN and coffee beans.
2. *Screening:*Studies utilizing alternative procedures/schemes instead of relying on CNN are excluded. Lack of sufficient relevance to CNN-based methodologies is grounds for dismissal from the review.
3. *Eligibility:*Objectives unrelated to image processing for coffee beans or methods inconsistent with categorization, verification, and detection (of defects etc.) were also not considered. The selected studies must align with the objectives of the review and substantiate the claims made within it.

C. Data Extraction

The extraction process proceeded in two phases to manifest the reliability of each study. The researchers abridged the scope based on the indexed studies and established prior references. Subsequently, 10 related studies were analysed to validate their integrity and compliance with the established guidelines. This arrangement facilitates the creation of a matrix that contains comprehensive statistics, quality assessments, and crucial results for efficient data extraction.

The initial phase was instituted with an exclusive mode of analysis, thereby involving each study in a review of descriptive statistics, including reporting methodologies and quality evaluations.

1. *Extraction Procedure:*Information characterized by appropriate consistency with the review objectives (accompanied by relevant titles, topic, and abstract), including key concepts related to CNN methodology applied to coffee beans were evaluated.
2. *Accuracy Metrics:* Accuracy rates and the extent of system complexity were recorded to compare the effectiveness of each developed CNN-based system.
3. *Limitations:*Recognize and register hindrances outlined in the selected studies to confer substantial considerations and draw improvements in CNN-based systems on Coffee beans.

D. Proposition Analysis

A robust framework was established to review studies related to coffee beans using CNN-based applications for various purposes (exclusively to classify, verify, and detect deficiency, etc.), facilitating in-depth exploration. Thus, the chosen studies were put through an extensive classification procedure which regards a few factors including:

1. *Outlined Guidelines*: a systematic protocol compliant to the review objectives.
2. *Data Integration:* Coherent evaluation of studies involving the application of Convolutional Neural Networks (CNN) to analyse the coffee beans.
3. *Implications and Recommendations:* Insights and challenges within the studies

require acknowledgment for further consideration.

4. *Methodological Analysis:* Highlights of the architectural framework, algorithm, and system nature applied in the selected studies.

III. RESULTS

A. *Convolutional Neural Network (CNN) as an Optimal Neural Network*

The Convolutional Neural Network (CNN) revealed a high-quality deep learning algorithm for image processing, setting the standard for improving accuracy estimation. While various machine learning algorithms have shown immense success in the field of classification, the transparent shift to CNN has had a significant impact, especially in sorting coffee beans through their morphological features. Hence, sets of literature have applied CNN's framework in the design of systems, manifesting well-collected findings on coffee beans.

As one of the pioneering networks, the Convolutional Neural Network (CNN) has been preeminent in processing data with a focus on physical attributes. It operates as a feed-forward artificial neural network [14], with a general architecture inspired by Biological Neural Networks [2]. Therefore, extraction of data in which coffee beans are subjected to whether for exclusive objectives that require physical feature observation, CNN can be effectively imposed.

In this review, ten published papers were compared and evaluated based on how they administer the Convolutional Neural Network (CNN) on coffee beans in different grounds of approach via utilizing their morphological structure.

B. *Concatenation of CNN-based published Studies on Coffee Beans*

At the outset of the review, 200 published articles were assessed from various sources including ResearchGate, IEEE Xplore, and Google Scholar. Duplicated results have been subtracted. Upon filtering, 100 publications were excluded, leaving 100 image-processing systems focusing on coffee beans for further evaluation. Then, 50 studies were removed due to repetition of procedure. Following this, 35 publications were found encompassing the objectives of the review, however coalesced with different neural networks. Finally, 15 studies were evaluated and underwent a comprehensive review and met the outlined criteria.

