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Vehicle Class Prediction at Toll Gate Using Deep Learning

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Abstract

In the era of digitalization and automation, efficiency in the traffic management system at toll gates is very important. One of the efforts to improve this efficiency is to develop an automatic vehicle class detection system using deep learning technology, especially Convolutional Neural Network (CNN). This research aims to design and implement a CNN model that is able to identify and classify the types of vehicles passing through toll gates. The model development process includes collecting and annotating vehicle image data, data pre-processing, and CNN model training and testing. The evaluation results show that the developed model is able to achieve an accuracy of about 96% in detecting vehicle classes, so it can be integrated with the toll gate system to increase the speed and accuracy in the vehicle classification process. Thus, this solution is expected to reduce the waiting time of toll users and improve operational efficiency.

***Keywords**: CNN, Deep Learning, Vehicle, Identification Image, Classification*

1. Introduction

The development of technology in Indonesia has experienced significant progress in various fields of life including transportation. This can be seen from many industries that have started using advanced technology to increase productivity and efficiency. Technology is increasingly important along with the increasing number of vehicles and the need for an effective traffic management system, especially at toll gates. According to data from the Central Bureau of Statistics (BPS) the number of all types of motorized vehicles (Motorcycles, Passenger Cars, Bus Cars, Goods Cars) in Indonesia in 2022 amounted to 148,261,817 million. The data is obtained through the registration of incoming vehicle registrations (Adha, 2020).

Transportation in Indonesia in the land sector has a type of vehicle class, especially on toll roads. the type of vehicle class in Indonesia is divided into 5 categories, especially for toll roads. For class Ⅰ types of light vehicles such as private vehicles, class Ⅱ types of trucks with two axles with two wheel axes which are generally larger and heavier than class I vehicles. Class Ⅲ types of vehicles with trucks with three axles Vehicles with three wheel axes, allowing to carry heavier loads. Class IV vehicles with four-axle trucks are usually used in heavy industry and construction to transport large materials and equipment. Class v vehicle types with five-axle trucks are used for the transportation of heavy and bulky goods (Afrillia et al., 2022).

Convolutional Neural Network (CNN), which has proven to be highly effective in a variety of functions, including image recognition, object detection, and image segmentation. Convolutional Neural Network (CNN) uses an artificial neural network architecture inspired by biological neural networks consisting of convolutional layer, pooling layer, and fully-connected layer (Purba et al., 2022).

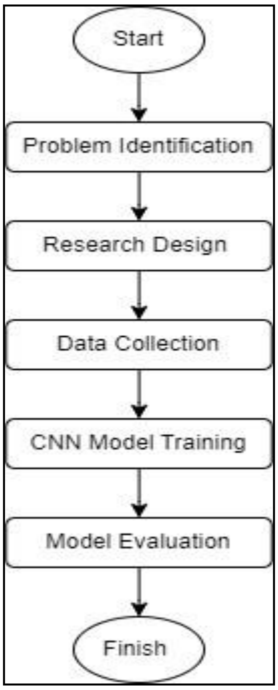
This (Swastika et al., 2019) research describes the analysis of car classification at automatic toll booths (GTO) using the Convolutional Neural Networks (CNN) algorithm.The results of this study indicate that the comparison of the performance of two CNN models for vehicle classification. The dataset used consists of vehicle images taken from previous literature as well as toll road CCTV recordings.

This (Li et al., 2020) research explains about Appropriate CNN Architecture and Optimizer for Vehicle Type Classification System on the Toll Road using Convolutional Neural Networks (CNN) algorithm. The results of this study were successfully used to develop a prototype of an automatic vehicle type classification system.

From the problems described earlier, it proves that some algorithms if combined or developed with various other methods can produce results that are less or can be close to perfect. Therefore, this research will develop an image-based vehicle type classification system using Convolutional Neural Network (CNN) with. The Convolutional Neural Network (CNN) method can detect objects and classify images very accurately, which is the reason why this research uses it. Based on this, the author will conduct research entitled “Development of CNN models on vehicle class detection cameras at toll gates”.This research is expected to provide results and efficiency in the process of identifying vehicles according to their classification by using tools that can classify according to the type of vehicle.

