Image Processing for Mechatronics (MCTR1010)

Project Milestone: MS#4

Team Number: # 6

Image Processing Operations for Lane keeping robot

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This abstract describes a differential lane-keeping vehicle that utilizes image processing techniques to stay within its designated lane. The proposed approach involves converting the image into a binary representation and applying opening and closing operations to enhance lane detection. By extracting horizontal lines from the pixel data, the midpoint difference between the detected lane and the image's center is determined to calculate an error value. A Proportional-Integral-Derivative (PID) controller is employed to adjust the pulse width modulation (PWM) signals sent to the vehicle's motors. This control mechanism aims to maintain the vehicle's position within the lane by continuously adapting the motor output based on the calculated error.

I. INTRODUCTION

This report presents the development of a lane keeping robot using image processing techniques. The objective of this research is to develop an autonomous robot capable of following a predefined path on a road or a track. The proposed system uses a camera mounted on the robot to capture images of the road and processes them in real-time to detect the lane markings. The images are first preprocessed to remove noise and improve contrast. Then, a combination of edge detection and color thresholding techniques is used to extract the lane markings from the image. The extracted lane markings are used to calculate the position and orientation of the robot relative to the lane centerline. Finally, a feedback control system is implemented to adjust the robot's steering angle to keep it on the lane centerline., in section II a brief literature review is discussed.

Figure 1: Lane Keeping Robot

II. Literature Review

Lane keeping is a crucial aspect of autonomous driving, where the vehicle must stay within the boundaries of the lane without driver intervention. Image processing techniques have been widely used for lane detection and lane keeping in autonomous vehicles. In this literature review, we will discuss the state-of-the-art traditional image processing techniques for lane keeping in vehicles.

Traditional image processing techniques for lane detection and lane keeping in autonomous vehicles mainly rely on edge detection, Hough transform, and Kalman filtering. In [1], the authors proposed a lane detection method that utilizes a Canny edge detector, Hough transform, and RANSAC algorithm to achieve accurate and robust lane detection. The proposed method demonstrated its effectiveness in real-world scenarios.

In addition to lane detection, path planning and control are also critical for achieving accurate and robust lane keeping in autonomous vehicles. In [2], the authors proposed a path planning and control method that utilizes a Kalman filter for tracking the lane center and a proportional-integral-derivative (PID) controller for steering the vehicle. The proposed method achieved accurate and smooth lane keeping in real-world scenarios.

Kalman filtering has also been used for lane detection and tracking in autonomous vehicles. In [3], the authors proposed a lane detection and tracking method that utilizes a Kalman filter to track the lane center and predict its future position. The proposed method achieved high accuracy in lane detection and demonstrated its effectiveness in real-world scenarios.

Yan et al. [4] proposed a lane detection method based on morphological operations. Their method uses a two-step process that includes the detection of thelane edge and the centerline.

Lane departure warning systems (LDWS) are also widely used in vehicles to alert the driver when the vehicle deviates from the lane. In [5], the authors proposed an LDWS that utilizes a Canny edge detector, Hough transform, and a straight-line fitting algorithm to detect the lane markings. The proposed LDWS achieved high accuracy in lane detection and demonstrated its effectiveness in real-world scenarios.

Finally, curve fitting and polynomial regression have also been used for lane detection and tracking in autonomous vehicles. In [6], the authors proposed a lane detection and tracking method that utilizes a polynomial regression algorithm to fit the lane markings. The proposed method achieved high accuracy in lane detection and demonstrated its effectiveness in real-world scenarios.

In conclusion, traditional image processing techniques have been widely used for lane detection and lane keeping in autonomous vehicles. The methods discussed in this review, including edge detection, Hough transform, Kalman filtering, curve fitting, and polynomial regression, have demonstrated their effectiveness in achieving accurate and robust lane keeping in real-world scenarios.

In this project a combination of those techniques will be used to detect the lane and control the autonomous vehicle to keep running on that lane.