FIGURE I.
PRISMA FLOW CHART OF STUDY SELECTION

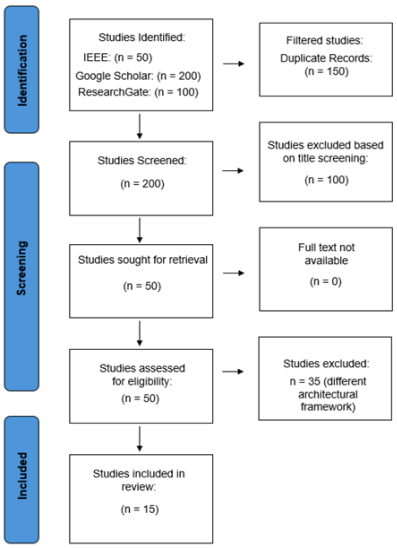

TABLE II.
REVIEW OF INTEGRATED SYSTEMS

Literature Title – Author (Year)	CNN Technique Used	Summary	Accuracy Rate
Coffee Grading with Convolutional Neural Networks using Small Datasets with High Variance - Wallelign, S., Polceanu, M., Jemal, T., & Buche, C. (2019)	CNN using small datasets with high data variability.	The research findings indicate that CNN models can extract features and classify input images with little to no	The accuracy rate value obtained throughout the test dataset using CNN model was 89.1%.

		preliminary analysis. It discusses ensemble approach as a way to improve accuracy while managing high variance in networks. Several models are trained with various starting parameters to provide a final, more accurate prediction.	
An Explainable and Lightweight Deep Convolutional Neural Network for Quality Detection of Green Coffee Beans - Hsia, C., Lee, Y., & Lai, C. (2022)	Lightweight Deep Convolutional Neural Network (LDCNN)	The findings of this research conclude that the LDCNN optimization model's predictability was reliable. Using LIME for visualization makes the effect of image normalization on model training clear. LDCNN uses several strategies, such as DSC, SE block, skip block, and activation functions like HS and ReLU, to produce a lightweight and effective model.	The LDCNN indicated an outstanding detection performance with an accuracy rate of 98.38% and an F1 score of 98.24% in the quality detection of green coffee beans.
Convolutional Neural Network and Industrial Robot Arm applied to an automatic coffee bean selection system - Calderon, C. A., Robles, J., Morocho, S., & Sarango, R. (2022)	Scara Epson robot arm with a Convolutional Neural Network-based classifier.	A CNN-based classifier and a Scara Epson robot arm were combined to create an autonomous coffee bean selection system. TensorFlow, OpenCV, Epson RC+, and Python were the software tools utilized in the construction of the algorithms.	As a result of the overlaps between coffee beans, a yield percentage of 100% was achieved for the first and second range of separation, and 61.5% for the third range.

An Implementation of Convolutional Neural Network for Coffee Beans Quality Classification in a Mobile Information System - Janandi, R., &Cenggoro, T. (2020)	Deep-Learning-Based Model for Mobile App	Cafeon, a deep-learning-based mobile app is used to classify coffee bean quality. The model was chosen between ResNet-152 and VGG16, but based on the research findings, ResNet-152 is better than VGG16 in terms of classification of coffee bean quality, and therefore was chosen as the classification model for Cafeon backend.	The accuracy rate with 110 images: ResNet-152 is 62.3% and VGG16 is 58.7%. Using 160 images: ResNet-152 is 73.3% and VGG16 is 66.8%.
Quality assessment of coffee beans through computer vision and machine learning algorithms – Santos, F.D. (2020)	Deep convolutional neural network	Coffee beans can be accurately identified and categorized using computer vision and machine learning techniques.	The model achieved an accuracy equal to 93% for classifying sour beans defects.
The Potential of Spectroscopic Techniques in Coffee Analysis—A Review - Munyendo, L. (2021)	Deep Convolutional Neural Network	Coffee can be evaluated with the use of spectroscopic techniques for multiple variables at different stages of the production process.	The majority of the examined studies displayed positive results, with root mean square errors of prediction (RMSEP) being less than 10% for the majority of the parameters and correlation coefficients (R2) over 0.8.
An image processing technique for coffee black beans identification - Arboleda, E. R. (2018)	CNN with 800 images of each category and tested it with 200 images of each category.	The RGB values were integrated in an image processing technique that eliminated the black beans in the image.	The CNN achieved an accuracy of 98.75% for the classification task.

