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Evaluation of Orange Fruit Quality Clustering Using a Real-Time X-Means Algorithm

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The citrus farming industry faces major challenges in maintaining product quality consistency due to subjective manual sorting processes that are prone to fatigue and have varying standards. This problem results in economic losses due to errors in detecting ripeness levels and physical damage that hinders market competitiveness. This study aims to design and implement an automated citrus fruit quality evaluation system using a real-time X-Means algorithm. The research method begins with visual data acquisition through a camera sensor using the automatic snapshot feature to convert physical objects into digital data. The data then undergoes preprocessing, which includes filtering to remove noise, color (RGB) and texture feature extraction, and normalization using Min-Max Scaling to balance parameter weights. The X-Means algorithm is used because of its ability to independently determine the optimal number of clusters through the evaluation of the Bayesian Information Criterion (BIC) score. The processing results show that the system is able to accurately group oranges into three categories: ripe, which are dominated by bright orange colors; unripe, which are dominated by green colors; and rotten, which are identified through rough textures and dull colors. The integration of this technology ensures that all decision-making occurs quickly and objectively, providing a practical solution for the industry to consistently improve product quality control efficiency in the field.
Keywords: Clustering, X-Means, Orange Quality, Digital Imaging, Real-time, Data Streaming.

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1. Introduction

The agricultural industry, particularly citrus commodities, faces a major challenge in maintaining consistent product quality that reaches consumers. Until now, the citrus sorting process has been dominated by human labor, which is subjective, prone to fatigue, and has varying assessment standards between individuals [1]. This problem is exacerbated by high production volumes that demand high sorting speeds while maintaining accuracy. Manual observation of changes in skin color and texture often fails to detect minor damage or subtle differences in ripeness, leading to economic losses due to the mixing of low-quality fruit with high-quality fruit. This inconsistency not only reduces the selling value in the domestic market, but also hinders export competitiveness [2]. Therefore, an automation system is needed that is capable of conducting objective quality evaluations without excessive manual intervention to minimize human error.

Problem solving in this study was carried out by applying a digital image processing system that is deeply integrated with the X-Means clustering algorithm based on streaming data. This system is specifically designed to capture real-time visual data of oranges through a camera sensor, which is then automatically converted into a stream of numerical data to be processed instantly without long delays [3]. Unlike conventional static analysis methods, the streaming data approach allows the system to continuously capture various variations in object and lighting conditions. The X-Means algorithm was chosen as the primary method due to its superior ability to independently determine the optimal number of clusters through BIC score evaluation, without the need for manual determination at the beginning of the process.

By combining color feature extraction (RGB) and skin surface texture analysis, the system can automatically provide quality labels such as ripe, unripe, or rotten categories [4]. The integration of this technology ensures that the entire decision-making process occurs in real time, guaranteeing highly responsive and accurate clustering that aligns with actual physical conditions in the field.

The main objective of this research is to design and implement a real-time X-Means algorithm-based evaluation system for clustering orange fruit quality. Through the development of this system, it is hoped that the process of grouping orange quality can be carried out more accurately and objectively in accordance with the actual physical conditions in the field [5]. Specifically, this study aims to integrate the stages of visual feature input analysis, such as color and texture, into a system architecture capable of automatically generating informative data clustering. Thus, the system is expected to provide quick classification decisions in determining the categories of ripe, rotten, or unripe oranges without relying on subjective human judgment. In addition, this study aims to validate the use of normalized numerical parameters to produce a balanced data distribution pattern in the final visualization stage. The success of this objective will provide a practical solution for the agricultural industry in improving the quality control standards of citrus products efficiently and consistently [6].

2. Literature and Problem Statement

Research on citrus quality classification has developed with various significant findings that underlie the use of automation technology. In their research, they found that the X-Means algorithm has a much more efficient computational advantage than conventional K-Means due to its ability to automatically determine the ideal number of clusters through the evaluation of the Bayesian Information Criterion (BIC) score [7]. However, in its implementation, they identified limitations in the current orange quality classification system, which is still difficult to apply in real-time to meet the high-speed demands of the industry. This is reinforced by findings emphasizing that the accuracy of clustering is highly dependent on the evaluation of consistent physical parameters so that the system results are in line with the actual conditions of the objects in the field [8]. In conclusion, this study will integrate the X-Means algorithm into a streaming data-based system architecture to overcome real-time processing constraints while ensuring objective and accurate orange quality evaluation results [9].

