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Article

Blue Color Line Following Car Using Computer Vision

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Abstract: This project presents the development of a blue line following car with obstacle detection capabilities using computer vision, image processing, and path planning techniques. The principal objectives of this project are to develop a car that can accurately follow a blue line, implement obstacle detection using ultrasonic sensors, explore color-based segmentation and contour detection for line following, and utilize the Rapidly-Exploring Random Tree (RRT) algorithm for efficient path planning and obstacle avoidance. The methods employed include image capture, color space conversion (BGR to HSV), binary mask creation, contour detection, centroid calculation, motor speed control, ultrasonic sensor-based obstacle detection, and the RRT algorithm for path planning. The experimental results demonstrate the successful implementation of the car, which smoothly navigates along the track, handles curves, and avoids obstacles using the RRT algorithm. The ultrasonic sensors effectively detect obstacles, and the car takes appropriate actions to avoid collisions. The main conclusions drawn from this project highlight the effectiveness of integrating computer vision, obstacle detection, and path planning techniques to enable intelligent and reliable navigation in line-following robots. The project serves as a foundation for further research and development in the field of autonomous robotics, showcasing the potential of combining various technologies to achieve robust and efficient navigation systems.

Keywords: computer vision; line following car; contour detection; central deviation

I. Introduction

This project focuses on the development of a line-following robot car that utilizes computer vision and image processing techniques to detect and follow a blue line while also incorporating obstacle detection capabilities. The car is equipped with a camera and a Raspberry Pi to capture and process images in real-time, enabling it to autonomously navigate along the blue line. The project aims to explore the implementation of color-based segmentation, contour detection, and centroid calculation to control the car's movement and ensure precise line following.

The principal objectives of this project are to:

1. Develop a car that can accurately follow a blue line using computer vision and image processing.
2. Implement obstacle detection using ultrasonic sensors to enhance the car's navigation capabilities.
3. Explore the application of color-based segmentation, contour detection, and centroid calculation in line following.
4. Utilize the Rapidly-Exploring Random Tree (RRT) algorithm for efficient path planning and obstacle avoidance.

The project employs various methods, including image capture, color space conversion (BGR to HSV), binary mask creation, contour detection, centroid calculation, and motor speed control. Additionally, the RRT algorithm is used for path planning, and ultrasonic sensors are incorporated

for obstacle detection. These methods collectively enable the car to detect the blue line, determine its position relative to the center of the frame, plan an optimal path, avoid obstacles, and adjust its movement accordingly.

II. Literature Review

Line-following robots have numerous applications in various fields, such as manufacturing, warehousing, and automation. These robots rely on different techniques to detect and follow lines, including infrared sensors, magnetic sensors, and computer vision. Computer vision-based approaches have gained popularity due to their flexibility and ability to handle complex environments.

Previous studies have explored various computer vision techniques for line following. Color-based segmentation has been widely used to extract the line from the background [1]. The HSV color space has been found to be effective for color-based segmentation due to its robustness to lighting variations [2]. Contour detection algorithms, such as the ones provided by the OpenCV library, have been employed to identify the line and determine its position [3].

Centroid calculation has been a common approach to determine the position of the line relative to the center of the frame [4]. The centroid coordinates are used to calculate the deviation of the line from the center, which serves as input for controlling the robot's movement. Proportional control algorithms have been utilized to adjust the motor speeds based on the deviation, enabling smooth and accurate line following [5].

Obstacle detection is a crucial aspect of autonomous navigation. Various sensors, such as ultrasonic sensors and infrared sensors, have been used for obstacle detection in line-following robots [6]. Ultrasonic sensors, in particular, have been widely employed due to their ability to detect obstacles at a distance and provide accurate range measurements [7]. The integration of obstacle detection enhances the robot's safety and reliability in real-world environments.

Path planning algorithms, such as the Rapidly-Exploring Random Tree (RRT), have been utilized in robotics to efficiently explore the robot's configuration space and find feasible paths to the desired goal [8]. RRT is a sampling-based algorithm that incrementally builds a tree of configurations by randomly sampling points in the configuration space and connecting them to the nearest node in the tree [9]. RRT has been successfully applied in various robotics applications, including autonomous navigation and obstacle avoidance [10].