Identification of physiological analysis parameters associated with coffee beverage quality - Freitas, M. N. (2020)	CNN with multivariate statistical analysis	The viability of coffee embryos revealed by the tetrazolium test results were positively correlated with the final sensory analysis score for the coffee beans.	Variation in the final sensory analysis score was explained up to 97.14% by the variables radical emergence (r2 = 2.27%), strong normal seedlings, (r2 = 0.56%), seedlings with expanded cotyledonary leaves (r2 = 0.53%), tetrazolium test results (r2 = 91.54%), and potassium leaching (r2 = 2.24%).
Analytical Approaches in Coffee Quality Control - Diaz-De-Cerio, E. (2019)	CNN with spectroscopic methods	Advanced analytical techniques allow the determination of several compounds such as volatile chemicals, caffeine, trigonelline, phenolic compounds, carbohydrate, and lipid constituents	The CNN technique achieved an overall accuracy of 94.4% for species classification and 87.5% for origin classification, which were higher than the results obtained by other methods such as principal component analysis (PCA), linear discriminant analysis (LDA), and support vector machine (SVM).
Deep Learning for Roasting Coffee Bean Quality Assessment Using Computer Vision in Mobile Environment - Hakim, M., Djatna, T., &Yuliasih, I.	Deep-learning-based integrated into smartphones.	Deep-learning-based computer vision is applied to evaluate the quality of industrial coffee roasting. The application system and	The accuracy for the deep learning model was over 97% and loss function of less than 0.075

		the roasting personnel are the two participants in the system. BPMN was developed and tested to evaluate coffee roasting quality.	
Classification of Green Coffee Bean Images Based on Defect Types Using Convolutional Neural Network (CNN) - Pinto, C. (2023)	CNN with 2 class classifications.	It demonstrates how to detect defects in green coffee beans using a CNN-based algorithm. A sizable dataset from Timor-Leste is used to test the system, with varying degrees of success. It also highlights the limitations of the system and areas for improvement.	The highest accuracy was 98.75% for black beans, and the lowest accuracy was 67.50% for broken beans.
A coffee bean classifier system by roast quality using convolutional neural networks and computer vision implemented in an NVIDIA Jetson Nano - Vilcamiza, G. (2022)	CNN with a deep learning model that consists of three convolutional layers.	The system that uses computer vision and neural networks to classify coffee beans according to quality is described. The technology demonstrated remarkable accuracy when tested on a low-cost device.	Coffee beans were classified by roast quality using the CNN technique, which produced an experimental accuracy of 91.33% and a theoretical accuracy of 99%.
Roasted Coffee beans Classification based on Convolutional Neural Network - Sethy, P.K. (2022)	CNN consists of several layers such as convolutional layers, pooling layers, ReLU layers, and fully connected layers.	The roasting levels of coffee beans, which are green, light, medium, and dark, directly affect the beverage quality. A convolutional neural network was proposed to classify these levels, achieving 97.5%	The proposed CNN model achieved 97.5% of accuracy.

		accuracy, demonstrating the growing demand for coffee among young people.	
Coffee Roast Intelligence - Ontoum, S., Khemananantakul, T., Sroison, P., Triyason, T., & Watanapa, B. (2022)	Android application platform using machine learning.	An Android software called Coffee Roast Intelligence is designed to improve accuracy of coffee bean roasting and ease of use. Users are informed about the roast level via text with the classification prediction's probability % shown.	The accuracy score is around 0.82, and the majority of outcomes are between 0.7 and 0.9.
Smart agriculture: real-time classification of green coffee beans by using a convolutional neural network- Huang, N., Chou, D., Lee, C., Wu, F., Chuang, A., Chen, Y., & Tsai, Y. (2020).	Deep learning of the convolutional neural network	The study utilized greyscale images for training and employed a Convolutional Neural Network (CNN) model to achieve an identification accuracy for distinguishing between good and bad coffee beans.	The accuracy score estimated as 94.63%.

C. Comparative Analysis of CNN-based Systems on Coffee Beans

The extensive data quantization disclosed significant diversity in transparency, coupled with dense accuracy rates. The chosen studies demonstrated nearly 100%, providing compelling evidence that Convolutional Neural Network (CNN) has the capability to surpass other machine learning algorithms in exclusive approaches for analysing coffee beans. The positive statistical records, combined with the architectural framework of CNN, emphasize the potential of the network in the field of quality coffee beans, making it a reliable choice for implementation.