References

[1] Choi, J., Park, J., & Hong, S. (2018). A robust lane detection algorithm for lane keeping assist systems. IEEE Access, 6, 39813-39820.

[2] Li, H., Du, L., Zhang, W., Zhao, X., & Chen, X. (2018). Lane keeping control algorithm for intelligent vehicles based on road detection. IEEE Access, 6, 13907-13914.

[3] Xu, Y., Wang, X., Zhang, B., & Tang, X. (2019). A novel lane detection algorithm based on dynamic region of interest and Kalman filter. Journal of Advanced Transportation, 2019, 1-10.

[4] Yan, J., Chen, W., & Yu, J. (2019). Lane detection method for intelligent vehicles based on morphological operations. Journal of Advanced Transportation, 2019, 1-11.

[5] Hwang, S., & Lee, S. (2019). Development of a lane departure warning system using Canny edge detection and Hough transform. Sensors, 19(4), 865.

[6] Wang, W., Wei, W., Li, Y., & Li, K. (2019). Lane detection algorithm based on polynomial regression for autonomous vehicles. Proceedings of the 2019 4th International Conference on Machinery, Materials and Computing Technology, 61-65.

III. Components List

The following list includes all the components needed for implementing the control circuit for our Lane Keeping Robot/Vehicle.

Component Required	**Number of Pieces**	**Location**	**Price**
Raspberry pi 4b	1	Free Electronics	4500
L298 H-Bridge	2	RAM Electronics	65
DC - Motors	2	RAM Electronics	25
SG90 Servo Motor	1	RAM Electronics	100
RS Raspberry pi Camera V2 Module Board 8MP Webcam Video	1	Free Electronics	850

IV. Project Diagram

hardware diagram:

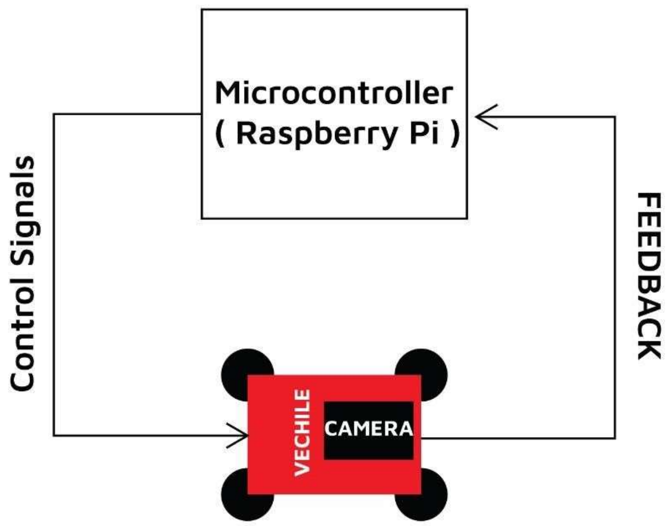


Figure 2: Hardware Diagram

circuit diagram:

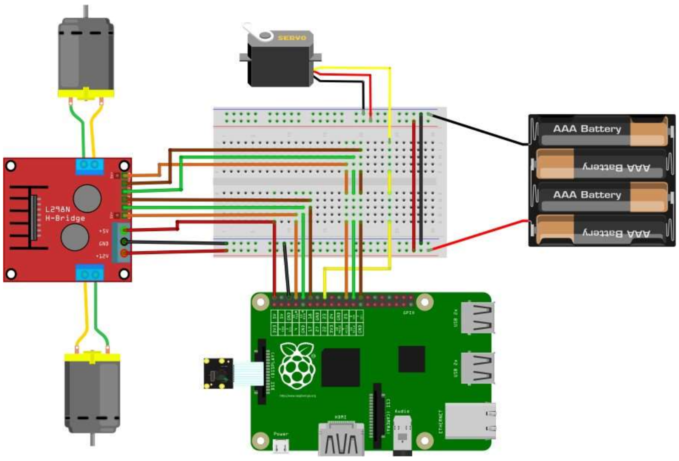


Figure 3: Circuit Diagram

The circuit is built using the following components: Raspberry pi 4b (system controller), RS Raspberry pi Camera V2 (feedback element), servo motor (responsible for car steering), two DC motors controlled via a H-bridge (responsible for car movement forward and backward) and finally batteries to supply the system with power.