2. Research Method

This research framework is made into the form of an overall diagram. The diagram form is the most important part to know the stages that will be achieved in this research. The overall form of the research stage diagram will produce a system that can function. The overall research framework can be seen in the following figure 1.



Source: Research’s Result (2024)

Figure 1. Flowchart of Research Framework

The research starts with problem identification, addressing the challenges of detecting vehicle classes at toll gates. Following this, the research design provides a flowchart that outlines the methodology. Data is collected from publicly available Kaggle datasets, featuring images of various vehicle types. The collected data is used to train a Convolutional Neural Network (CNN) model. The model's performance is then evaluated and validated using metrics such as confusion matrix, accuracy, precision, and recall. The research finishes with these evaluations to assess the model's effectiveness in classifying vehicle types.

2.1. Object Recognition

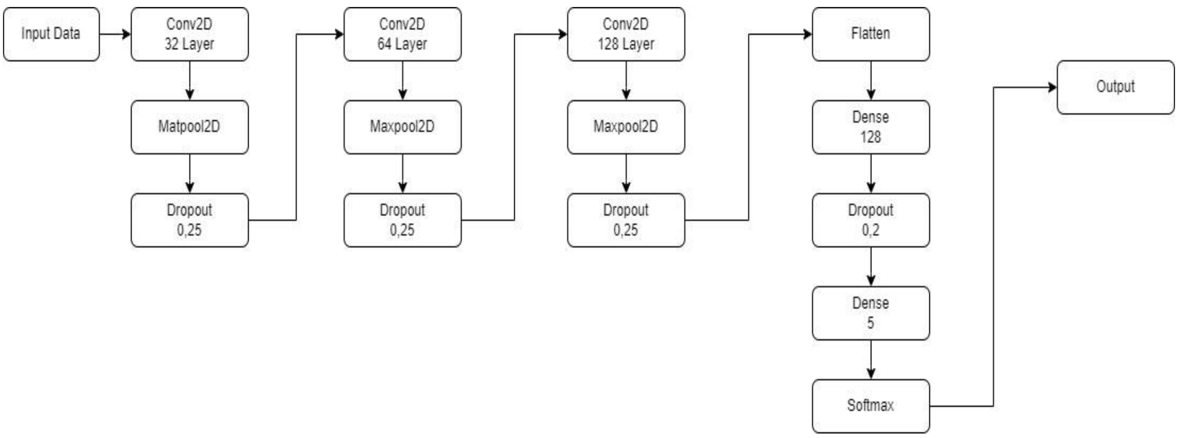
Object recognition technology is the main research in computer vision. One of its main functions is to recognize objects in the image and tell them their position and direction, so that computers can simulate the human brain and human eye functions. Facial recognition systems, augmented reality, virtual reality, and machine vision are some of the industries that can use this technology. Various companies and scientific research institutions have become research centers on the application of deep learning in the field of object recognition as a result of the continuous development of deep learning (Suartika E. P et al, 2016).

2.2. Fully Connected

The Fully Connected layer is where all activation neurons from the previous layer are connected to neurons in the next layer, called the fully connected layer (Abijono et al., 2021). Neurons from the previous layer, or feature map, must be converted into one-dimensional data before they can connect with all neurons in the fully connected layer. Flatten or reshape is the method used to complete the process. The vector that will be used as the input of this layer comes from the flatten process.

2.3. Convolution Neural Network (CNN)

Convolutional Neural Network (CNN) is an evolution of multilayer perceptron (MLP) that aims to process two-dimensional images (Gupta et al., n.d.). CNN is a neural network method that functions to process two-dimensional data, including detecting, recognizing, and analyzing visual images and recognizing objects in image data. CNN consists of neurons that have weight, bias, and activation functions. CNNs use a convolution process, where a convolution kernel, or filter, is applied to an image of a certain size. By doing this, the computer can derive new representative information from multiplying parts of the image with the filter used. Once done with the activation function, the pooling process is performed. Until enough feature maps are obtained to proceed to the fully connected neural network, and the output of the fully connected neural network is the class.