3. Research Method

This research method uses a systematic approach that combines real-time visual data acquisition with clustering algorithms to group orange fruit quality.

Clustering Evaluation Architecture

The system architecture is designed as a structured flow that integrates automatic data retrieval, feature value transformation, and final classification without manual intervention. The overall work process of this system is illustrated in the diagram.

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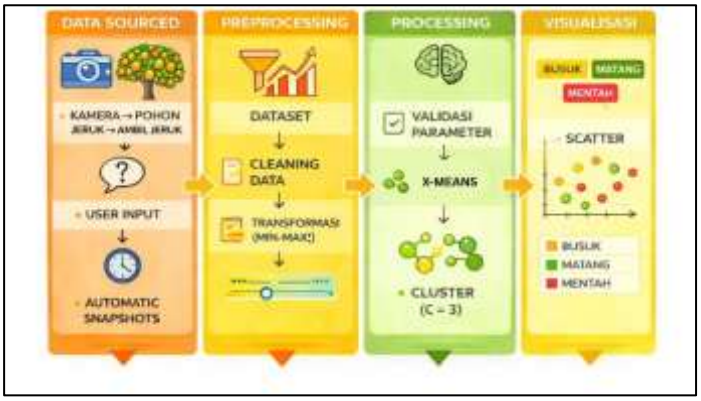

Figure 1. Flowchart of Orange Quality Data Processing in a Real-time Clustering System

The following is a complete explanation of the steps in the orange quality classification system architecture:

1. Data Sourced

   The Data Sourced stage is designed as the main foundation for converting physical objects from orange trees into digital data through an automatic image capture mechanism. Through the integration of visual sensors and user input parameters, the system ensures that each image snapshot produced has consistent quality standards in order to provide an accurate raw database for further evaluation processes.

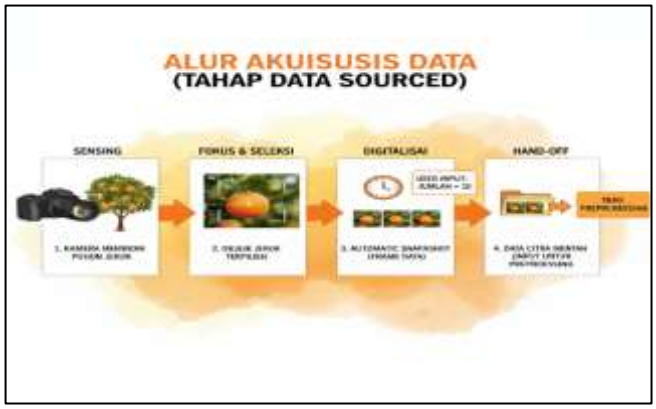

Figure 2. Sourced data flow

   Here is a point-by-point explanation of each stage:

   The Data Sourced stage is designed as the main foundation for converting physical objects from orange trees into digital data through an automatic image capture mechanism. This process begins with the Sensing stage, where the camera functions as a sensor to capture visual input from the real environment by targeting the entire orange tree [10]. Next, in the Focus & Selection stage, the system focuses on individually selected orange fruit objects to obtain sharper and more specific image details. This flow ends with the Digitization stage, where automatic image capture occurs through the Automatic Snapshot feature to produce raw image data that is ready for use. Through the integration of visual sensors and input parameters, the system ensures that each snapshot has consistent quality standards to provide an accurate database for further evaluation [11].

2. Preprocessing

   This process purifies raw images through filtering and cleaning to isolate orange objects from background noise. Next, feature extraction (color and texture) is performed to convert visual data into mathematical variables [12]. Finally, Min-Max Scaling is applied

$$\chi new = \frac{\chi - \chi min}{\mathrm{X\,max} - \mathrm{X}min}$$

to normalize all values to a scale of 0–1 in order to eliminate bias between parameters. This stage is crucial to ensure that the clustering algorithm works accurately, evenly, and efficiently in classifying orange quality in real time [13].

