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Design of a road marking violation detection system at railway level crossings

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ABSTRACT

When a train passed through a railway-level crossing, a common phenomenon was that many vehicles attempted to overtake others by crossing into lanes designated for oncoming traffic, resulting in both roads becoming congested with motorized vehicles. At that time, no system was in place to enforce penalties for violating road markings at level crossings. Therefore, a system capable of detecting such violations when trains pass through was needed. The designed system utilized a Raspberry Pi 4, a webcam, and an ultrasonic sensor. The single shot detector (SSD) method was employed for vehicle classification. The optical character recognition (OCR) method was used for character recognition on license plates. The research involved object detection at level crossings using varied objects (cars and motorcycles) with license plates categorized into two types: white background plates with black numbers and black background plates with white numbers. Based on the research results, turning on the webcam when the bar opened and closed using an ultrasonic sensor got an average error of 0.573% and 0.582%. The system could distinguish objects with an average recognition delay of 0.554 seconds and 0.702 seconds for car and motorbike objects. Regarding number plate detection, the success rate of character recognition stood at 64.45%.

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1. INTRODUCTION

Railway transportation is a commonly utilized mode of transport in nearly every country, including Indonesia. During operations, it is inevitable for railway tracks to intersect with land transport modes, such as roads. This intersection between a railway line and a public road is referred to as a railway crossing. A railway crossing is the point where the railway intersects with the highway [1]. Indonesia is one of the countries grappling with safety issues at railway crossings [2]. In Indonesia, a common occurrence at railway crossings when trains pass is the movement of vehicles, such as cars and motorbikes, that should be using only one lane. However, when the train passes, many vehicles cross over the road markings, resulting in both lanes becoming fully occupied by cars and motorbikes. This situation occurs in both directions of the road, causing vehicles from opposite directions to face each other after the train has passed. This incident is extremely hazardous as it can lead to accidents [3]. The main objective point of this work is to provide warnings to drivers who crossroad marking boundaries when trains pass through level crossings by recording license plate data in a database. This data can then be used by police as grounds for issuing fines. This research is important to ensure that car and motorcycle drivers adhere to regulations at railway crossings.

Research has been conducted to prevent accidents at railway level crossings, one method of which involves calculating the distance between the driver and the level crossing using camera images stored in the vehicle [4]. In addition to accidents, this will also cause congestion [5]. There are numerous studies on modifications to level crossings aimed at reducing accidents, including research on algorithms for traffic control at these crossings [6]. Another research revolves around managing traffic lights at railway-level crossings through the application of computer vision [7]. Additionally, other studies investigate obstacles at railway-level crossings, demonstrating that the developed system can effectively detect objects at these crossings and can be implemented in real-world scenarios [8]. Raspberry Pi is utilized as a microcontroller in this research, along with digital image processing to identify objects and read the number plates of cars or motorbikes closest to the doorstop. Digital image processing is extensively employed in various domains, including fire-detection applications [9], rail wear detection [10], for autonomous vehicles [11], and many more. This research differs from previous studies because earlier research aimed to improve railway systems or monitor train conditions to prevent accidents. Currently, the system used to warn those who violate road markings at railway crossings involves direct announcements by railway guards. However, this approach has proven ineffective. Therefore, a system is needed that can provide warnings and deter violations through the issuance of fines. However, this study focuses on designing a system aimed at penalizing vehicle users who violate road markings by recording their license plate numbers. This data can then be used by police for issuing fines.

2. METHOD

2.1. Flowchart system

Figure 1 depicts the overall operation of the system, starting with the input of an ultrasonic sensor to determine the distance between the road surface and the railway crossing gate when the gate is closing. The ultrasonic sensor used for distance detection is positioned at the midpoint of the railway crossing gate. If the distance value from the gate to the road surface is ≥110 cm and ≤140 cm, the sensor sends a signal to the Raspberry Pi to activate the webcam. The webcam captures a video and identifies the detection area according to the lines on the opposite lane. Afterward, the system performs vehicle object detection using the single shot detector method to classify objects. In this study, objects are classified into two categories: motorcycles and cars. If the system detects an object according to the specified classifications, it will produce a warning sound output through a wireless Bluetooth speaker. Subsequently, after 15 seconds, vehicle plate detection will be conducted using the Haar cascade classifier method, and the resulting data will be sent to the database.

