

Comparative Analysis of Linear Discriminant Analysis and Support Vector Machine Methods in an Automated Cash Parking Payment System

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Abstract— One innovation that can be implemented is an automated parking system with an automatic cash payment method. This system allows vehicle users to conduct payment transactions without direct interaction with parking attendants, through a payment machine integrated with the parking entry and exit control system. This mechanism not only speeds up the parking process but also minimizes human error and enhances transparency in transaction recording. In this research, a cash payment system for an automated parking system will be developed that is capable of accepting Indonesian rupiah banknotes, recognizing banknote denominations and verifying their authenticity, calculating the total transaction amount, and providing change in the form of banknotes. The automated cash payment system in the parking system consists of a banknote acceptance mechanism, a banknote dispensing mechanism, and a banknote denomination recognition system. Banknote denomination recognition is performed based on banknote image analysis. The research objects used in banknote recognition are Indonesian rupiah banknotes issued in 2022 with denominations of IDR 20,000, IDR 10,000, and IDR 5,000. The banknotes provided as change in this system are IDR 10,000 and IDR 5,000 denominations. The system's performance test results indicate that the image processing unit, utilizing the Support Vector Machine (SVM) algorithm, achieves high precision in banknote identification. In testing the 2022 emission banknotes for the Rp5,000, Rp10,000, Rp20,000, and Rp50,000 denominations, the device reached an accuracy rate of 98%. Furthermore, when tested against counterfeit money samples obtained from Bank Indonesia, the system demonstrated a 100% accuracy rate in detection. Additionally, the system showed perfect reliability in transaction logic, where the calculation and dispensing of the correct change achieved a 100% accuracy rate.

Keywords— *Cash Payment, Support Vector Machine (SVM), Linear Discriminant Analysis (LDA) Raspberry Pi, and Automated Parking Systems*

I. INTRODUCTION

Parking systems that rely on human attendants are prone to revenue leakage; a case in point occurred at Vita Insani Hospital in North Sumatra, where a parking attendant embezzled funds. This incident came to light after the Department of Transportation (Dishub) failed to receive financial reports from the hospital for a period of 61 days. An investigation revealed that while the hospital had actually submitted the parking levy reports to the Siantar City Transportation Department, an attendant identified by the initials JS had embezzled the funds during that 61-day period, resulting in a financial loss to the state amounting to IDR 48.6 million [1]-[5].

The parking system at Vita Insani Hospital utilized attendants and paper tickets to process transactions. Data regarding vehicle counts and parking levies was recorded using Microsoft Excel, with entries made directly by the parking attendants. According to the Head of the Siantar City Transportation Department, this process created a potential for a lack of transparency on the part of the attendants and other involved employees[6].

Previous research has introduced various innovations; for instance, a 2026 study by Trice Salsabila, Riyadhul Fajri, and Heri Gustami developed a coin detection system using the Support Vector Machine method [2][7]. Additionally, in 2020, Septa Cahyani utilized Linear Discriminant Analysis (LDA) to

extract image characteristics and maximize the distance between classes while minimizing the distance between training data within the same class; this approach reduced the computational time required for recognizing handwritten uppercase letters using Euclidean Distance [8]-[10].

One innovation that could be implemented is an automated parking system featuring an automated cash payment mechanism. This system allows vehicle owners to complete payment transactions without direct interaction with an attendant, utilizing a payment machine integrated with the parking entry and exit control systems. Such a mechanism not only accelerates the parking process but also minimizes human error and enhances transparency in transaction record-keeping. This study aims to develop a cash payment system for an automated parking system capable of accepting Rupiah banknotes, recognizing their denominations, verifying their authenticity, calculating transaction totals, and dispensing change in the form of banknotes. The automated cash payment system comprises a banknote acceptance mechanism, a banknote dispensing mechanism, and a banknote denomination recognition system. Denomination recognition is performed through banknote image analysis. The banknotes used for recognition in this study are the 2022 series Rupiah notes in denominations of Rp 5,000, Rp 10,000, Rp 20,000, and Rp 50,000. The system dispenses change in denominations of Rp 10,000 and Rp 5,000.

