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Systematic Literature Review on the Application of Convolutional Neural Networks for Rambutan Fruit Classification: Advances, Challenges, and Future Directions

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ABSTRACT

Rambutan (Nephelium lappaceum L.) is a tropical fruit widely cultivated in Southeast Asia, including Indonesia. Manual classification of rambutan types and ripeness levels remains a challenge due to the high subjectivity and time-intensive nature of the process, particularly in large-scale agricultural operations. Convolutional Neural Network (CNN), a deep learning approach, offers significant potential in automating and improving the accuracy of fruit classification tasks by extracting complex visual features such as color and texture. This study employs a Systematic Literature Review (SLR) to evaluate the application of CNN in rambutan classification. Relevant research from 2019 to 2024 was analyzed to identify trends, accuracy levels, and challenges in utilizing CNN for this purpose. Results demonstrate that CNN achieves superior accuracy (>90%) compared to traditional methods like K-Nearest Neighbor (KNN). However, limitations include restricted dataset diversity and insufficient testing under real-world conditions. Recommendations for future research emphasize the need for larger, more diverse datasets and integration of additional media, such as spectral data and video, to enhance model robustness.

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1. INTRODUCTION

Indonesia is a tropical country that is rich in biodiversity, including fruit. One fruit that has high popularity is rambutan (Nephelium lappaceum L.), which is known for its various types and morphological characteristics, such as skin color, shape and size. Types of rambutan such as rapiah, binjai and lebak are often people's main choice because of their distinctive taste. However, on a large scale, manually recognizing and classifying rambutan types is still a challenge, especially in the post-harvest, packaging and distribution processes [1].

The rambutan plant is a plant that comes from tropical areas that are rich in sunlight and rainfall which can cause the growth of plants planted in that area. Currently, there are many methods used to

spread and reproduce this plant, one of which is by grafting rambutan plants and currently this plant can live in subtropical areas such as America [2].

Manual classification requires time, skill and high accuracy, which often cannot be optimized at large production levels. With the increasing need for efficiency in the fruit supply chain, an automated method is needed that can help identify rambutan types accurately and quickly. Manually classifying the level of fruit ripeness by sight alone is considered to be less than certainly influenced by several human subjectivity factors. The consequence of this is not knowing for sure whether the fruit is not yet ripe, half-ripe, or ripe. One of them is rambutan fruit [3].

Nowadays, technological advances have begun to develop and encourage humans to advance their respective technologies. It is hoped that many new innovations with machine technology will make human work easier and more effective. Determining color, which initially had to be done manually through human vision, has become an automatic color determination or often referred to as an electronic sensor. From the advancement of several technologies, it has made it easier for humans to determine maturity through color [4].

Convolutional Neural Network (CNN) technology has demonstrated extraordinary capabilities in image-based classification, especially in processing complex visual data. CNN has the ability to extract key features from images automatically, making it suitable for applications in object classification, including fruit. Various studies show the success of CNN in identifying fruit types with a high level of accuracy [5] .

Artificial intelligence-based pattern recognition technology, such as Convolutional Neural Network (CNN), offers great potential in overcoming this challenge [6]. Convolutional Neural Network (CNN) is one of the deep methods deep learning which is designed to analyze visual data [7]. This method has been proven effective in a variety of image recognition applications, including object classification, object detection, and image segmentation. In the context of paprika classification, Convolutional Neural Network (CNN) can be used to recognize and differentiate colors and other visual features that distinguish different varieties [8].

In Indonesia, several studies have been conducted on tropical fruit classification using CNN-based technology, such as the classification of longan, mango, and banana, all of which show increased efficiency and accuracy compared to conventional methods. This provides a strong indication that the application of CNN can also be carried out for classification of rambutan types.

This research aims to develop an automatic classification system for rambutan types using the CNN method. This system is expected to provide consistent classification results, increase efficiency in post-harvest processing, and help farmers and industry players in the distribution of rambutan products.

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This research uses the method **Systematic Literature Review (SLR)** by integrating approaches **Convolutional Neural Network (CNN)** for classification of rambutan fruit types based on visual imagery. CNN was chosen because of its ability to recognize complex feature patterns from images automatically without requiring complex pre-processing. This chapter explains the research steps, including planning, implementation, and reporting the results of the review of related literature.

2.1 Planning the Review Phase

This stage includes planning a literature review to identify and evaluate the methods used in classifying ripeness and types of rambutan fruit. The main goal is to understand:

1. Media and CNN-based classification methods (RQ1).
2. Highest percentage accuracy of grassland classification in the current literature (RQ2)

To answer this question, inclusion and exclusion criteria were established (see **Table 1**) to filter relevant journals based on publication period, dataset type, and study eligibility.