Source: Research's Result (2024)

Figure 2. Research Diagram Block

Dropout is a method that can speed up the training process and prevent overfitting. Dropout is done to reduce overfitting and increase learning speed.

Overfitting is a state where, even though all the data has been correctly presented there is still a mismatch in the prediction process. Both visible and hidden neurons are removed through dropout. Neurons that no longer exist are selected randomly by the system with a probability of zero to one (Dzulqarnain et al., 2019). False Negative (SN) and False Positive (SP) are two parameters that can be used to calculate F1-Score, recall, and precision. If a class in the system is identified as having a negative value but is not detected in the non-negative data, then a false negative value occurs. Conversely, if a class is identified as having a positive value but is not detected in the non-negative data, then a false positive value occurs. The following is the content of the confusion matrix (Azhari et al., 2021).

3. Results and Analysis

The results of the research that have been carried out related to this research include several important stages, which involve scenarios conducted on the developed system and functional testing of the website. These tests cover several important aspects to ensure that the system functions as expected.

3.1. Functional Testing of the Website Results

Functional testing of the website was conducted using the blackbox method to ensure that the website could operate properly as expected during the research. The main focus was to verify that all the features that were used as per their functionality such as the camera sensor, document print, and graphical result display, were working properly. This process not only ensures that each technical component functions as intended, but also ensures that the user interface provides a digitized and automated experience for the user.

Table 1. Blackbox Test Results on the Website

No.	Menu	Information
1.	Home page	Success: The home page was displayed correctly.
2.	Upload file	Success: displays the file upload page.
3.	Diagram	Successful: can view the vehicle class diagram
4.	File upload page	Successful: The file upload page is successful: Users can print the excel file and get accurate results.

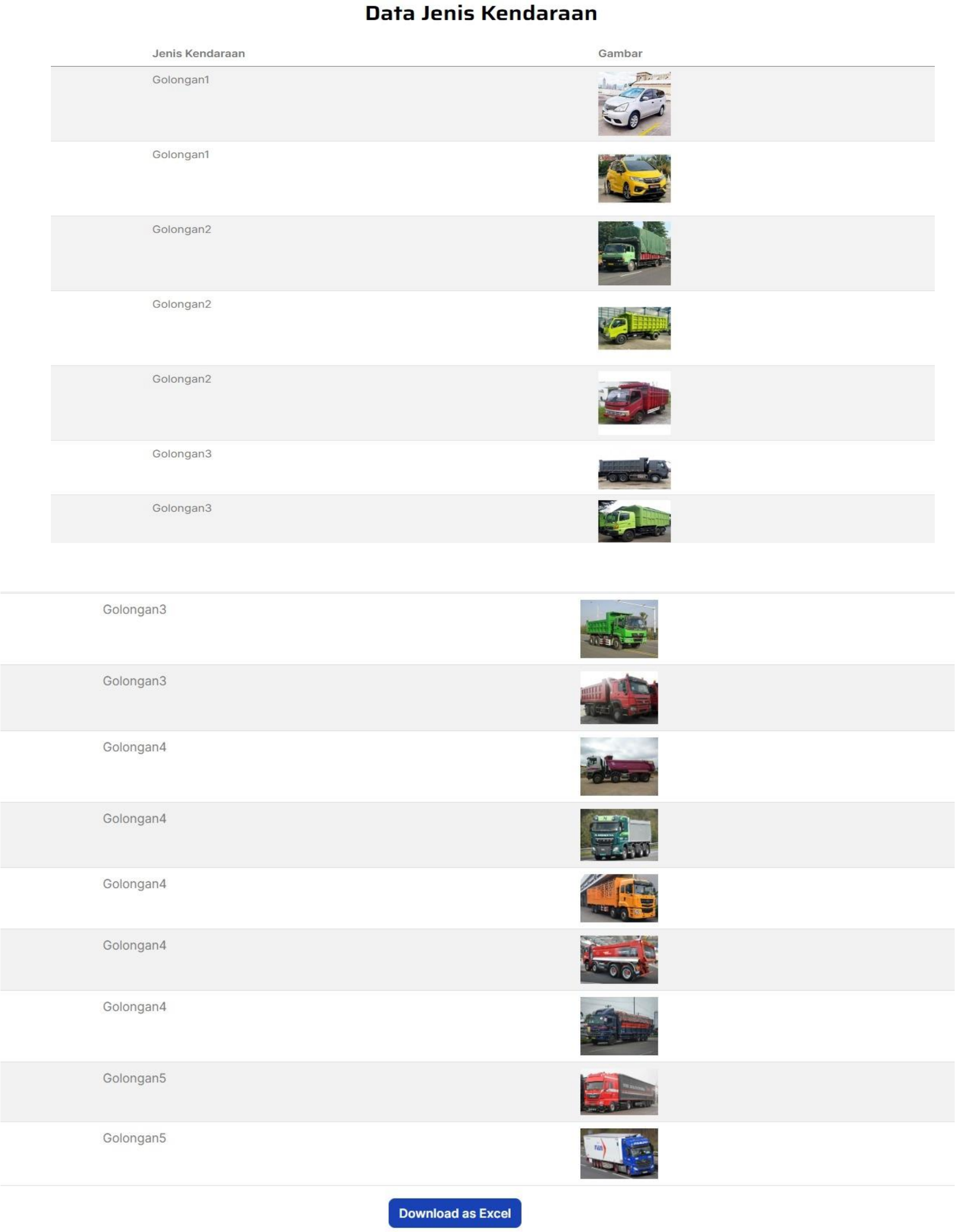
Source: Research's Result (2024)