Reviewing the context of each study, various CNN models produced high accuracy percentages that hold effective application of their framework design. As a classifier tool, CNN models obtained accuracy rates ranging from 90 to 99.99 percent. CNN with spectroscopic methods, multivariate statistical analysis, and LDCNN, etc., implies an outstanding report. Applications in which CNN was deployed also encompassed optimal scores, endowing rates ranging from 97 to 99 percent.

However, in contrast to the other high-rating CNN models on coffee beans, the studies that produced below 90% accuracy standard, albeit yielded inconsistent numbers from other models to express varied methodical courses, deploys valuable insights for enhancing the proposed CNN model.

The conclusive accuracy rates of the selected studies demonstrated the varying aspects of different CNN models. These results entail reliable utilization of CNN's algorithms, which were exploited in different applications related to coffee beans, showcasing the versatility and efficacy of CNN in addressing various challenges in coffee bean analysis.

IV. DISCUSSION

A. Comprehensive Assessment on the Effectiveness of CNNs for Coffee Bean Classification

The findings presented in the study illustrate the effectiveness of Convolutional Neural Network in assessing coffee bean quality classification. The studies include a variety of CNN techniques and methods such as Lightweight Deep Convolutional Neural Network (LDCNN), Deep CNN, several layers: convolutional, pooling, ReLU, and fully connected layers, spectroscopic methods, machine and deep learning.

Almost 100% accuracy level has been indicated in various studies mentioned in the literature review. Roasted Coffee beans Classification based on CNN, the study model achieved 97.5% of accuracy. In Quality Identification, "Deep Learning for Roasting Coffee Bean Quality Assessment Using Computer Vision in Mobile Environment", the deep learning model achieved an accuracy of over 97%. In defect analysis on the study of Classification of Green Coffee Bean Images Based on Defect Types Using Convolutional Neural Network (CNN), for Black beans, the highest accuracy obtained was 98.75%.

B. Comparative Analysis of CNN Techniques in Coffee Bean Quality Classification on Existing Literature

The results of the studies demonstrate that CNN models using small datasets with high data variability can classify images with no preprocessing [18]. CNN with a deep learning model (three convolutional layers) results to great accuracy on low-cost device [17]. CNN with spectroscopic methods can determine different compounds [5].

Using deep convolutional neural network, coffee beans can be accurately identified via computer vision and machine learning techniques [16]. Furthermore, its spectroscopic techniques can also be used [11] and via mobile app [9].

The predictability of Lightweight Deep Convolutional Neural Network (LDCNN) was reliable and image normalization's effect on model training is clear [7].

C. Examining CNN Challenges and Limitations in Classifying Coffee Bean Quality

While Convolutional Neural Network (CNN) has shown excellent results in classifying coffee bean quality, it still has its limitations. The variations in the accuracy rate in different CNN models and techniques shows how these methods affect the classification including factors such as difficulty in generalizing, model architecture selection, environment, and diverse datasets.

A low accuracy rate has been obtained through a small dataset (high variable) using CNN which was 89.1%. Through deep learning, the rate for ResNet-152 is 62.3% and VGG16 is 58.7% for 110 images. 73.3% and 66.8% for 160 images.

V. CONCLUSION

The review has satisfied the objectives from comparing the CNN models deployed on various approaches for coffee beans to identifying the efficiency that these models demonstrated. It illustrated the integration of published systems into a discrete structure for transparent records, showcasing a variety of CNN algorithms aimed at identifying, verifying, and providing diagnostic evaluation on coffee beans. The review presented accuracy rates ranging from 90 to 100 percent, highlighting the versatile capabilities of proposed Convolutional Neural Network architectures for enhancing the production of raw coffee bean materials. However, despite the application of other engineered models, some studies fell below the 90% accuracy standard, which concludes that other CNN

frameworks entail limitations. Nevertheless, Convolutional Neural Network, at most degree, provided statistical documents that establish concrete claims, which are evident in the selected publications. CNNs offer promising solutions for enhancing the quality control and assessment processes in coffee production, paving the way for more efficient and accurate coffee bean analysis in the future.

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