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Integration of Computer Vision and Microcontroller in Autonomous Braking Systems to Enhance Operational Safety of Inspection Trains

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Abstract— *In the realm of railway safety and operational efficiency, the use of advanced inspection trains is critical. This study explores the integration of a disc brake system with computer vision technology to enhance braking precision in inspection trains. The system detects and measures the distance to obstacles, such as humans and vehicles, converting this data into servo motor angles that control braking force. This dynamic approach allows the braking response to be adjusted in real-time based on distance data obtained from image processing, which is communicated via serial communication to the train's control system. The research aimed to assess the effectiveness of this integrated method in real-world scenarios. The results demonstrated that braking responses based on distance data from image processing could be effectively managed through serial communication with the inspection train's control system. Specifically, for human obstacles, the braking time was 5 seconds from an initial speed of 4.95 km/h, with a stopping distance of 3.4375 meters. For motorcycle obstacles, the braking time was 6 seconds from an initial speed of 4.69 km/h, with a stopping distance of 3.909 meters. These findings underscore the significant potential of integrating computer vision technology with braking systems in inspection trains, enhancing not only safety but also overall operational performance.*

Keywords—*Computer Vision, Braking System, Microcontroller, Motor Servo.*

I. INTRODUCTION

Inspection train is a type of transport vehicle with or without self-drive and is used to inspect infrastructure (railroad) and can carry officers and can load work materials [1].

In its operation, the inspection train also has a working mechanism like a train in general where there is a drive system and braking system. According to the results of his interview with Takdir Santoso as Vice President of PT KAI Operational Area (DAOP) 3 Cirebon explained that the inspection train, more precisely the inspection lorry, has specifications that use diesel as the main power. However, as a technological development on other inspection trains carried out by [1], updating the drive of the inspection train from a diesel motor to an electric drive using a BLDC Motor so that it can be more environmentally friendly with a mechanical braking system from the Disc Brake System braking controlled directly from the cabin.

In the Disc Brake braking system, the inspection train is carried out by involving a braking control system using a microcontroller and utilizing a Servo Motor as an actuator that will press the brake disc [2]. With this control system, it is possible to provide braking levels according to the braking needs with the operator manually from the cabin. However, as technology develops, automatic braking systems have begun to be created by involving sensors as setpoints such as research conducted by [3] using Ultrasonic distance sensors to detect objects and calculate the distance between the vehicle and the object so that braking decisions can be declared according to a pre-set distance setpoint, but the sensor will respond to any object in front of it.

As an implementation of the advancement of artificial intelligence applied to this mode of transportation, the ultrasonic sensor is replaced with a camera that can detect objects and estimate the distance of objects so that the train can brake automatically.

II. RESEARCH METHODOLOGY

This research is a research that is a development (RnD) of research that has been done before, namely by involving artificial intelligence in the inspection train braking system.

A. Hardware Design

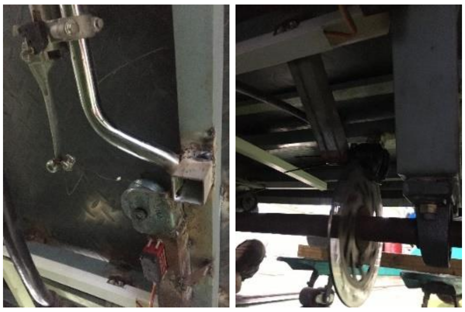

Fig. 1. Hardware mounting design

The design of this tool was implemented specifically on the Madiun State Polytechnic inspection cart wheel assembly, focusing on the strategic placement of the Servo Motor. The Servo Motor is positioned to interface directly with the Braking System handle, a critical component in controlling the flow of hydraulic fluid. When activated, the Servo Motor pulls on the brake handle, initiating fluid flow within the system. This fluid then exerts pressure on the Piston that sits inside the Caliper. As the Piston is pushed outward, it forces the brake pads to clamp

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tightly onto the brake disc, creating the friction necessary to gradually slow and eventually stop the inspection cart. This design precision ensures that the braking force can be applied smoothly and effectively, providing reliable control over the speed of the cart, which is essential for performing safe and accurate inspections. In addition, the system allows for fine-tuned adjustment of the braking intensity, depending on specific operational requirements or obstacles detected ahead.