3.2. Test Results

Source: Research's Result (2024)

Figure 3. Website

In Figure 3 is a screenshot of a website named "TransDetect." The homepage features a project focused on the development of a Convolutional Neural Network (CNN) model for vehicle classification using detection cameras at toll gates. The website includes two main buttons below the project description: "Kamera Deteksi" (Detection Camera) and "Upload File," suggesting functionality for camera detection and file uploading. The background image shows a cityscape with roads and vehicles, reinforcing the theme of traffic and vehicle detection.



Data Jenis Kendaraan

Jenis Kendaraan	Gambar
Golongan1	
Golongan1	
Golongan2	
Golongan2	
Golongan2	
Golongan3	
Golongan3	
Golongan3	
Golongan3	
Golongan4	
Golongan4	
Golongan4	
Golongan4	
Golongan4	
Golongan5	
Golongan5	

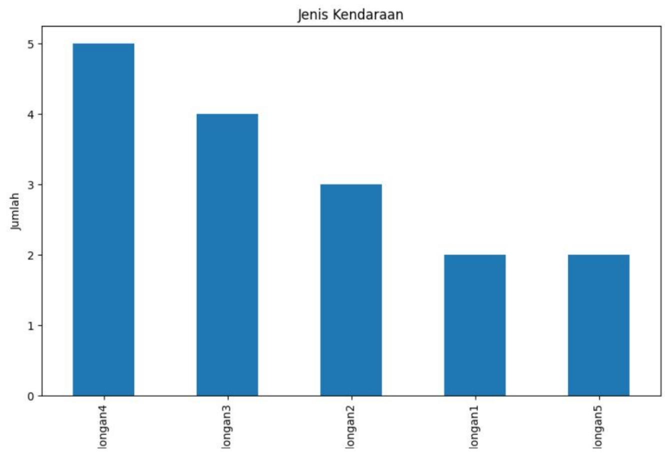
Download as Excel

Source: Research's Result (2024)

Figure 4. Third Results

In Figure 4 The image "gambar 4" shows a table titled "Data Jenis Kendaraan" (Vehicle Type Data) that presents the results of the vehicle detection system, which classifies vehicles into different categories or classes (golongan). The table has two columns: "Jenis Kendaraan" (Vehicle Type) and "Gambar" (Image). Here are the details of the detected vehicle types: (1) Golongan 1: Image 1: A white car. Image 2: A yellow car. (2) Golongan 2: Image 1: A large green truck. Image 2: A yellow truck. Image 3: A red truck. (3) Golongan 3: Image 1: A black truck. Image 2: A green truck. The table indicates that the CNN model has successfully categorized the vehicles based on their types, showing the corresponding images of each detected vehicle.