This research utilizes Raspberry Pi as the microprocessor, ultrasonic sensors to detect the distance from the road to the level crossing gate, a webcam to capture images of vehicles at the level crossing, and a buzzer to provide warnings for vehicles that violate. Raspberry Pi is also employed for vehicle classification and for identifying and translating characters on license plates within the detection area. The single shot detector (SSD) method is employed to detect and classify vehicle objects, while the optical character recognition (OCR) method is used to translate characters on license plates. A car or motorbike in proximity to a doorstop but not within its designated lane indicates that it has crossed the road marking limit. Therefore, cars or motorbikes near the doorstop will receive a warning through a buzzer. Two minutes after the buzzer is activated, the camera will capture the vehicle's license plate number, which will then be converted into alphanumeric characters. Subsequently, this information will be transmitted to a designated website serving as a database for traffic violators who have crossed road markings. This study only detects and classifies two objects, namely cars and motorcycles. Additionally, the research only records license plates that violate road markings along with the timestamp of data acquisition. The owner data of the detected license plates remains dummy data that has not been integrated with government license plate data.

2.2. Hardware system

The hardware system comprises Raspberry Pi as a microcontroller, a webcam camera for capturing images, an ultrasonic sensor to measure the distance from the crossing gate to the road, and a buzzer to emit warning sounds for cars or motorbikes violating the road markings. To maintain the power, the webcam camera will activate when the distance from the doorstep to the road reaches 110 to 140 cm. If the distance value from the device to the road is ≥110 cm and ≤140 cm, the sensor will send a signal to the Raspberry Pi to turn on the webcam, and the webcam will take a video, then determine the detection area according to the line in the opposite direction. The use of Raspberry Pi was chosen because Raspberry Pi has been widely used in object recognition [12] and [13]. In addition, Raspberry Pi can also be used to perform object detection in real-time [14]. Figure 2 depicts the electronic hardware system design comprising Raspberry Pi, a webcam camera, an ultrasonic sensor, and the warning sound emitted via a Bluetooth speaker. Figure 3 depicts the prototype of the railway doorstop, constructed at a scale of 1:2 in comparison to the original doorstop. The positioning of the device aligns with the initial design, situated in the center of the railway doorstop prototype.