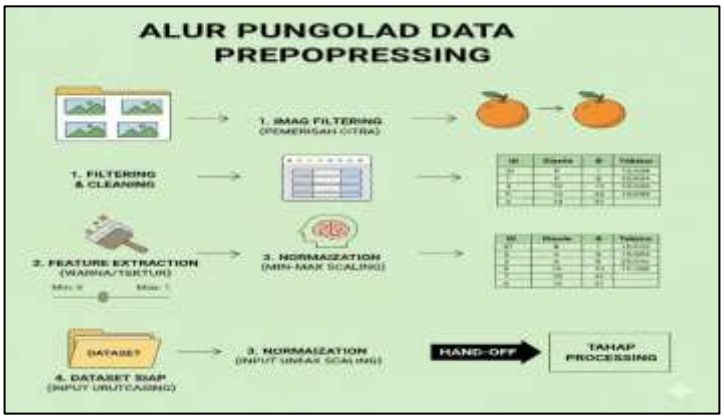

Figure 3. Sourced Prepocessing

Here is a brief explanation of the points regarding the data preprocessing stages based on the image:

a. Filtering & Cleaning
   This initial stage focuses on processing raw images from the dataset:
   Process: Image filtering is performed to separate the main object from the background.
   Objective: To remove noise from the image so that the orange object is clearly isolated for easier identification.

b. Feature Extraction
   After the image is cleaned, the system extracts important information contained within the image.
   Process: Takes specific parameters in the form of color and texture characteristics.
   Result: Visual data from the orange image is converted into numerical data or tables (such as R, G, B values, and texture values).

c. Normalization (Min-Max Scaling)
   The extracted numerical data was then standardized.
   Process**:** Min-Max Scaling was used to convert all feature values into a scale ranging from 0 to 1 [5].

$$\chi new = \frac{\chi - \chi min}{\mathbf{X\,max} - \mathbf{X}min}$$

   Purpose: To eliminate bias between parameters so that each feature (color/texture) has a balanced weight when processed by the algorithm.

d. Output Preprocessing
   This is the final result of the entire data preparation process.
   Condition: The data has been cleaned, standardized, and organized in a format that is ready for use.
   Hand-off: The normalized dataset is then passed on to the Processing Stage (such as clustering or classification) to accurately determine the quality of the oranges

3. Processing
After the orange image data has been successfully purified and normalized in the previous phase, the workflow continues to the Processing Stage [14]. This stage is the core of the system's intelligence, where the algorithm will validate parameters and apply the X-Means method to automatically cluster the data into three clusters (C=3) based on the extracted physical characteristics [15].

Parameter Validation: The system rechecks the extracted numeric variables (color and texture) to ensure that the data is ready to be processed by the algorithm.

a. X-Means: Uses the X-Means algorithm (an extension of K-Means) to automatically find the number of clusters and cluster data based on feature similarity.
b. Cluster (C = 3): Orange data is grouped into 3 main clusters, which represent objective categories of orange physical condition.
c. Final Goal: To produce a grouping pattern that will be forwarded to the visualization stage to determine whether the orange falls into the Rotten, Ripe, or Unripe category.

4. Visualisasi

After processing the data using intelligent algorithms, the system enters the final stage, which is visualization [16]. In this phase, the results of data grouping are presented in an easy-to-understand graphical form, where each orange object is objectively mapped into a specific quality category based on the similarity of its characteristics [17].

The visualization stage includes several important elements:

a. Scatter Plot: The processed data is displayed in a scatter plot to see the distribution of each orange sample in the coordinate space.
b. Clustering Results: Points on the graph are grouped into three different colors representing the results of automatic system identification.
c. Quality Categorization: The system assigns the final classification of oranges into three main groups:
   Rotten: Represented by the yellow label/color on the diagram.
   Ripe: Represented by the green label/color on the diagram.
   Raw: Represented by the red label/color on the diagram.
d. Ultimate Goal: To provide users with quick and accurate visual information about the ripeness of oranges based on processed numerical data.

Data Set Analysis

The data set analysis stage is a crucial first step in identifying the basic characteristics of the entire sample of orange images used in the system [18]. In this section, the raw data is evaluated to ensure that the diversity of varieties and physical conditions of the oranges is adequately represented before entering the next stage of processing. Through this analysis, the integrity of the extracted numerical features can be validated to ensure the accuracy of quality grouping in the final stage [19].

Figure 4. Data set analysis

The process of creating the dataset in this study was carried out through a series of systematic stages, starting from image acquisition to data preparation. The initial stage began with direct image capture using a camera sensor directed at orange trees to capture the actual visual conditions. After capturing images of the wider environment, the system automatically performs a selection stage to identify and separate the orange fruit objects from the background of irrelevant leaves or branches [20].