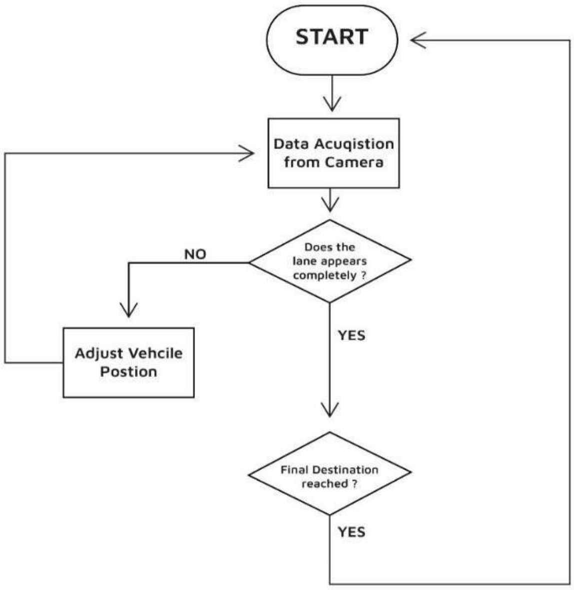


Figure 4: Flow Chart

V. Project Limitations

List of limitations that can face the project in bullet points, illustrating each limitation should be provided.

- **Image quality and environmental factors**: The effectiveness of lane detection heavily relies on the quality of the captured images. Poor lighting conditions, shadows, reflections, or adverse weather conditions like rain or fog can affect the accuracy of lane detection and lead to erroneous results.
- **Limited lane detection accuracy**: The proposed method's accuracy is influenced by the complexity and variability of lane markings on different road types. If the lane markings are faded, unclear, or absent, the algorithm may struggle to accurately detect and track the lanes, leading to potential errors in determining the error value.
- **Dependence on a clear view of the road**: The system relies on having an unobstructed view of the lane markings ahead. If the view is obstructed by obstacles, curves, or other vehicles, the accuracy and reliability of the lane detection may be compromised.
- **Tuning and calibration requirements**: The PID controller's performance depends on appropriate tuning and calibration of its parameters, which can be time-consuming and require expertise. Inadequate tuning may result in poor lane-keeping performance or instability.
- **Restricted field of view of the camera**. The camera's limited perspective may prevent the vehicle from adequately correcting its lane position if it experiences a significant overshoot during steering. In such cases, if the vehicle deviates too far from the desired lane due to a high overshoot

VI. TOPIC 01 (EX. Image Acquisition and Filtration)

The following pictures show an original image before and after preforming some ofthe geometric & intensity level transformations:

*Figure 5: original lane 380*600*

Figure 6: Rotated image

Figure 7: Cropped Image

Figure 8: Greyscale Image

Figure 9: Contrast Enhancement

- This section is for images captured using the raspberry pi camera

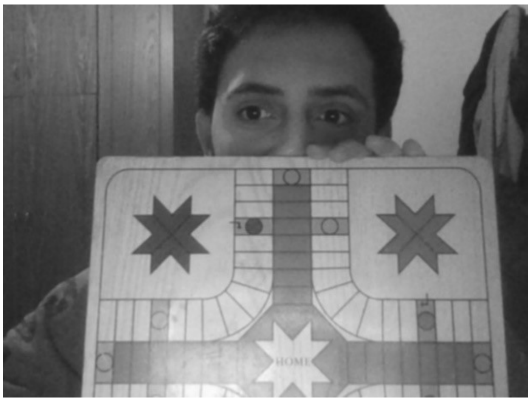


Figure 10: Light Blur Effect

Figure 6: Contrast Enhancement

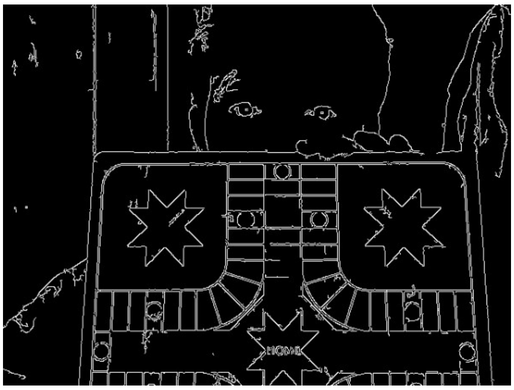


Figure 11: Edge Detection

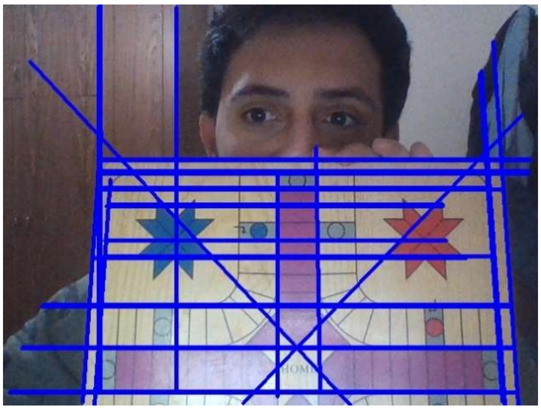
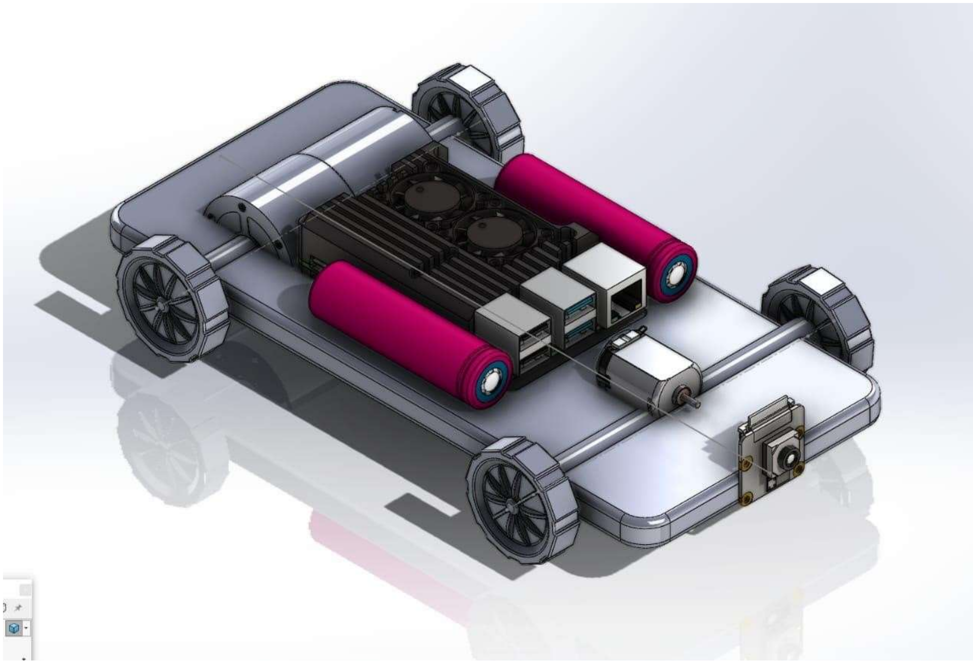


Figure 12: Line Detection

SolidWorks initial Model:

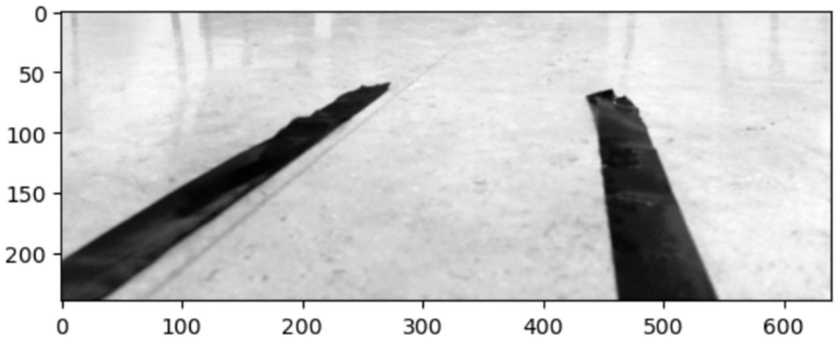


VII. Image Processing operations

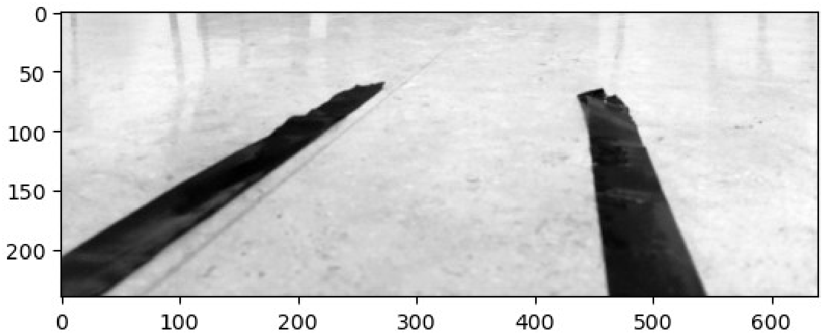
The following pictures represent the image processing operations done by our hardware so we can send the appropriate commands to the motors in order for our Vehicle to maintain its path in the specific lane.