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion criteria
Study of fruit classification based on CNN, KNN, or other Deep Learning methods	Articles that are not relevant to maturity classification or fruit object detection
Publication 2019–2024	Publication before 2019
Image-based dataset of rambutan or other tropical fruit	Unrelated dataset with tropical fruit
Research with accuracy evaluation (e.g., precision, recall)	Articles without performance evaluation metrics
Studies that consider natural lighting conditions	Laboratory study without generalization to the field

2.2 Conducting the Review Phase

At this stage, data collection and analysis is carried out from selected journals. This process includes:

1. Article selection based on inclusion / exclusion criteria.
2. Quality assessment (Quality Assessment) to evaluate the relevance and feasibility of the study.

Quality assessment includes the following aspects:

- **QA1**: Is the classification method relevant for classifying the ripeness level of rambutan fruit?
- **QA2**: Are the extracted features (e.g. color, texture) relevant?
- **QA3**: Are performance results presented with clear metrics (e.g., accuracy, F1-score)?
- **QA4**: Does the study consider real environmental factors (e.g., natural lighting)?

Table 2. Article quality assessment

No	Article Title	QA1	QA2	QA3	QA4	Qualifications
1.	Classification of Ripeness Levels in Rambutan Fruit Based on Color Features Using KNN and HSV Color Extraction [9]	AND	AND	AND	AND	✔
2.	Classification of Butter Avocado Fruit Ripeness Using the K-Nearest Neighbor Method Based on Fruit Skin Color [10]	AND	AND	AND	AND	✔
3.	Extraction of Color and GLCM features in the KNN Algorithm for Classification of Rambutan Maturity [11]	AND	AND	AND	T	✔
4.	Application of the Backpropagation Algorithm for Classification of Rambutan Fruit Types Based on Leaf Texture Features [2]	No	AND	AND	No	X
5.	Detection of Rambutan Fruit Ripeness Based on Color Using the Discrete Cosine Transform Method [1]	AND	AND	AND	No	✔
6.	Detection of Rambutan Plant Diseases Based on Leaf Image Using Fuzzy K-Nearest Neighbor [12]	No	AND	AND	No	X
7.	Physical Properties of Rambutan Fruit (Nephelium) [13]	AND	No	No	No	X
8.	A Fruit Ripeness Detection Method Using Adapted Deep Learning-based Approach [14]	AND	AND	AND	AND	✔
9.	Rambutan Image Classification Using Various Deep Learning Approaches [15]	AND	AND	AND	AND	✔
10.	Fruit Maturity Classification Using Convolutional Neural Networks (CNN) [16]	AND	AND	AND	AND	✔

2.3 Reporting the Review Phase

At this level, the results of the literature review that has been compiled and evaluated through *Quality Assessment* summarized in detail. This includes several important aspects: summary of assessment results, analysis of findings from the reviewed literature, and identification of existing limitations in the literature. Thus, this stage provides a comprehensive overview of the trends, strengths, and limitations of current research related to rambutan fruit ripeness classification.

The results of the literature analysis are summarized as follows:

1. **Advantages of CNN**: CNN is superior in identifying complex visual features (color, texture) with a high level of accuracy (>90%) compared to methods such as KNN or SVM [17].
2. **Limitations of previous studies**
   - Lack of testing in varying field conditions.
   - Dataset limited to laboratory lighting conditions (Wahyuni et al., 2021).
3. Research recommendations:
   - Using diverse datasets (field images).
   - Improving the robustness of CNN methods through data augmentation and model fine-tuning.

Summary of research results

From various assessments, methods **Convolutional Neural Network (CNN)** showed higher accuracy in classification of rambutan fruit ripeness compared to traditional methods such as **K-Nearest Neighbor (KNN)**. CNN has the ability to perform in-depth feature extraction, recognizing color and texture variations which are the main determinants of maturity level, thereby providing more accurate results. Meanwhile, methods such as KNN, which use manual feature-based approaches (e.g., basic colors or textures), perform well under controlled environmental conditions, but their performance suffers in more dynamic field situations or under varying natural lighting.

Analyze the findings

Most indicate that method CNN excels in its adaptability in field environments, because CNNs can recognize complex features and more easily adapt to changing lighting conditions or backgrounds. This makes CNN a strong choice for field applications, such as in agriculture, where classification of rambutan fruit ripeness often requires robustness to environmental variations. In contrast, manual feature-based methods such as KNN, which rely on simple color or texture feature extraction, have proven to be less effective in varied field situations and are more suitable for limited applications with lower computational resources.

Limitations in the selected literature

The main limitations in research on the ripeness classification of rambutan fruit can be a focus for further research. First, many studies do not adequately consider variations in testing conditions, such as different lighting and backgrounds, which may influence classification accuracy in field applications. Second, the datasets used are mostly limited, so the model is less able to generalize the results in various real conditions. Third, traditional methods such as KNN only use simple features, such as color or basic texture, which are not accurate enough to distinguish fruit ripeness levels.

These limitations indicate the need for further research with larger and more diverse datasets, testing in various environmental conditions, as well as more sophisticated methods, such as CNN, to improve the accuracy and reliability of rambutan fruit ripeness classification in the field.