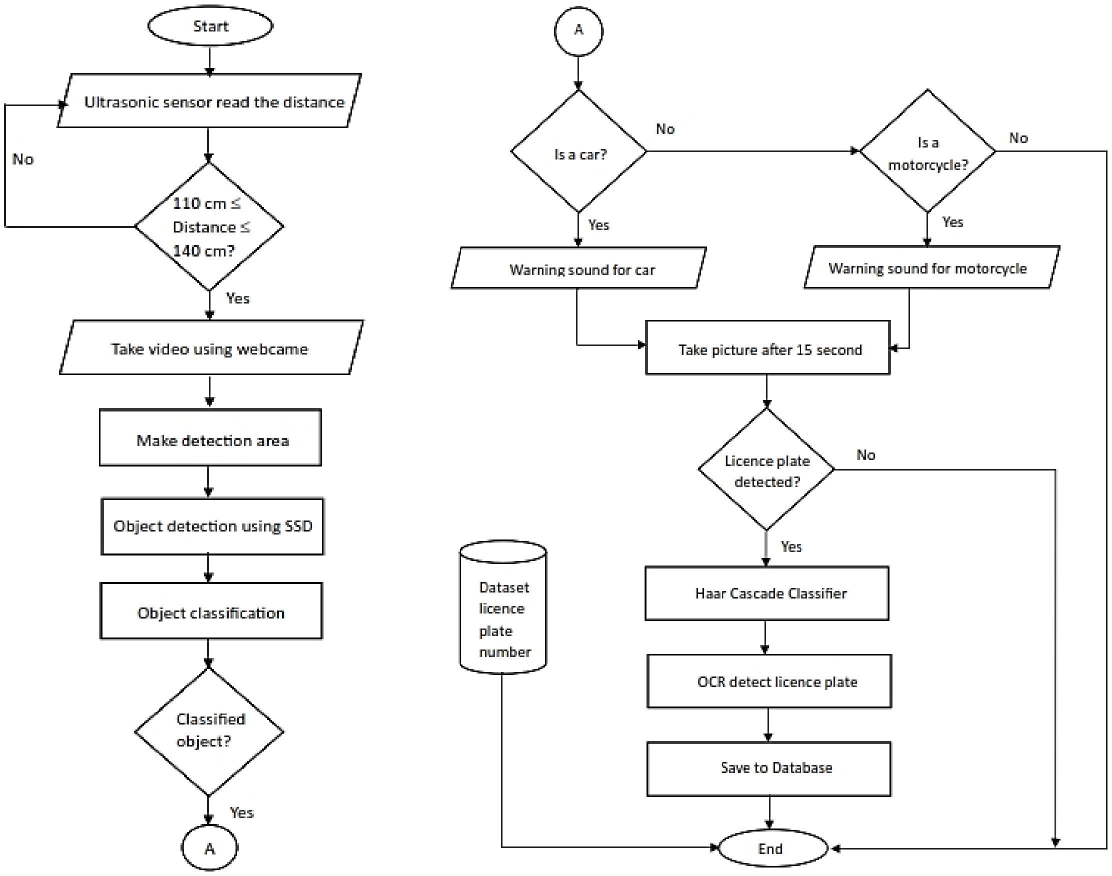


Figure 1. Flowchart system

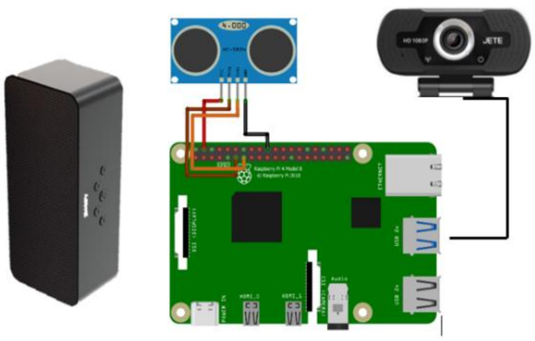


Figure 2. Electronic system design

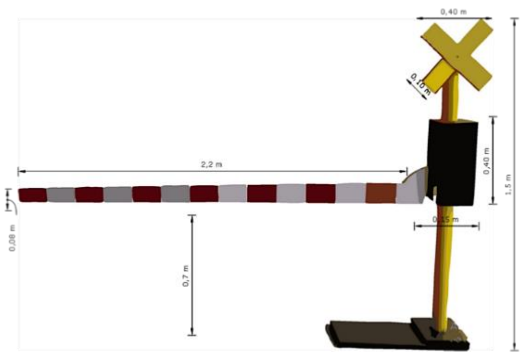


Figure 3. Prototype railway door crossing

2.3. Object classification

Object detection is a crucial parameter in this research. If an object is detected within the detection area, it signifies a violation of road markings. The objects in this research are categorized into two classifications: cars and motorbikes. The method employed for object classification is the SSD method. SSD was selected due to its high accuracy and rapid processing capabilities [15]. According to research, SSD yields higher precision compared to a support vector machine (SVM) [16]. In the conducted research, the processed data consisted of 1 frame per second (fps), wherein the intended real-time condition during the study refers to testing being carried out in real-time within actual environmental settings, resulting in a delay in object classification timing.

The initial procedure for object classification involves capturing a video at the railway level crossing. Subsequently, this video is segmented into multiple frames. Figure 4 depicts the establishment of a detection area where vehicles surpassing the road marking limit are considered for classification. Once the detection area is defined, the subsequent step is to classify the detected objects. Object classification testing is conducted through two approaches: first, directly at the railway crossing site, and second, in alternative locations utilizing the developed prototype. Detection areas in images using Python as a programming language and using Raspberry Pi OS and visual studio code for software.