B. *Flowchart*

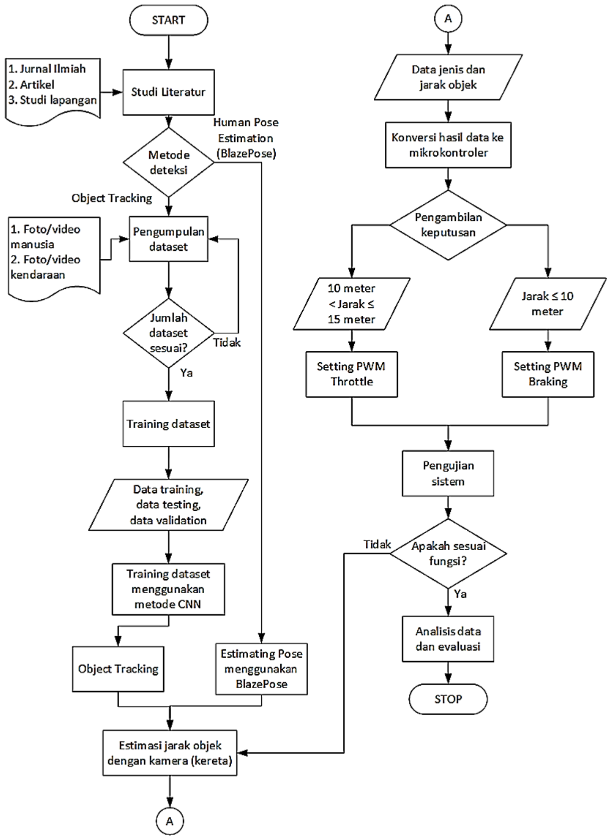

Fig. 2. Flowchart system

The discussion focuses on processing the distance data obtained from the object detection system and distance estimation using Computer Vision so that it becomes a braking command on the Madiun State Polytechnic inspection train.

C. *Braking System*

Braking System a method to provide obstacles / obstacles to a moving object so that the object can be slowed down regularly to reduce its speed or even stop the rate of the object [4]. The function of braking in general is as follows:

1. As a tool to reduce the speed of an object in motion.
2. Equipment or systems that can maintain / maintain a rate of moving objects in various types of trajectories.
3. Maintain safety and comfort for objects or those contained therein.

In a braking system, the main parameters in determining the effectiveness of a braking system include Braking Distance and Braking Time.

D. *Braking Time*

Braking time is the time required for the vehicle to brake so that the vehicle stops completely [5]. The braking time is calculated from the first time the braking is done until the vehicle stops, measured in units of time (s). An example of a braking time graph can be seen in Fig. 2.

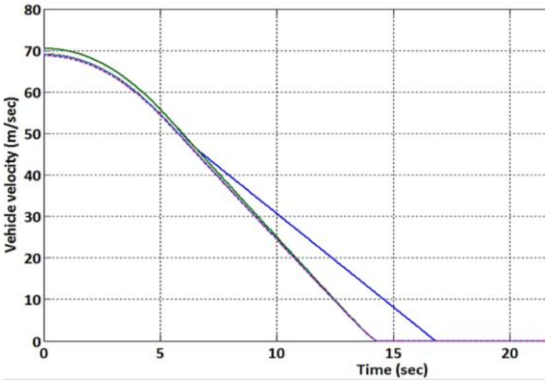

Fig. 3. Braking time graph

This braking time can be determined when the inspection train starts to decelerate marked by a decrease in train speed until the train stops completely. Or if the initial speed and braking distance are known, the braking time can be calculated using the following equation:

$$\text{Braking time} \quad = \quad \frac{\mathbf{2}}{\text{Starting}} \times \text{Braking distance}$$

E. *Braking Distance*

Braking distance is an ability of braking that works so that the vehicle comes to a complete stop [6]. In another definition, braking distance is the relationship between speed reduction to distance or braking distance to the time required so that the vehicle comes to a complete stop or V = 0. An example of a braking distance graph can be seen in Fig. 3.