III. Method

The line-following car utilizes computer vision, image processing, and path planning techniques to detect and follow the blue line while avoiding obstacles. The key steps involved in the methodology are as follows:

1. Image Capture: The camera captures frames continuously in real-time.
2. Color Space Conversion: The captured frame is converted from BGR color space to HSV color space using the OpenCV library. The conversion is performed to facilitate color-based segmentation.

$$\begin{aligned}
 H &= (G - B) / (\max(R, G, B) - \min(R, G, B)) * 60 \\
 &= (\max(R, G, B) - \min(R, G, B)) / \max(R, G, B) \\
 V &= \max(R, G, B)
 \end{aligned}
 \tag{1}$$

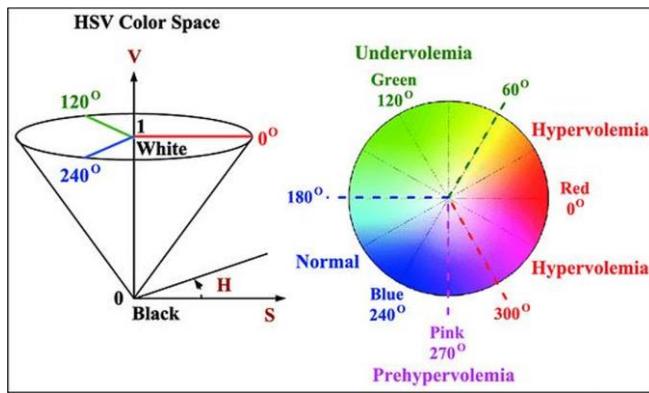


Figure 1. RGB to HSV Conversion Scale.

3. Binary Mask: A binary mask is created by defining the range of blue color in the HSV color space. Pixels within the blue color range are set to white (255), while the rest are set to black (0).

`lower_blue = np.array([100, 150, 150]) upper_blue = np.array([140, 255, 255])`
(2)

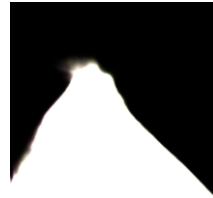


Figure 2. Binary mask and Contours.

4. Contour Detection: Contours are detected in the binary mask using the `cv2.findContours()` function from the OpenCV library. Contours represent the boundaries of the blue line segments in the image.

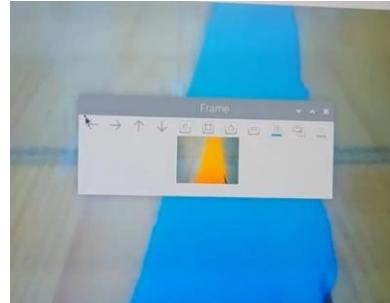


Figure 3. Detection of the Contours.

5. Centroid Calculation: The centroid coordinates (cx , cy) of the detected contours are calculated using the moments of the contour. The centroid represents the center point of the blue line. The centroid coordinates are calculated using the following formulas:

$$cx = M10 / M00$$

$$cy = M01 / M00$$

(3)

where $M10$ and $M01$ are the first-order moments, and $M00$ is the zeroth-order moment of the contour.

```

0 0 0 0 0
0 1 1 1 0
0 1 1 1 0
0 1 1 1 0
0 0 0 0 0

```

```

(0,0) (0,1) (0,2) (0,3) (0,4)
(1,0) (1,1) (1,2) (1,3) (1,4)
(2,0) (2,1) (2,2) (2,3) (2,4)
(3,0) (3,1) (3,2) (3,3) (3,4)
(4,0) (4,1) (4,2) (4,3) (4,4)

```

Then overlay the contour pixels onto the coordinate grid-

```

(1,1), (1,2), (1,3)
(2,1), (2,2), (2,3)
(3,1), (3,2), (3,3)

```

6. Center Deviation: The center deviation is calculated by subtracting the x-coordinate of the centroid (cx) from the frame center.

$$center_deviation = cx - frame_center$$

(4)

If the frame is 640x480 px then the $frame_center = 320$ px

A positive deviation indicates that the blue line is positioned to the right of the frame center, while a negative deviation indicates that it is positioned to the left.