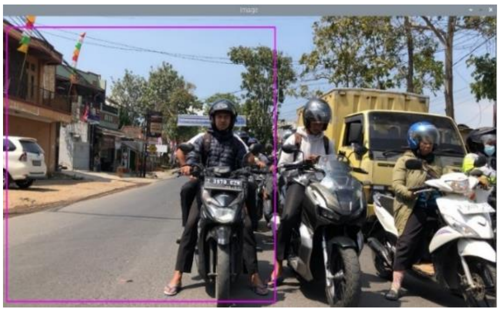


Figure 4. Detection area image

2.4. Vehicle number plate detection

The number plate object detection method uses the Haar Cascade classifier to detect letters and numbers on the number plate using the OCR method. The use of the Haar cascade classifier and OCR for plate detection has also been done in previous studies [17]. The difference between this research and the one conducted is that after object detection and character recognition, the results of character recognition are stored in the database and displayed on the website. Sending data to the database will be the basis for ticketing for violating road markings. The use of OCR was chosen because OCR is one of the good methods used for character recognition with fairly good accuracy [18]. OCR is widely used for handwriting research, including for recognizing English handwritten text [19], Malayalam handwritten text [20], Devanagari script handwriting [21], and many more. OCR is also used in research for the digitization of medical records, where the error results of OCR reached 6%, which is lower than using the Gated-CNN-BLSTM algorithm method, which is 9% [22]. Detection license plate using Python as a programming language and using Raspberry Pi OS and visual studio code for software.

3. RESULTS AND DISCUSSION

This section discusses the research results depicted in figures and tables. This section will be divided into several parts. The first part discusses the testing of each component individually, followed by testing the entire system as a whole. System testing for each component includes ultrasonic sensor testing, object detection testing, license plate reading testing, and data transmission testing to the database.

3.1. Experiment ultrasonic sensor reading of webcam conditions

The doorstop automatically closes upon the arrival of a train schedule. During the closure process, an ultrasonic sensor measures the distance between the height of the crossbar and the road surface. If the distance falls within the range of ≥110 cm and ≤140 cm, the webcam activates, and the system becomes operational. The distance ≥110 cm and ≤140 cm is chosen based on the actual height of the railway crossing gate above the ground (as per the prototype constructed), which is 110 cm. The webcam activation threshold begins when the ultrasonic sensor detects a distance from the gate to the ground below 140 cm. This ensures that by the time the crossing gate is fully closed (at a distance of 110 cm from the ground), the webcam is ready to capture images and perform detection and classification tasks. This is done so that the system does not continuously activate the camera. The ultrasonic sensor readings are tested under clear weather conditions and good illumination (during daytime), allowing the ultrasonic sensor to accurately measure the distance between the crossing gate and the ground. However, in adverse weather conditions such as rain or insufficient lighting, the readings from the ultrasonic sensor may become less accurate.

Table 1 presents the system testing results comparing ultrasonic sensor readings with webcam activation conditions across varying distances from the lowest to the highest range and from the furthest to the closest distance positions. From the data in Table 1, it is observed that the webcam activates when the sensor readings range from 109.86 to 139.61 cm and from 110.09 to 138.15 cm between the gate and the road surface. Conversely, the webcam remains inactive when the sensor readings are between 9.97 to 100.14 cm, 147.97 to 189.14 cm, 10.07 to 103.14 cm, and 154.04 to 189.88 cm. The sensor ultrasonic data was cross-checked with actual distances using a ruler. Table 1 indicates that the average error of ultrasonic sensor readings is 0.573% and 0.582%. The average error in Table 1 is calculated using (1):

$$error(\%) = \frac{|measurement\ value - measured\ value|}{measurement\ value} * 100\% \quad (1)$$

Table 1. The influence of sensor readings on webcam conditions from low to high and from high to low distances

Sensor readings on webcam conditions from low to high distances				Sensor readings on webcam conditions from high to low distances			
Reference value meter (cm)	Sensor reading result (cm)	Sensor reading error rate (%)	Webcam condition	Reference values of the meter (cm)	Sensor reading results (cm)	Sensor reading error rate (%)	Webcam condition
10	9.97	0.30	Off	190	189.88	0.06	Off
20	19.58	2.10	Off	180	179.93	0.03	Off
30	29.97	0.10	Off	170	170.16	0.09	Off
40	40.12	0.30	Off	160	160.56	0.35	Off
50	50.61	1.22	Off	150	154.04	2.69	Off
60	59.69	0.51	Off	140	138.15	1.32	On
70	70.14	0.20	Off	130	129.75	0.19	On
80	80.18	0.22	Off	120	119.96	0.03	On
90	90.31	0.34	Off	110	110.09	0.08	On
100	100.14	0.14	Off	100	103.14	3.14	Off
110	109.86	0.12	On	90	90.31	0.34	Off
120	119.70	0.25	On	80	80.18	0.22	Off
130	128.96	0.80	On	70	70.31	0.44	Off
140	139.61	0.27	On	60	60.09	0.15	Off
150	147.97	1.35	Off	50	49.97	0.06	Off
160	160.14	0.08	Off	40	40.12	0.30	Off
170	170.58	0.34	Off	30	30.14	0.46	Off
180	177.98	1.12	Off	20	19.97	0.15	Off
190	189.14	1.12	Off	10	10.07	0.70	Off
Average error (%)		0.573		Average error (%)		0.582	