II. METHOD

A. Research Flow

The research to be conducted involves the development of a device—a process that is systematic, planned, and clearly structured throughout. To address the formulated research questions, the project requires comprehensive planning, the preparation of tools and materials, the creation of system block diagrams and flowcharts, the establishment of procedures, and the scheduling of activities, culminating in a fully functional device and system.

Furthermore, this study falls under the category of Science and Technology (IPTEK) development research; it builds upon prior research regarding the implementation of digital image processing. The study covers the entire development process, ranging from the conceptual design of the system and application to the detailed system design and implementation, ultimately resulting in the construction of the complete system.

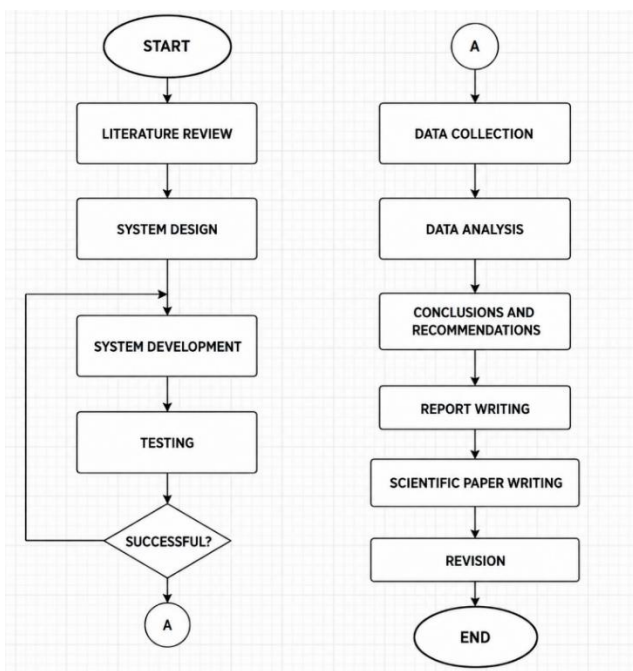


Figure 1. Research Flow

This method (Figure 1) consists of nine stages, beginning with a literature review of references related to Linear Discriminant Analysis to determine the object and parameters. This stage involves the creation of a servo motor test system model that can collect and dispense change to determine the durability of the servo motor. A USB camera is also tested to capture images of the money to determine the system's ability to recognize watermarks and authenticate the money.

B. Flowchart

The system flowchart (Figure 2) begins with the process of reading the UID (Unique Identifier) from an RFID card. A successfully detected UID is used to determine the vehicle's status. If the UID is not yet registered in the system, the vehicle is logged for entry (check-in), recording the time of arrival. Conversely, if the UID is already registered, the system

identifies the vehicle for exit (check-out) and calculates the parking fee based on the time difference between entry and exit. The applied parking rate is Rp5,000.00 per hour of parking area usage.

Once the parking fee is determined, the cash acceptance mechanism is activated. A stepper motor draws the money inserted by the user toward the scanning mechanism to detect the banknote's denomination and authenticity. If the detection process reveals that the inserted money is counterfeit or the amount is insufficient to cover the required parking fee, the stepper motor returns the money to the user, and the LCD displays a message indicating that the payment process was unsuccessful.

If the money is verified as authentic and the amount is equal to or greater than the parking fee, it is routed to the storage compartment. Subsequently, if the amount received exceeds the parking fee, the system activates the change-dispensing mechanism, wherein a DC motor dispenses the appropriate amount of change based on the difference. Upon completion of the payment process, the LCD displays a message confirming that the transaction was successful.