After the target object has been successfully identified, the system runs an auto-cropping mechanism to isolate each orange into a more specific image frame so that the focus of observation is only on the physical characteristics of the fruit. This cropping process is very important to ensure that the extracted features, such as color and texture, are not distorted by noise from areas outside the object [21]. The results of this automatic cropping are then collected into a single dataset consisting of ripe, unripe, and rotten orange categories. All of the selected and cropped data is then validated and normalized using the Min-Max Scaling method to ensure that the dataset has consistent quality standards before being processed by the X-Means algorithm [22].

Parameter Analysis

After all citrus image data has gone through the preprocessing and processing stages, the next step is Parameter Analysis [23]. At this stage, key variables that have been extracted, such as color intensity (R, G, B) and texture values, are evaluated in depth to understand how the unique characteristics of each citrus fruit contribute to the final clustering results [24]. This analysis serves to validate that each numerical parameter has a consistent correlation with the physical category of the orange, so that the system can provide objective and accurate classification decisions.

No	Parameter	Technical Description	Role in Classification
1	Color	Numerical representation of color space values (such as R, G, B) extracted from orange image pixels.	Determine the basic categories of ripeness, for example, green for unripe and orange for ripe.
2	Texture	Analysis of orange peel surface patterns is usually calculated using methods such as Gray Level Co-occurrence Matrix (GLCM).	Detect the physical condition of the skin; uneven or rough texture may indicate that the orange is starting to rot or spoil.
3	Saturation	The level of purity or intensity of color in an orange image, which indicates how strongly the color appears.	Helps distinguish fresh ripe oranges (bright/vibrant color) from wilted or rotten oranges (faded/dull color).
4	Brightness	The lightness or darkness of the color in the orange image is influenced by the reflection of light on the object.	Used to identify dark areas that may be rot spots or color contrasts that indicate perfect ripeness.

The parameter analysis stage is a phase of in-depth evaluation of key variables that determine the success of orange quality classification in a real-time clustering system. There are four main parameters that are extracted and validated, namely color, texture, saturation, and brightness. The color parameter (RGB) serves to determine the basic category of ripeness through pigment dominance, such as orange for ripe and green for unripe. The texture feature is analyzed to detect the physical condition of the skin, where an uneven or rough surface pattern may indicate that the fruit is starting to rot. Furthermore, saturation or intensity is used to distinguish the freshness of oranges through color density, while the brightness parameter helps identify rot spots or dark areas due to uneven light reflection on the object [25]. All of these numerical parameters are evaluated consistently to ensure that each unique characteristic of the orange contributes accurately to the system's decision in producing an objective grouping between the ripe, unripe, and rotten categories.

4. Results and Discussion

This section presents the results of implementing the X-Means algorithm in clustering orange quality based on visual data captured in real time. The evaluation process was carried out by analyzing how the system

automatically mapped color and texture features into specific clusters without initial labels. The discussion focused on the effectiveness of the algorithm in distinguishing between ripe, unripe, and rotten categories, as well as validating the clustering results based on numerical parameters generated by the system.

Clustering Process

At this stage, an evaluation is conducted on the implementation of the X-Means algorithm in clustering orange image data that has undergone a real-time pre-processing phase. This clustering process is at the core of the system for recognizing natural patterns in the data without any manual labeling at the outset, whereby the algorithm automatically validates the input parameters to determine the most optimal cluster structure. Through this mechanism, each orange sample is mapped into feature space coordinates based on the similarity of its visual characteristics, resulting in a division into three main clusters that objectively represent quality categories. The following explanation will detail how the data distribution is formed and how the system assigns quality labels to each resulting group.

Based on the implementation of the system in a real environment, the following is an explanation of the image processing results for each orange quality category:

a. Ripe Orange Category

Figure 5. Ripe Oranges

The image shows perfectly ripe oranges marked with orange/amber labels. The system automatically recognizes these objects based on the dominance of bright colors with high saturation, which are numerically grouped by the algorithm into clusters of the highest quality for consumption.

b. Unripe Orange Category

Figure 6. Unripe Orange

The image shows the detection results of oranges that are still raw or unripe, with a characteristic green color. Through the visual feature extraction process, the system validates that the ripeness level of these objects is still low, so that through automatic cluster division, the objects are separated from the ripe and rotten categories to provide objective classification results.

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c. Rotten Orange Category

Figure 7. Rotten Orange

The image shows the results of identifying oranges in a rotten condition, marked with a red label in the system. Technically, the X-Means algorithm clusters these samples into the rotten cluster due to the detection of texture parameters that indicate surface defects or dark spots, as well as color intensity that tends to be dull or faded.