3.2. Object classification testing

The images derived from the recorded video results are subsequently categorized into two objects: motorbike objects and car objects. Testing is conducted utilizing a previously developed prototype, which employs a detection area tailored to the characteristics of level crossings. In Figure 5, the green line delineates the detection area, while the blue line represents the classification of motorbike objects. It is evident from the figure that there are two motorcycles; however, those outside the detection area are not classified. Figure 6 illustrates the classification of the car object. The detection area is indicated by a green line, while the car classification is denoted by a red line. Throughout the detection process, the time delay necessary for object classification is assessed. Table 2 displays the time required for object classification. The average time for classifying motorbike objects is 0.702 seconds, while for classifying car objects, it is 0.554 seconds.

3.3. Vehicle number plate detection test

The detection of vehicle number plates utilizes the Haar Cascade classifier, while character recognition on the number plate is achieved using OCR. The process of detecting and recognizing characters on the number plate involves several steps, including cropping, grayscale conversion, resizing, dilation, and erosion. To find out the starting percentage of success in character recognition, we can use (2):

$$\text{Success } (\%) = \frac{\sum \text{closest character}}{\sum \text{true character}} * 100\% \quad (2)$$

The outcomes of the system's character recognition success calculation for the characters within the number plate. Table 3 displays the experiment involved in conducting 5 tests using the same number plate object. In the case of the number plate with a white background, several tests failed to recognize the characters on the plate. Conversely, with the black number plate, it was observed that all characters were successfully recognized. Out of the five tests conducted with the white plate, only two tests were successful in character recognition, whereas all tests conducted with the black plate successfully recognized the characters. The entire testing was conducted under clear weather conditions and bright illumination, specifically during daylight hours.