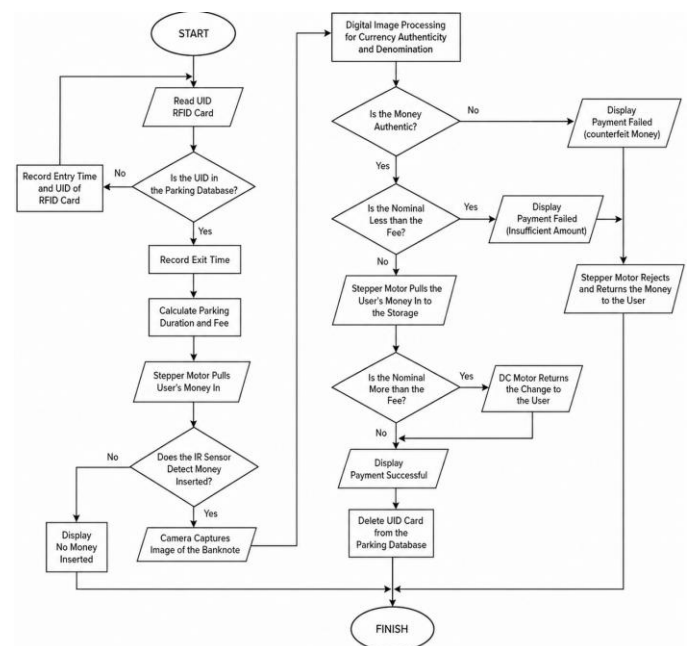


Figure 2. Flowchart

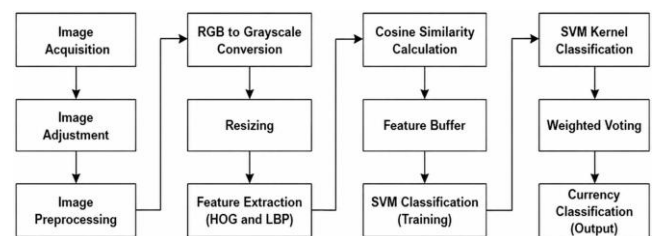


Figure 3. Flowchart System

The Figure 3 for the banknote image classification system begins with an image acquisition process using a camera to capture the banknote image provided by the user. The acquired image undergoes preprocessing, which includes converting the image from RGB to grayscale and resizing it to ensure a

uniform image size. Subsequently, features are extracted using a combination of Histogram of Oriented Gradients (HOG) [11][12] and Local Binary Pattern (LBP) [13]-[16] methods to generate a feature vector representing the banknote's shape and texture characteristics.

The resulting feature vector is compared against background features using the Cosine Similarity method to verify that the processed image actually contains a banknote. If the image is deemed valid, the feature vector is stored in a feature buffer; feature averaging is then performed across several consecutive frames to obtain a more stable feature representation capable of mitigating the effects of noise and minor image variations.

The averaged feature vector serves as input for a Support Vector Machine (SVM) model to classify the banknote's denomination, followed by a classification of its authenticity. Prediction results from multiple frames are then processed using a weighted voting method based on the confidence score of each prediction, yielding more consistent, accurate, and stable classification results regarding denomination and authenticity.

C. System Block Diagram

The system is designed (Figure 4) using an ESP32 microcontroller as the main controller, managing the device's operational mechanisms and processing payment transaction data. A Pi Camera connected to a Raspberry Pi captures images of 2022-series banknotes; these images are then processed using digital image processing techniques and an SVM classification algorithm to determine the denomination and authenticity of the inserted currency.

An infrared (IR) sensor detects the presence of currency within the scanning mechanism when the ESP32 activates a stepper motor to draw the banknote into the scanner. Once identification is complete, valid banknotes are stored; if a refund is required, a DC motor activates to dispense the change to the user.

Additionally, an RFID module and a 16×2 LCD serve as the user interface. The RFID module identifies vehicles by reading card UIDs to manage check-in and check-out processes, while the 16×2 LCD displays information to the user, such as system status, the required parking fee, and payment transaction results.