Figure 13: lane sample image

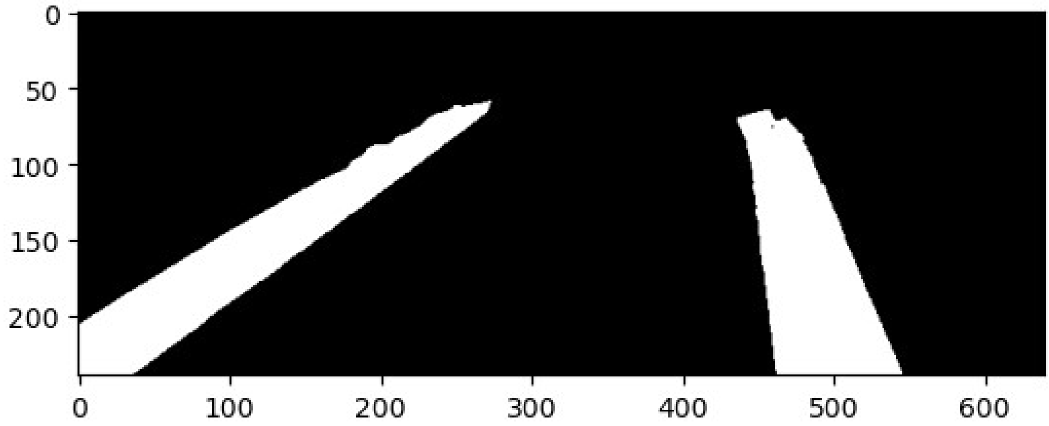
- Greyscale conversion



- Image Normalization

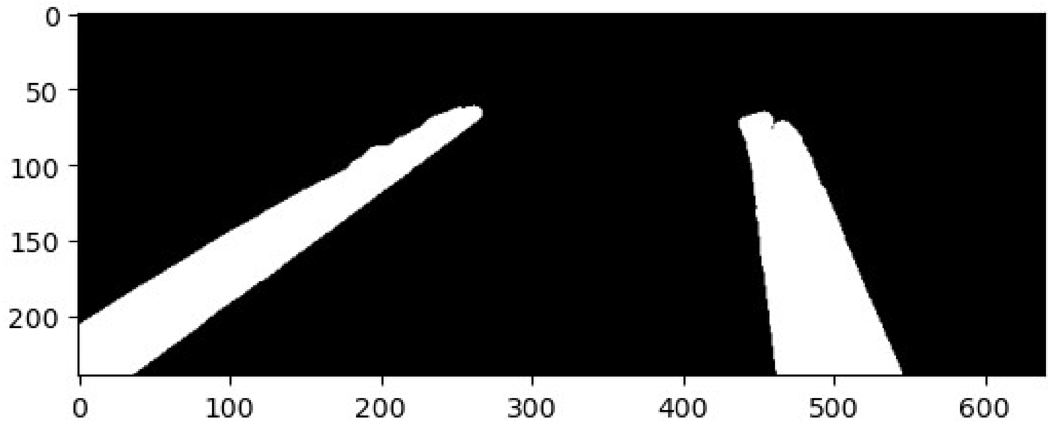


- Thresholding, conversion to a binary image

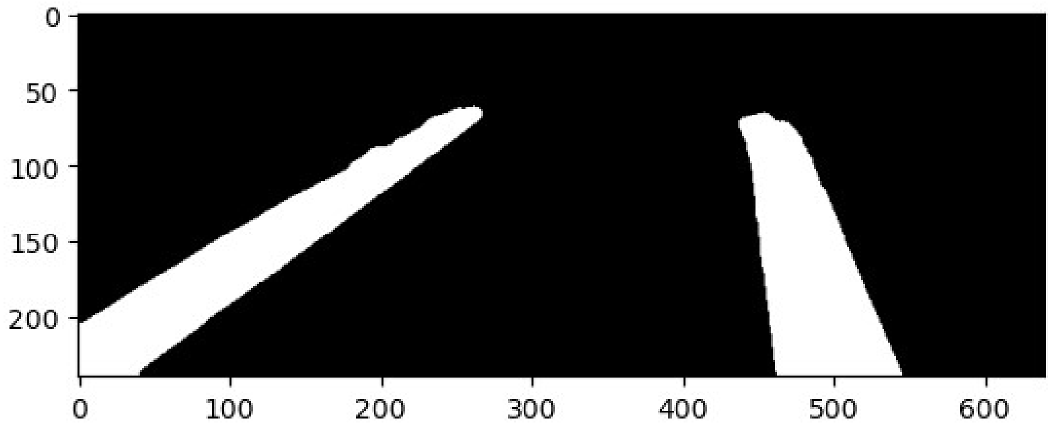


For opening and closing operations note that an 11x11 kernel of the shape of an ellipse was chosen

- Opening



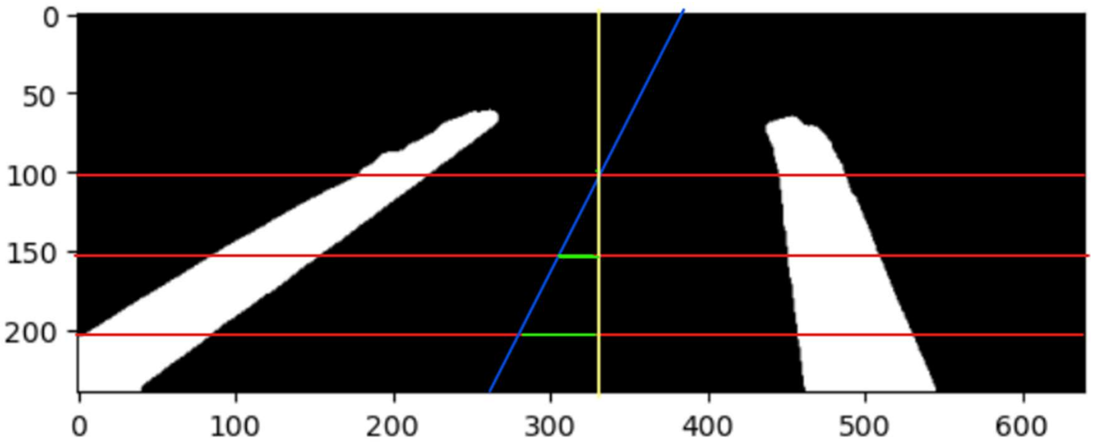
- Closing



➢ Lane Slope Extraction

Multiple horizontal slices are taken from the image, detection of change of pixels indicates the start of the lane marking, each line intersects 4 pixels which are, x1: lane 1 start, x2: lane 1 end, x3: lane 2 start, x4: lane 2 end,