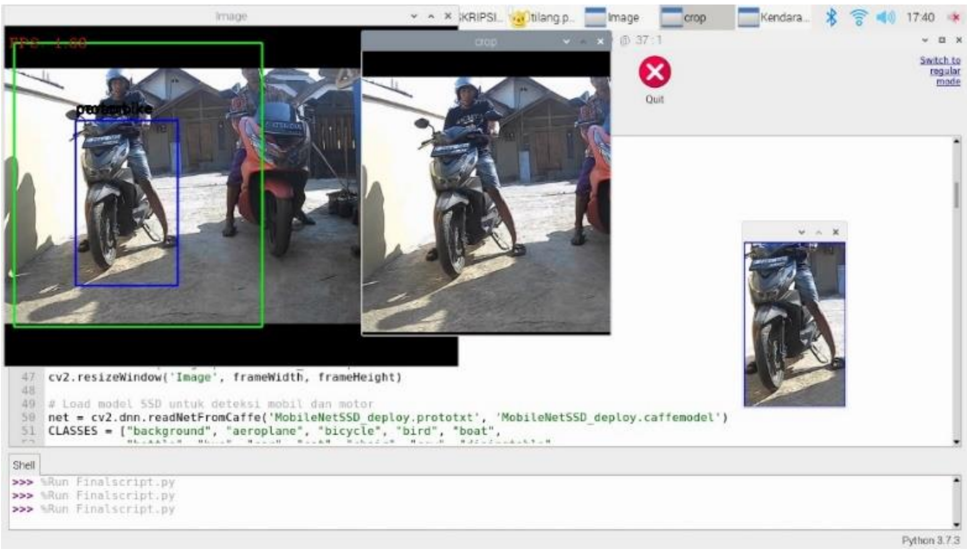


Figure 5. Classification of motorbike objects

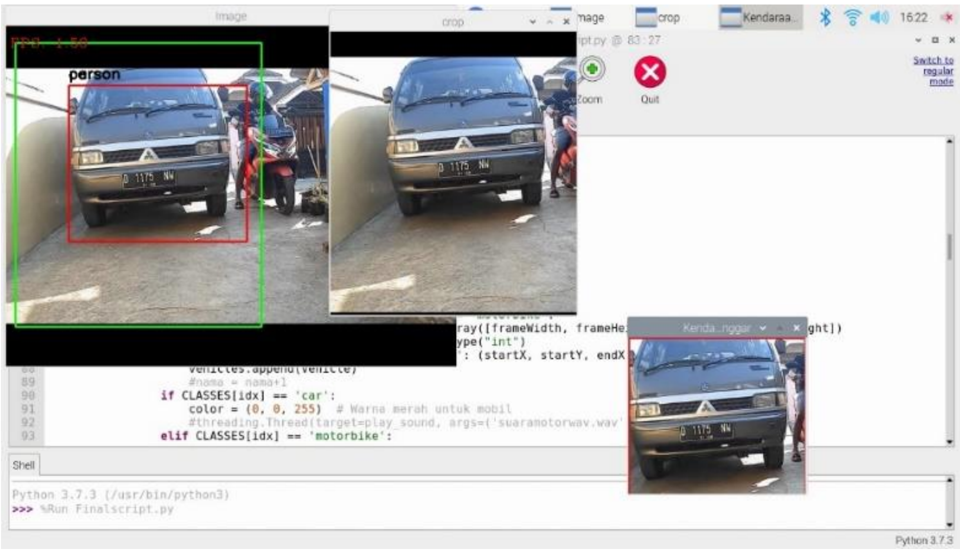


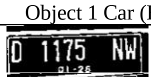
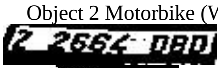
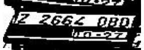
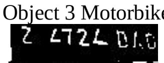
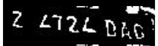
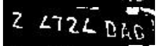
Figure 6. Classification of car objects

Table 2. Object classification time delay table

Testing	Object classification time	
	Motorbike	Cars
1	0.78	0.65
2	0.91	0.57
3	0.62	0.56
4	0.73	0.47
5	0.47	0.52
Average *delay*	0.702	0.554

Furthermore, to obtain a number plate that can be easily detected and recognized, the camera's position relative to the number plate must be perpendicular. If the number plate obtained from the video results is misaligned, this also affects the character recognition process on the number plate. Number plates with black backgrounds are easier to recognize characters because they align better with the image processing process, particularly the grayscale conversion. When grayscale conversion is performed, characters on black plates appear brighter compared to those on white number plates. The entire testing was conducted under clear weather conditions and bright illumination, specifically during daylight hours.

Table 3. Number plate testing table

Testing to-	Original character	Image processing	Character recognition result	Percentage (%)
Object 1 Car (Black Plate)				
1	D1175NW		O1175NW	85.17
2			O1175NW	85.17
3			D1175NW	100
4			D1175NW	100
5			O11Z5NW	71.42
Object 2 Motorbike (White Plate)				
1	Z2664DBD		Z2664DBI	87.50
2			Z2664DBD	100
3			-	0
4			-	0
5			-	0
Object 3 Motorbike (Black Plate)				
1	Z4724DAQ		Z4724DAO	87.50
2			ZL72LDAO	62.50
3			ZL72LDAG	62.50
4			ZL72LDAC	62.50
5			ZL72LDAC	62.50
Average percentage of success (%)				64.45

In Figure 7, it is noted that both classified objects, namely cars and motorcycles, can be identified. This is evident from the detection areas on the cars and motorcycles exceeding the road marking boundaries. In both instances where motorcycles violate the road markings, the first detected motorcycle is the black-colored one, where classification data and license plate information are obtained. The adjacent motorcycle object is detected after obtaining the license plate of the first motorcycle object. In Figure 8, it is observed that the system is capable of classifying objects and determining them as motorcycles. However, for the yellow-colored motorcycle, the characters on the license plate cannot be recognized due to the poor quality of the detected license plate image. Because the license plate is not aligned with the camera placement, the system cannot recognize the license plate on the car at all. Therefore, the angle of the camera capture concerning the license plate on the object also needs to be considered.