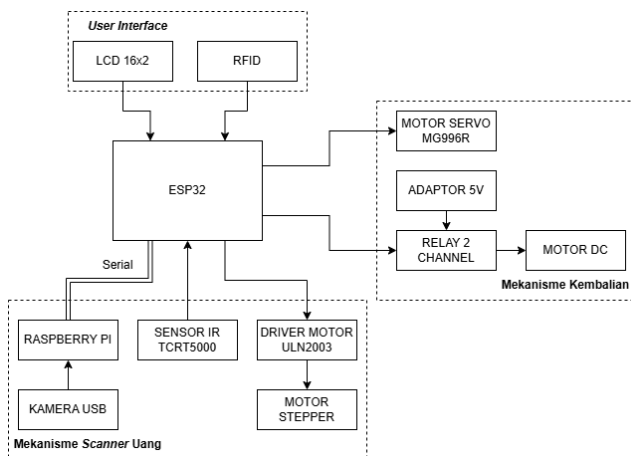


Figure 4. Block Diagram

D. Wiring

The design or layout of the proposed system is presented as the configuration of the components that will be implemented in the device. The ESP32 functions as the main data-processing unit (microcontroller) and is connected to the DC motor, stepper motor, infrared sensor, LCD, and RFID module. The infrared sensor is used to detect the position and presence of the inserted banknote. The stepper motor functions to pull the banknote into the scanning mechanism, while the DC motor is used to dispense the change. Meanwhile, the LCD and RFID module function as the user interface for the payment transaction, as shown in Figure 5.

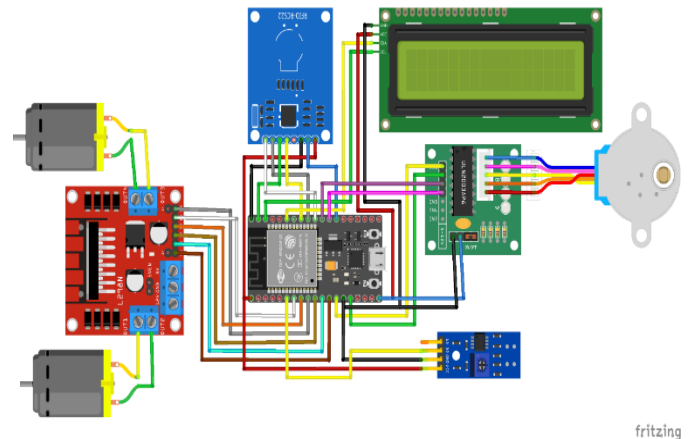


Figure 5. Wiring

III. RESULTS AND DISCUSSION

A. System Implementation

The system design created a device with various mechanisms. The first mechanism is the user interface used by the user to operate the device. This mechanism consists of two components: an I2C LCD as the user display and an RFID MFRC522 as the user's parking card detector.

B. Results

The second mechanism is the money scanner mechanism, which functions to detect the authenticity and denomination of the inserted currency. This mechanism consists of various components, such as a stepper motor to pull or push the currency, a DC motor to pull the currency into the storage, a USB camera to detect the authenticity and denomination of the currency, and a UV lamp to illuminate the currency for authenticity. The performance evaluation results of the nine algorithm models on all dataset classes are presented in Table I. The evaluation shows that the YOLO-based model consistently outperforms the MobileNet and MobileViT-based models on all accuracy metrics (Figure 6).



Figure 6. User Interface Mechanism

C. Change Mechanism

The final mechanism is the change mechanism, which controls the release of change and pushes it through. This mechanism consists of two components: a servo motor that controls the dispensing of change and a DC motor that propels the change to the user, as shown in Figure 7.



Figure 7. Internal Components of the Change-Return Mechanism

This mechanism is a unified device system controlled by a microcontroller in the form of ESP32 and Raspberry Pi 4. The resulting device is square with dimensions of 32.5 x 30 x 30 cm made of PVC as the outer protection, as shown in Figure 8.



Figure 8. Money Scanner Mechanism



Figure 9. Parking System Equipment

The design for the device, which is based on the front view of the Money Scanner Mechanism Accuracy drawing, features an RFID reader for customer check-in and check-out, a rectangular box with holes for cash insertion, and an LCD display for the amount to be paid. The side view also shows a place to store change, which is driven by a servo motor. A USB camera captures images of the money, which will be processed through digital image processing using a linear discriminant analysis method, as shown in Figure 9.

D. Testing of the Linear Discriminant Analysis (LDA) Algorithm

The image processing testing using the Linear Discriminant Analysis (LDA) algorithm was conducted through two main testing stages to evaluate the performance of the designed system. The first stage involved testing the training data accuracy of the developed algorithm, which aimed to determine the model's ability to recognize image patterns based on the training dataset. The training data accuracy test was divided into two categories: banknote denomination classification accuracy and banknote authenticity classification accuracy, as shown in Table I.