Clustering Visualization

The following are details of the cluster mapping results generated by the system:

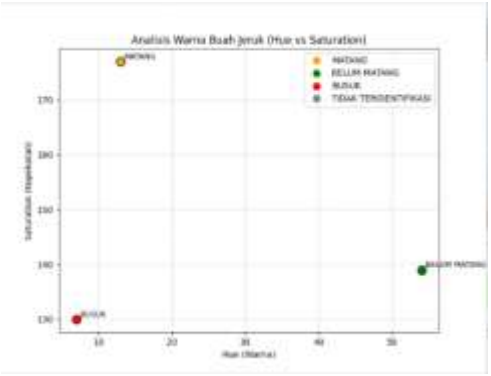

Figure 8. Scatter Plot Visualization

After the X-Means algorithm completes the iteration process and calculates the Bayesian Information Criterion (BIC) score, the system generates a final data mapping in the form of an informative visual representation. This visualization stage aims to present the distribution of orange objects in coordinate space based on the similarity of numerical features that have been extracted previously. Through a scatter plot display, the natural grouping patterns between the ripe, unripe, and rotten categories can be clearly seen, facilitating evaluation of the system's accuracy in objectively distinguishing fruit quality.

RGB Visualization

Label	Saturation	Texture	Brightness	R	G	B
Unripe Orange	93.6700	31.4500	110.1900	80	110	44
Ripe Oranges	165.1900	25.9700	247.9100	245	148	43
Rotten Orange	90.3400	27.8300	159.0700	159	67	27

a. RGB Unripe Orange

Based on the data provided, this unripe orange fruit has color characteristics dominated by a Green (G) value of 110, which is significantly higher than the Red (R) value of 80 and Blue (B) value of 44, creating a spider graph that leans towards the green axis. The Brightness value of 110.1900 and Intensity of 93.6700 indicate light reflection on the still-dense green skin, while the Texture value of 31.4500 represents a

surface that tends to be rough and porous. Overall, this combination of parameters accurately describes the physical profile of a young green orange that has not yet entered the stage of full ripeness.

Figure 9. RGB Unripe Orange

b. RGB Ripe Orange

Based on the data provided, ripe citrus fruits (as shown in the Spider RGB B#2 graph) display colors that are in stark contrast to unripe fruits, with Red (R) reaching a maximum value of 245, Green (G) at 148, and Blue (B) at only 43, resulting in a graph visualization that is sharply drawn towards the red axis. The very high Brightness value of 247.9100 and Intensity of 165.1900 reflect a striking and clean bright orange color, characteristic of fruit that is ready to harvest. In addition, the lower Texture value of 25.9700 compared to unripe fruit indicates that the orange peel has softened and its pores tend to be flatter as it reaches perfect ripeness.

Figure 10. RGB Ripe Orange

c. RGB Rotten Orange

Based on the data provided, rotten oranges (represented by the Spider RGB B#3 graph) show a significant decline in color quality, with a Red (R) value of 159, Green (G) of 67, and Blue (B) at the lowest level of 27. This creates a graph profile that still leans towards the red axis but with a much narrower and dimmer coverage area compared to ripe fruit, which is in line with a Brightness value of 159.0700 and an Intensity of 90.3400. The decrease in these numbers reflects the loss of the orange peel's natural shine due to oxidation or tissue damage, while the Texture value of 27.8300 indicates a change in the surface structure of the peel, which is becoming unstable due to the decay process.

Figure 11. RGB Rotten Orange

5. Conclusion

This study successfully implemented an automated orange fruit quality evaluation system using the X-Means algorithm based on real-time streaming data. Based on the test results and discussion, it can be concluded that the use of the X-Means algorithm is very effective in overcoming the weaknesses of subjective manual sorting. The system is capable of performing independent clustering by determining the optimal number of groups through the evaluation of the Bayesian Information Criterion (BIC) score, which divides the quality of oranges into three main categories: ripe, unripe, and rotten.

Color (RGB) and texture feature extraction has been proven to be an accurate parameter in distinguishing the physical condition of fruit, where data normalization using Min-Max Scaling plays an important role in improving the stability of the clustering process. Overall, the integration of digital image processing technology with the X-Means algorithm provides a consistent, fast, and objective solution for the agricultural industry to improve product quality control standards and minimize human error in the sorting process in the field.

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