Upon detection of an object at a level crossing, the system activates a buzzer to warn the object not to cross the road markings. If the object is still detected after the buzzer warning, the system proceeds to recognize the license plate characters, recording them as violation records. Research findings also indicate the successful functionality of the buzzer and data transmission to the database. However, there is a need for improvement in the character recognition component to ensure recognition under all conditions. The system's purpose is to provide warnings and deterrence to road marking violators at level railway crossings, an area where effective warning and deterrence systems are currently lacking, particularly in Indonesia.

3.4. Testing sending data to the database

Following the character reading test on the number plate, the subsequent step involves transmitting the number plate character data to the database. Figure 9 depicts an image of the website designed for recording violations of road markings at railway-level crossings. Image capture occurs when the system detects a motorbike or car passing through the road, followed by a warning issued through a Bluetooth speaker to prompt the vehicle to switch to the appropriate lane. Subsequently, after a 2-minute interval, a picture is taken of the vehicle that violates the road markings at the front. This image is then transmitted to the website along with the timestamp of the violation.

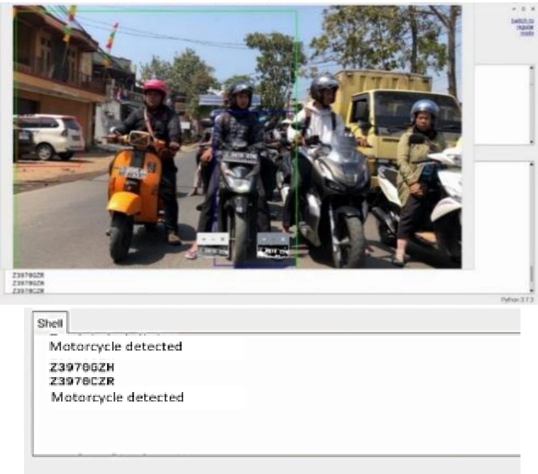


Figure 7. Detection and classification of objects along with license plate reading on the first motorcycle object (black color)

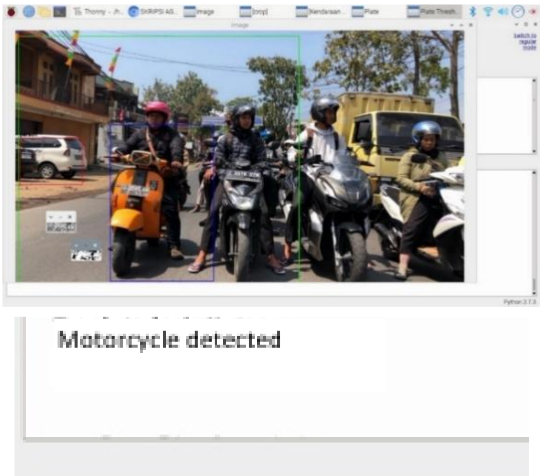


Figure 8. Illustrates the detection and classification of objects along with the license plate reading on the second motorbike (highlighted in yellow)

No.	Number Plate	Owner	Information	Time of Violation
1	Z4724DAQ	Agung Ihwan Nurdin	Exceeding road markings	2023-09-03 14:31:08
2	D1175NW	Gilang Ramdani	Exceeding road markings	2023-09-02 16:47:50
3	Z2664DBD	Adelia Nurfitria	Exceeding road markings	2023-09-02 16:59:44
4	Z3155FY	Undang Supriatna	Exceeding road markings	2023-09-04 13:43:59
5	Z2047GZA	Jubaedah	Exceeding road markings	2023-09-05 12:45:50
6	Z4557EP	OBJEK 1	Exceeding road markings	2023-09-07 10:19:39

Figure 9. Website for recording violators of road markings at railway level crossings

3.5. Data analysis and discussion

This research aims to prevent traffic congestion and accidents when railway crossing gates are open caused by motorists using both sides of the road. The use of both sides from opposite directions can lead to congestion and pose accident risks. This study designs a system to detect vehicles crossing road marking boundaries and alert drivers to refrain from doing so. It also aims to deter violations by recording the license plates of vehicles that cross the markings while trains are passing, which can lead to subsequent legal actions. This research is crucial as its primary goal is to create a deterrent effect, fostering awareness among drivers not to cross road markings when trains are passing. Effective use of capable microcontrollers and optimizing the camera system for various conditions are key aspects for future system development.