TABLE I
TESTING OF THE LINEAR DISCRIMINANT ANALYSIS (LDA) ALGORITHM

No	Training Data	Accuray (%)
1	Denomination	95.93
2	Authenticity	99.68

The second stage involved real-time detection testing by inserting both genuine and counterfeit banknotes into the banknote scanning mechanism. This testing aimed to evaluate the system's ability to perform direct identification under actual operating conditions. In this stage, the observed parameters included the classification results and the confidence value, which represents the level of certainty generated by the system during the digital image processing. These parameters were used as indicators to evaluate the accuracy and reliability of the implemented algorithm.

E. Testing of the Support Vector Machine (SVM) Algorithm

TABLE II
TESTING OF THE SUPPORT VECTOR MACHINE (SVM) ALGORITHM

No	Detection Result	Accuracy (%)
1	Denomination	95.93
2	Authenticity	99.68

Real-time detection testing was conducted by inserting both genuine and counterfeit banknotes into the banknote scanning mechanism. This testing aimed to evaluate the system's ability to perform direct identification under actual operating conditions. The parameters observed in this stage included the classification results and the confidence value, which represents the level of certainty generated by the system during the digital image processing. These parameters were used as indicators to evaluate the accuracy and reliability of the implemented algorithm, as shown in Table II.

F. Confusion Matrix

Based on the testing results, the confusion matrix was used as an evaluation method to analyze the performance of the LDA and SVM algorithms in classifying banknote images. The confusion matrix provides information on the number of data samples that were correctly classified as well as those that were incorrectly classified. Therefore, the results obtained from the confusion matrix can be used as a basis for comparing the performance of the two algorithms.

G. Confusion Matrix for Banknote Authenticity Classification Using LDA

TABLE III
CONFUSION MATRIX FOR BANKNOTE AUTHENTICITY CLASSIFICATION USING LDA

		Prediction	
		Genuine	Counterfeit
Actual	Genuine	16	0
	Counterfeit	4	12

$$Accuracy_{authenticLDA} = \left(\frac{TP + TN}{TP + TN + FN + FP} \right) \times 100 \%$$

$$Accuracy_{authenticLDA} = \left(\frac{16 + 12}{16 + 0 + 4 + 12} \right) \times 100 \%$$

$$Accuracy_{authenticLDA} = \left(\frac{28}{32} \right) \times 100 \%$$

$$Accuracy_{authenticLDA} = 0,875 \times 100 \%$$

$$Accuracy_{authenticLDA} = 87,5 \%$$

The evaluation results show that the LDA algorithm achieved an accuracy of 87.5% in identifying banknote authenticity. A recall value of 100% indicates that all genuine banknotes were correctly identified without being misclassified as counterfeit banknotes. This is particularly important for an automated payment system because it can

minimize the rejection of genuine banknotes, as shown in Table III.

H. Confusion Matrix for Banknote Authenticity Classification Using SVM

TABLE IV
CONFUSION MATRIX FOR BANKNOTE AUTHENTICITY CLASSIFICATION USING SVM

		Prediction	
		Genuine	Counterfeit
Actual	Genuine	16	0
	Counterfeit	4	16

$$Accuracy_{authenticSVM} = \left(\frac{TP + TN}{TP + TN + FN + FP} \right) \times 100 \%$$

$$Accuracy_{authenticSVM} = \left(\frac{16 + 16}{16 + 0 + 0 + 16} \right) \times 100 \%$$

$$Accuracy_{authenticSVM} = \left(\frac{32}{32} \right) \times 100 \%$$

$$Accuracy_{authenticSVM} = 1 \times 100 \%$$

$$Accuracy_{authenticSVM} = 100 \%$$

The evaluation results show that the *Support Vector Machine* (SVM) algorithm was able to correctly classify all test data without producing any classification errors. All 16 samples of genuine banknotes were successfully identified as genuine banknotes, while all 16 counterfeit banknote samples were correctly identified as counterfeit. Therefore, there were no *false positive* or *false negative* values during the testing process, as shown in Table IV.