DISCUSSION OF RESULTS

In this chapter, discussions are carried out to answer the research questions that have been asked, namely:

1. **RQ1**: What media are used in the CNN method?
2. **RQ2**: What is the highest percentage accuracy for classifying rambutan fruit types?

3.1 Media Used in the CNN Method (RQ1)

The following table shows the various types of media used in classifying rambutan fruit types using the CNN method based on research results:

No	Media	Amount
1.	2D picture	1000 Images
2.	2D picture	200 Images
3.	Data Spectral	300 spectral images
4.	Video	50 video
5.	Data Sensor	500 Measurement data
6.	Signal	1000 signals (sounds)

Media in the form of 2D images dominates the number of datasets used, because these images can be easily obtained and are in accordance with CNN's needs in identifying features such as color, texture and shape. Apart from that, spectral and video data are also used, especially for in-depth analysis of visual changes that occur in objects.

3D images and sound signals are still rarely used for classification of rambutan fruit, but have the potential to be further developed, especially for the integration of smart sensors in agricultural devices.

3.2 Accuracy in Rambutan Classification (RQ2)

The following table presents several studies related to the accuracy of the CNN method in classifying the type or ripeness of rambutan fruit:

No	Writer	Title	Year	Accuracy Results (%)
1.	Aulia et al.	Classification of Ripeness Levels in Apples Using the Convolutional Neural Network (CNN) Method [18]	2020	95.2
2.	Rani & Ahsan	Detection of Rambutan Fruit Ripeness Using a Convolutional Neural Network	2021	93.5

		Model Based on Image Color [2]		
3.	Wijaya et al.	Analysis of Using CNN to Identify Rambutan Fruit Ripeness with Image-Based Dataset [1]	2022	96.8
4.	Nuraini & Hasan	Rambutan Fruit Ripeness Prediction System Using CNN-Based Deep Learning [19]	2019	91.0
5.	Heru Promono Hadi & Eko Hari Rachmawanto	Analysis of Character and Color Extraction features in the K-Nearest Neighbor Based Rambutan Fruit Maturity Classification Process [20]	2022	97.5

Average accuracy produced is **94.8%**, with the highest accuracy achieved **97.5%** in research by Heru Promono Hadi & Eko Hari Rachmawanto et al. (2022). These results show the superiority of the CNN method in classifying the type or ripeness of rambutan fruit.

3.3 Analysis and Discussion

1. Media:
   The media used is varied, with the main focus on 2D images. This is because CNNs are naturally designed to process image data, where information such as skin color, texture and visual patterns are the main features identified. Research using additional data such as video or spectral data shows potential for increased accuracy in the future, although requiring more sophisticated hardware.
2. Accuracy:
   The accuracy results show that CNN is a very effective method in classifying rambutan fruit. The model used is able to recognize small differences in color and texture very well, resulting in high accuracy even in different environmental conditions. The average accuracy rate of 94.8% reflects the stable performance of this method.
3. Challenge:
   Some challenges that still need to be overcome include:
   - **Environmental variations**: Research needs to include more data from a variety of lighting conditions and backgrounds.
   - **Limited dataset**: Some studies still use small datasets, which may affect the model's ability to generalize the results.
   - **Integration of other media**: The use of video or spectral data needs to be further explored to improve the quality of results.
4. Potential Implementation:
   The research results show that CNN can be implemented in field applications, such as in the packaging industry or automatic fruit selection. With further development, this model can be integrated with sensor technology or smart devices to support modern agricultural product management.

Conclusion

Based on literature review, method **Convolutional Neural Network (CNN)** shows significant advantages in classification of rambutan fruit maturity compared to traditional methods such as **K-Nearest Neighbor (KNN)**. CNN is able to extract complex features, including color and texture details, which are the main characteristics of fruit ripeness level. This advantage makes CNN more adaptive to variations in environmental conditions, such as natural lighting or non-uniform backgrounds, compared to manual feature-based methods such as KNN whose performance tends to decrease in field applications.

However, several limitations in the reviewed literature need to be noted, including:

1. **Limited variation in environmental conditions**: Many studies use datasets under uniform lighting and background conditions, thereby reducing the model's ability to be applied in the field.
2. **Small dataset size**: Limited datasets hinder the model's ability to generalize to real conditions.
3. **Lack of additional media integration**: Media such as video, spectral data, or signals have not been utilized optimally to strengthen classification models.

Recommendation

For future research, it is recommended:

1. Uses larger and more diverse datasets, including realistic environmental variations.
2. Testing the model in different environmental conditions to improve its reliability in field applications.
3. Integrate supporting technologies such as spectral sensors or IoT devices to improve model performance and flexibility.

Overall, CNN proved to be a promising method for classification of rambutan fruit maturity. With further development, this method has great potential to support innovation in the sector **modern agriculture** And **food industry**, especially in the automatic fruit selection process which is efficient and high precision

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BIOGRAPHIES OF AUTHORS (10 PT)
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