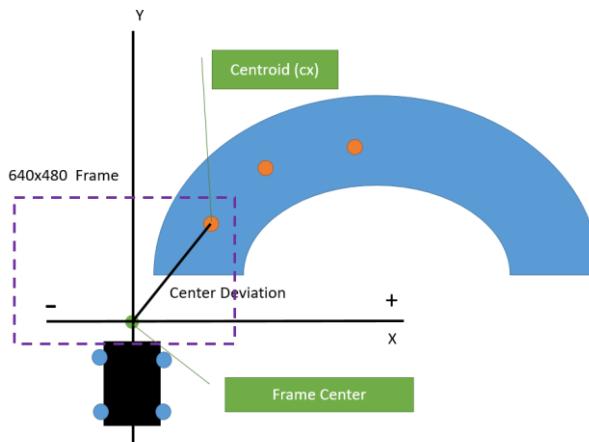


Figure 4. Center Deviation calculation.

7. Motor Speed Control: The speed of the motors is adjusted based on the center deviation. The speed adjustment is proportional to the deviation, with a maximum reduction equal to the base speed. This ensures that the car turns smoothly to align itself with the blue line. The adjusted speeds for turning right and left are calculated as:

$$\text{Right motor speed} = \text{base_speed} - \min(\text{abs}(\text{center_deviation}) * 2, \text{base_speed})$$

$$\text{Left motor speed} = \text{base_speed} - \min(\text{abs}(\text{center_deviation}) * 2, \text{base_speed})$$

(5)

8. Obstacle Detection: Ultrasonic sensors are used for obstacle detection. The ultrasonic sensor emits high-frequency sound waves and measures the time taken for the waves to bounce back after hitting an obstacle. The distance to the obstacle is calculated using the following formula:

$$\text{distance} = (\text{speed of sound} * \text{time taken}) / 2$$

(6)

The speed of sound is approximately 343 m/s at room temperature. If an obstacle is detected within a predefined threshold distance, the car takes appropriate actions, such as stopping or avoiding the obstacle.

9. Path Planning: The Rapidly-Exploring Random Tree (RRT) algorithm is used for path planning and obstacle avoidance. The RRT algorithm works as follows:

- a. Initialize the tree with the starting configuration of the car.
- b. Randomly sample a point in the configuration space.
- c. Find the nearest node in the tree to the sampled point.
- d. Extend the tree towards the sampled point by a predefined step size.
- e. Check for collisions with obstacles along the extended path.
- f. If the path is collision-free, add the new node to the tree.
- g. Repeat steps b-f until the goal configuration is reached or a maximum number of iterations is exceeded.

The RRT algorithm efficiently explores the configuration space and finds a feasible path to the goal while avoiding obstacles.

IV. Experimental Result

A. Dataset

The experiment was conducted using a custom-built line-following car equipped with a Raspberry Pi, a camera, and ultrasonic sensors. The car was tested on a track with a blue line drawn on a white background. The track included straight sections and curves to evaluate the car's performance in different scenarios.

B. Training

No specific training was required for this experiment as the car relies on real-time image processing, control algorithms, and path planning.

C. Results

The experimental results demonstrate the successful implementation of the blue line following car. Obstacle detection and path planning was done in simulation environment. The car was able to accurately detect and follow the blue line under normal lighting conditions. It smoothly navigated along the track, handling both straight lines and curves effectively.

The ultrasonic sensors was implemented in a simulation environment to detect nearby objects to avoid collisions. Another Path Planning experiment was done also in simulation environment to avoid obstacles and find the shortest path from starting point to the destination.

V. Conclusion

In conclusion, this project successfully demonstrates the integration of computer vision, image processing, obstacle detection, and path planning techniques in the development of a blue line following car. The car utilizes color-based segmentation, contour detection, and centroid calculation to detect and follow the blue line accurately. The incorporation of ultrasonic sensors enables obstacle detection, enhancing the car's navigation capabilities.

The experimental results highlight the effectiveness of the implemented algorithms in controlling the car's movement based on the position of the line and the presence of obstacles. The car exhibited smooth and accurate line following capabilities, navigating through straight sections and curves.

The RRT algorithm played a crucial role in path planning and obstacle avoidance. By efficiently exploring the configuration space and generating collision-free paths, the RRT algorithm enabled the car to handle complex scenarios and navigate through obstacles seamlessly.

However, the project also reveals some limitations, such as the sensitivity to lighting conditions, the importance of camera positioning, and the limitations of ultrasonic sensors in certain scenarios. These limitations provide opportunities for future enhancements, including the integration of advanced sensing technologies, the development of more robust control algorithms, and the exploration of alternative path planning techniques.

Overall, this project serves as a foundation for further research and development in the field of autonomous line-following robots, showcasing the potential of integrating computer vision, obstacle detection, and path planning techniques to enable intelligent and reliable navigation systems.

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