I. LDA Algorithm Confusion Matrix for Banknote Denomination Classification

TABLE V
LDA ALGORITHM CONFUSION MATRIX FOR BANKNOTE DENOMINATION CLASSIFICATION

		Prediction			
		5.000	10.000	20.000	50.000
Actual	Rp 5.000	3	4	1	0
	Rp 10.000	0	8	0	0
	Rp 20.000	0	1	7	0
	Rp 50.000	0	5	2	1

$$Accuracy_{denominationLDA} = \left(\frac{3 + 8 + 7 + 1}{32} \right) \times 100 \%$$

$$Accuracy_{denominationLDA} = \left(\frac{19}{32} \right) \times 100 \%$$

$$Accuracy_{denominationLDA} = 0,593 \times 100 \%$$

$$Accuracy_{denominationLDA} = 59,3 \%$$

The test results show that the LDA algorithm achieved an overall accuracy of 59.38% in recognizing banknote

denominations. Of the 32 test samples, 19 samples were correctly classified, while 13 samples were incorrectly classified, as shown in Table V.

J. SVM Algorithm Confusion Matrix for Banknote Denomination Classification

TABLE VI

SVM ALGORITHM CONFUSION MATRIX FOR BANKNOTE DENOMINATION CLASSIFICATION

		Prediction			
		5.000	10.000	20.000	50.000
Actual	Rp 5.000	8	0	0	0
	Rp 10.000	0	8	0	0
	Rp 20.000	0	0	8	0
	Rp 50.000	0	0	0	8

$$Accuracy_{denominationSVM} = \left(\frac{8+8+8+8}{32} \right) \times 100 \%$$

$$Accuracy_{denominationSVM} = \left(\frac{32}{32} \right) \times 100 \%$$

$$Accuracy_{denominationSVM} = 1 \times 100 \%$$

$$Accuracy_{denominationSVM} = 100 \%$$

The evaluation results show that the Support Vector Machine (SVM) algorithm achieved excellent performance in recognizing banknote denominations. All 32 test samples, consisting of four denomination classes, were correctly classified without any classification errors. There were no false positive or false negative values for any class, resulting in 100% for all evaluation metrics, as shown in Table VI.

The table above shows that the linear discriminant analysis algorithm can detect counterfeit and genuine 5,000, 10,000, and 50,000 rupiah notes.

K. Change Dispenser Mechanism Accuracy

Based on the test results of the change dispenser mechanism, an analysis was conducted to evaluate the system's performance in dispensing change according to the predetermined conditions. The data analysis was performed by applying the obtained test results to the accuracy formula to quantitatively measure the success rate of the change dispenser mechanism, as shown in Table VII.

TABLE VII

CHANGE DISPENSER MECHANISM ACCURACY

No	Condition	Status (Binary)
1	Counterfeit Money of Matching Denomination	1
2	Counterfeit Money of Lower Denomination	1
3	Counterfeit Money of Higher Denominations	1
4	Genuine Currency of The Correct Denomination	1
5	Insufficient Amount of Genuine Currency	1
6	Higher Denomination Real Money	1
Accuracy		100%

L. Return Mechanism Accuracy

The data on the accuracy of the return mechanism is presented to understand the appropriateness of the mechanism for dispensing money according to the condition of the change.

Data analysis was performed by entering the test results into the accuracy formula, as shown in Table VIII.

TABLE VIII

RETURN MECHANISM ACCURACY

No	Condition	Status (Binary)
1	Change 5.000	
2	Change 10.000	
3	Change 15.000	
4	Change 20.000	
5	Change 25.000	
6	Change 30.000	
7	Change 35.000	
8	Change 40.000	
9	Change 45.000	
Accuracy		

IV. CONCLUSION

Based on the results of the model training stage using Python, both algorithms demonstrated high performance. LDA achieved an accuracy of 99.68% for banknote authenticity classification and 95.93% for banknote denomination classification, while SVM achieved an accuracy of 99.68% for banknote authenticity classification and 99.37% for banknote denomination classification. Based on the results of the real-time testing using the confusion matrix calculation, the LDA algorithm achieved an accuracy of 87.5% for banknote authenticity classification and 59.3% for banknote denomination classification. The real-time testing results indicate a significant decrease in LDA's performance, particularly in banknote denomination recognition.

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