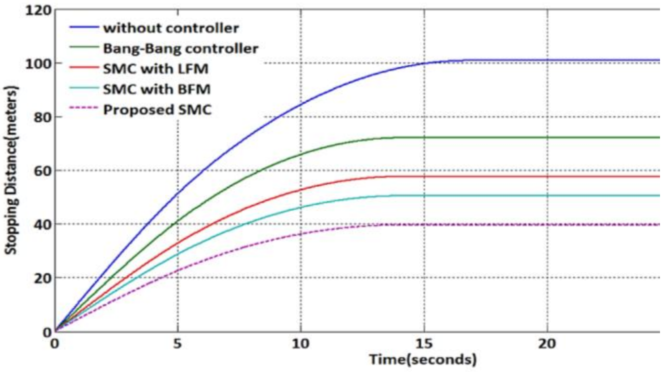

Fig. 4. Braking distance graph

With the known initial speed and braking time needed so that the inspection train stops, the braking distance can be determined using the following equation:

$$\text{Braking distance} \quad = \quad \frac{\mathbf{1}}{\mathbf{2}} \times V0 \times \text{Braking time}$$

F. Mikrokontroler ESP32

The ESP32 microcontroller is a microcontroller module made by the Espressif Systems company by adopting and updating the system from the ESP8266 which is the previous version of the ESP microcontroller equipped with the addition of a WiFi module so that the ESP32 microcontroller can connect internally with a WiFi network [7].

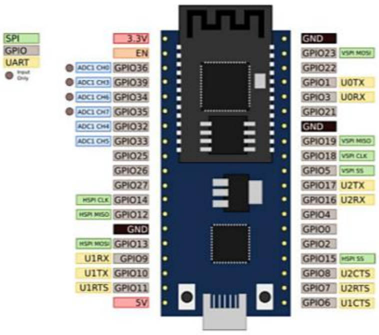

Fig. 5. Microcontroller ESP32

G. Servo Motor

Servo motor is a motor with a closed feedback system where the position of the motor will be informed back to the control circuit contained in the internal system of the servo motor [8]. Servo motors have the ability to rotate in two directions, namely Clockwise (CW) and Counter Clockwise (CCW) with a maximum deflection angle in each direction of up to 90º so that the total deflection angle that works on the servo motor is 180º.

Fig. 6. Servo Motor

H. Disc Brake

Disc Brake is one type of vehicle braking system that works with the principle of converting kinetic energy into thermal energy generated through friction between the disk that rotates together with the wheel with the braking pad pressed with the disc [9].

III. RESULT AND DISCUSSION

Dynamic testing is carried out by testing the system on an actual scale, namely the system is tested on a straight track in the Railway Laboratory Building D Campus 2 Madiun State Polytechnic. Field conditions during the testing process, namely by running the inspection train at maximum speed then there are obstacles in the form of human objects and vehicles with different test scenarios.

A. Braking Results on Human Objects

In dynamic testing on human objects using a test scenario that provides obstacles to the inspection train that will pass with human objects standing on the rail so that the performance of the autonomous braking system that has been made can be seen.

Fig. 7. Image Processing Frame on Human Object

From Fig. 7, the frame results show the inspection cart getting closer to the human object with a detection system that is able to detect the human object and estimate the distance of the object. The data generated in this test is as follows:

TABLE 1. Braking Data on Human Objects

Frame	Accuracy (%)	Performance	Distance (m)	Servo Angle (°)	Status Motor
1	100	0,983956086	8,133333333	30	OFF
2	100	0,985268291	6,771084337	90	OFF
3	100	0,976318885	5,253012048	120	OFF
4	100	0,968455979	4,09375	150	OFF
5	100	0,959457607	0	180	OFF
6	100	0,952524702	0	180	OFF
7	100	0,957795978	0	180	OFF

From the data above, it can be seen that the detection system is able to detect objects starting from a distance of 8.1333 meters which is then converted into an angle from the servo motor so that it can stop the speed of the inspection train. The braking graph obtained is as follows:

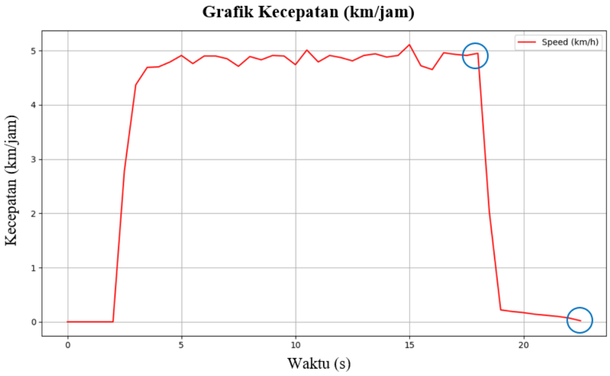

Fig. 8. Velocity Deceleration Graph on Human Object

From the speed deceleration graph shown in Fig. 8, the average speed of the inspection train reached 4.69 km/h while the initial braking speed was 4.95 km/h which then took 5 seconds for the train to stop. Thus, the braking distance can be calculated with the following analysis:

$$\begin{aligned}
V0 &= 4{,}95\ km/jam \approx 1{,}375\ m/s \\
Braking\ Time &= 5\ s \\
Braking\ Distance &= \frac{1}{2} \times V0 \times Braking\ Time \\
&= \frac{1}{2} \times 1{,}375\ m/s \times 5\ s \\
&= \frac{1}{2} \times 6{,}875
\end{aligned}$$

$$= \quad 3{,}4375 \text{ meters}$$

So, the distance needed for the train to stop is 3.4375 meters.

B. *Braking Results on Vehicle Objects*

The test scenario in the dynamic system test or inspection train is in a state of motion then given an obstacle in the form of a motorcycle vehicle placed on the tracks right in front of the train so that testing can be carried out on the autonomous braking system that has been made.

Fig. 9 Image Processing Frame on Vehicle Object

In Fig. 9 shows the inspection train approaching the vehicle object and then the train stops a certain distance from the vehicle object. The braking test data is shown below:

TABLE 2. Braking Data on Vehicle Objects

Frame Count	Class Name	Confidence	Distance (m)	Servo Angle (°)	Motor Status
1	Motorcycle	0.93619	13,3870	0	ON
2	Motorcycle	0.90730	11,2903	0	ON
3	Motorcycle	0.93119	9,42222	0	OFF
4	Motorcycle	0.88013	7,85542	60	OFF
5	Motorcycle	0.86526	4,46875	120	OFF
6	Motorcycle	0.77742	0	180	OFF
7	Motorcycle	0.77344	0	180	OFF

From the data displayed in Table 2, it is known that the object began to be detected at a distance of 13.387 meters and then the train moved closer and then braked until the train stopped near the position of the vehicle object. The deceleration graph due to the braking obtained is shown below:

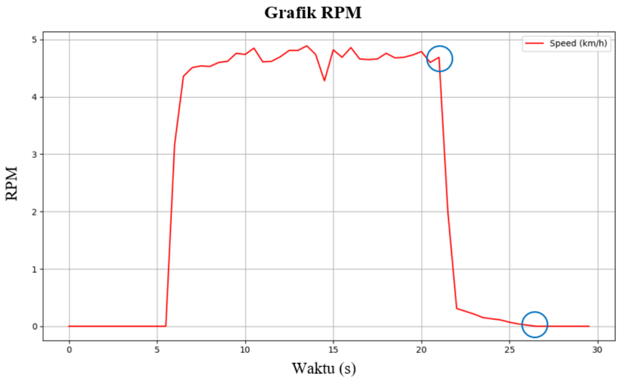

Fig. 10. Velocity Deceleration Graph on Vehicle Object

It is known that the average speed of the train in this test is 4.62 km / h but the initial speed of braking is 4.69 km / h which then the train decelerates to a stop with a time of 6 seconds. With this data known, the braking distance can be known through the following equation approach:

$$\begin{aligned} V0 &= 4{,}69 \text{ km/jam} \approx 1{,}303 \text{ m/s} \\ \text{Braking Time} &= 6 \text{ s} \\ \text{Braking Distance} &= \frac{1}{2} \times V0 \times \text{Braking Time} \\ &= \frac{1}{2} \times 1{,}303 \text{ m/s} \times 6 \text{ detik} \\ &= \frac{1}{2} \times 7{,}818 \\ &= 3{,}909 \text{ meters} \end{aligned}$$

So the distance needed for the train to stop is 3.909 meters on the vehicle object.

IV. CONCLUSION

With the research that has been done, it is found that the braking response based on distance data from image processing can be made by integrating it through serial communication and then forwarded to the inspection train control system, especially the braking system. The results obtained are that on the human object, the braking time is obtained for 5 seconds from the initial speed of 4.95 km / h and produces a braking distance of 3.4375 meters. Meanwhile, the braking results on the motorcycle object produce a braking time of 6 seconds with an initial braking speed of 4.69 km / h and produce a braking distance of 3.909 meters.

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