The midpoint of each lane is acquired and we get the midpoint between those two to get the center pixel of the lane, this center pixel is then compared with the center pixel of the image giving us an error between both pixels

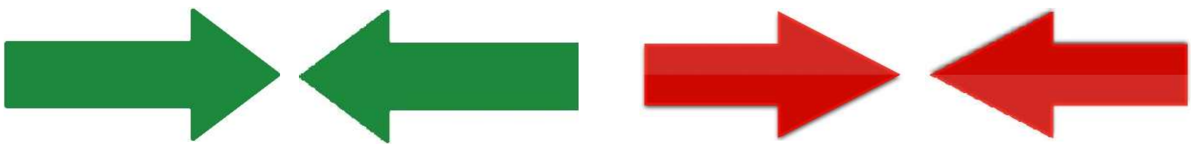


The red lines are the samples taken from the image, the blue line is the lane slope, the yellow line is the center column of the image, the green line indicates the difference between both values. Each line has a weight to contribute to the computation of the weighted average of the error. The PID is fed that weighted error and control the motors to handle keeping the vehicle within the lanes

VIII. EXPERIMENTAL RESULTS

Testing codes for motor actuation using feedback from the camera:

For the steering test two images used as green and red arrows, when the camera detects the average red channel values are greater than the green channel the vehicle will be moving forward and vice versa, the image is then transformed into a binary image, the steering will be according to detecting the arrow heads, the image is divided into two equal halves, the half with more non zero bits will indicate the direction of the arrow head thus signaling the servo responsible for the steering to either rotate left or right.



PWM signal is sent to the motors according to the brightness of the image, the brightness is ranging from 0 to 255, the range is divided into 5 segments, [0,50] the motor will rotate backward with highspeed, [50,100] the speed will decrease, [100,150] the motor will stop, [150,200] the motor will move forward with low speed, [200,255] the motor speed will ramp up in forward direction

IX. CONCLUSINS AND FUTURE RECOMMENDATIONS

In conclusion, the differential lane-keeping vehicle utilizing image processing and a PID controller presents a promising approach for maintaining lane position based on visual input. However, several limitations should be considered to enhance its effectiveness and robustness in real-world scenarios.

The project's limitations, such as sensitivity to environmental factors, limited lane detection accuracy, susceptibility to noise and occlusions, and challenges in complex traffic scenarios, highlight areas for improvement. Addressing these limitations could involve refining the image processing algorithms to handle diverse road conditions, enhancing the robustness of lane detection in the presence of noise and occlusions, and incorporating advanced techniques to handle complex traffic scenarios.

Improving the field of view of the camera system would be beneficial, allowing the vehicle to capture a wider perspective and facilitate prompt corrections in cases of high steering overshoot. This could involve exploring alternative camera placement or utilizing multiple cameras for a broader coverage area.

Additionally, future research could focus on integrating other sensor modalities, such as radar or lidar, to complement the camera-based lane detection system. Sensor fusion techniques can enhance the vehicle's perception capabilities, providing redundancy and improving reliability in lane-keeping tasks.

Furthermore, continuous development and fine-tuning of the PID controller are crucial to optimize its performance. Parameter tuning methodologies and adaptive control techniques should be explored to ensure stable and accurate control responses in varying driving conditions.

Finally, conducting extensive testing and validation in diverse real-world scenarios, including different road types, lighting conditions, and traffic densities, is essential to validate the system's performance and reliability. Collecting a comprehensive dataset and leveraging machine learning approaches can help improve the system's lane detection accuracy and robustness