Data Chart



Source: Research's Result (2024)

Figure 5. Fourth Result

The image is a bar chart titled "Data Chart," which shows the distribution of detected vehicle types based on their categories (golongan). The x-axis represents the vehicle categories, labeled as "Golongan1" through "Golongan5," and the y-axis represents the number of vehicles detected in each category (Jumlah).

Here is a summary of the data presented in the chart: (1) Golongan 4: Detected 5 vehicles. (2) Golongan 3: Detected 4 vehicles. (3) Golongan 2: Detected 3 vehicles. (4) Golongan 1: Detected 2 vehicles. (5) Golongan 5: Detected 2 vehicles.

The chart illustrates that "Golongan 4" has the highest number of detected vehicles, followed by "Golongan 3," "Golongan 2," and both "Golongan 1" and "Golongan 5" with the same number of detected vehicles. This visualization helps in understanding the frequency distribution of different vehicle types detected by the system.

The table 2 is illustrates the performance metrics of a classification model across five different classes (Golongan1 to Golongan5), encompassing precision, recall, f1-score, and support for each class. Golongan1, Golongan3, and Golongan5 all exhibit perfect precision, recall, and f1-scores of 1.00, indicating flawless classification for these classes. Golongan2 has a slightly lower precision of 0.98 but maintains perfect recall and an f1-score of 0.99, suggesting minimal false positives. Golongan4 shows a precision of 1.00, a recall of 0.97, and an f1-score of 0.99, indicating a small number of false negatives. Overall, the model achieves an impressive accuracy of 0.99, correctly classifying 99% of the samples. The macro average, which treats each class equally, shows a precision of 1.00, a recall of 0.99, and an f1-score of 1.00. Similarly, the weighted average, which accounts for the number of samples in each class, reflects the same high values, confirming the model's consistent and exceptional performance across all classes.

Table 2. Model Performance Evaluation Result

Class	Precision	Recall	F1-Score	Support	Results
Group 1	1.00	1.00	1.00	33	The model successfully classifies all class 1 instances correctly without error.
Group 2	0.98	1.00	0.99	48	There were few positive predictions in group 2 but all instances that were actually group 2 were found.
Group 3	1.00	1.00	1.00	37	The model successfully classifies all group 3 instances correctly without error
Group 4	1.00	0.97	0.99	38	There is a slight negative error in group 4 but the precision remains high indicating a very accurate prediction for the recognized instances.
Group 5	1.00	1.00	1.00	44	The model successfully classifies all group 5 instances correctly without error

Source: Research's Result (2024)

4. Conclusion

It can be concluded that this research uses the Convolutional Neural Network (CNN) algorithm, a method that is widely used in various studies and is one of the popular technological developments to solve transportation problems with quite good results. The accuracy of this research reached 96%. The developed CNN model shows a very high level of accuracy, with precision, recall, and F1-score values close to 1.00 for each vehicle class. This indicates that the model is able to classify vehicles very accurately and effectively.

In conclusion, the "TransDetect" project successfully demonstrates the application of a CNN model for vehicle classification at toll gates, with accurate categorization and clear visual representation of results. The system's ability to handle real-time detection and file uploads, along with its effective classification performance, underscores its potential for practical deployment in traffic management and toll collection systems. The high accuracy and robust performance metrics further validate the model's effectiveness in solving transportation problems.

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Author Contributions

Suci Lutfia Nisa was responsible for the implementation of the research, data collection, and analysis of the results. Sopian Soim and Muhammad Zakuan Agung provided guidance in the design of research methodology, data interpretation, and preparation of the final manuscript.

Conflicts of Interest

The author has no conflicts of interest to declare.

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