Several studies have been conducted to prevent accidents at railway crossings, focusing on infrastructure development without raising awareness among railway crossing users. One such study involves the detection of railway track damage [23], the detection of train location [24], and the monitoring of railway tracks [25]. The use of cameras at railway crossings is employed for the decentralization of railway systems, where decentralizing railway crossing systems becomes a long-term solution to railway crossing issues [26]. Previous studies have focused on the devices used at railway crossings. However, this research aims to create a deterrent effect, particularly for drivers who violate road markings using a webcam, to prevent accidents. The deterrent effect generated by the system becomes the strength of the system because once drivers are deterred, they are less likely to commit violations that could lead to accidents.

The use of a webcam and Raspberry Pi 4 in the initial hypothesis is expected to yield good results. The webcam can provide good results in image acquisition processes [27], and the Raspberry Pi 4, as hardware, can also be proficiently used in digital image processing and as a control for the overall system [28]. However, in the conducted research, the webcam did not function well because it can only be used in the daytime under clear weather conditions. The webcam fails to produce good images during nighttime and rainy conditions. Furthermore, the use of Raspberry Pi 4 also proved less proficient, evidenced by the jerky movement of objects during detection and classification (not smooth). A drawback of this research is the relatively long detection delay. This delay may occur because the Raspberry Pi utilized performs dual functions, namely processing images obtained and simultaneously controlling and recording data for the sensor. The initial hypothesis using the SSD method showed promise in accurately analyzing object detection, as SSD can serve as an effective and efficient detection method, demonstrating good performance across various datasets [29]. In the conducted research, it was found that the use of SSD performed well in detecting and classifying objects such as cars and motorcycles. The hypothesis regarding the use of OCR showed promising performance for license plate detection [30]. However, in the conducted research, OCR still has some shortcomings, including its inability to distinguish between characters or numbers that have similar shapes, such as distinguishing between the number 2 and the letter Z.

Based on the research results, the ultrasonic sensor readings used as triggers for webcam conditions exhibited low error readings of 0.573% and 0.582%. In the object classification tests, the system successfully classified two different objects: cars and motorcycles. However, both classifications experienced significant delays, specifically 0.702 seconds for cars and 0.554 seconds for motorcycles. During testing with pre-recorded videos, the object classification process did not run smoothly; playback of the video caused delays in movement, affecting the detection and classification results. Regarding vehicle license plate detection and reading tests for violators, the system achieved a success rate of 64.45%. The accuracy of license plate reading relied on the OCR's ability to interpret characters. During testing, the system encountered reading errors where the number 7 was misread as the letter Z, the letter D as the letter E, and the letter Q as the letters O, G, or C. Additionally, the vehicle's license plate had to be aligned parallel to the camera for accurate reading. Future research can focus on how to improve readability delays and increase the accuracy of number plate readings.

4. CONCLUSION

This research has successfully designed a system capable of detecting vehicles that violate road markings at railway crossings. The conducted research has successfully controlled the camera conditions using ultrasonic sensor readings as triggers, but OCR not being optimal in translating letters and numbers on license plates. For further research, to reduce delay, the system can be attempted to separate the control function and the recording function using two microprocessors, or it can be attempted to replace the microprocessor being used. Additionally, the camera's position must be precisely aligned with the number plate to ensure proper recognition of the characters on the number plate. Various methods can be employed for license plate character detection to determine which character recognition method is more accurate. Another limitation is that the system developed in the current research does not include measures to secure the data of license plates stored in the system. To address the shortcomings of this research, several steps can be taken. One approach is to replace or possibly add microcontrollers, with one dedicated to image processing and another for system control. Additionally, consideration could be given to upgrading the camera to enable the system to perform detection and classification under various conditions, such as nighttime or rainy weather. Future research could also focus on enhancing data security measures for license plate data, such as encrypting license plate information or improving system security overall. Moreover, challenges posed by environmental conditions and varying lighting levels need to be thoroughly investigated and resolved.

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