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Computer Vision Based on Autonomous Robotic Vehicle

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Abstract: The development of vehicles that operate without direct human control has significantly transformed the automotive industry, paving the way for safer and more efficient transportation systems. With the rising number of road accidents and the lack of a structured approach to road safety, there is an urgent need for intelligent solutions. In this project, we present a cost-effective autonomous driving prototype built using the Raspberry Pi platform. The system includes a Pi Camera Module for real-time image and video capture, enabling effective lane detection through image processing algorithms. These techniques help the vehicle identify road lanes and maintain proper positioning while navigating. By integrating lightweight deep learning models with affordable hardware, our solution is suitable for applications in research, academic learning, and early-stage prototyping. The system highlights the practical potential of autonomous vehicles to independently and intelligently operate in real-world driving environments.
Keywords: Autonomous vehicle, R-Pi, GPS, Decision making, machine learning.

I. INTRODUCTION

The rise of Artificial Intelligence (AI), embedded systems, and low-cost sensors has made it possible to build smart vehicles that can drive themselves. These autonomous vehicles use cameras and sensors to see their surroundings, make decisions, and move without any human help. This improves road safety and reduces human driving errors. In this project, we built a low-cost self-driving robot using a Raspberry Pi as the brain to control motors and sensors. The robot drives on a fixed track, using real-time images and sensor data. A Pi Camera captures the road ahead, ultrasonic sensors detect obstacles, and a GPS module with a compass helps with navigation and direction.

The robot uses image processing methods like Canny edge detection and Hough line transformation to find lane markings. For detecting traffic lights, a small machine learning model is trained on Google Colab and then run on the Raspberry Pi. Navigation is improved by using formulas like the Haversine and Forward Azimuth, which help calculate distance and direction between locations.

This compact robotic vehicle uses a camera for vision, sensors for obstacle detection, and GPS for location tracking to drive on its own. By combining these technologies, it can navigate in real time without human help. This makes it an excellent tool for education, research, and testing new self-driving systems.

CoreFunctionalModules

1) *Self-Driving System:*
- Therobot canmoveforward,backward,turn left or right and stop based on road conditions.
- It detects lanes and objects using a camera and adjusts direction automatically.
- Lanedetection ensures therobot stays in the correct path.

2) *AutonomousNavigation:*
- Therobotseestheroadusingthe canny edge algorithm.
- This allows the robotto make decisions on its own and move safely.

3) *Real-TimeTelecommunicationSystem*
- The vehicle includes a real-time communication system using tools like Blynk, Telegram, or Wi-Fi modules, allowing remote monitoring and control.
- This system can send alerts (like obstacle detection or location updates) and receive commands from users.
- It enables the vehicletobe part ofconnected smart transport networks, supporting IoT- based control and feedback.

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II. LITERATURESURVEY

Recent advancements in artificial neural networks (ANNs) have significantly influenced the development of autonomous systems. The NobelPrize in Physics 2024 recognized foundational work in ANNs, emphasizing their impact on real-time perception and control systems. These models, capable of learning patterns from complex visualdata, have been instrumental in enabling low-power platforms suchas theRaspberryPitoperform critical

Tasks like lane detection and object recognition in autonomous vehicles [1].

In the realm of embedded AI, Falaschetti (2023) demonstrated the deployment of an optimized Tiny- YOLOv3 model on Raspberry Pi 4 for vehicle and pedestrian detection.Their system balanced detection accuracy and speed, establishing the feasibility of real-time vision-based navigation using compact,low-cost hardware [2].

Further, a study published in MDPI Electronics (2023) evaluated an improved YOLOv7-Tiny architecture on embedded processors, achievingframe rates exceeding 100 FPS with mean average precision (mAP) values between 60–70%. This work supportsthegrowingtrendofdeployingmoderndeep learning models in constrained environments forhigh-performance object detection [3].

Srivastava et al. (2021) proposed an indoor autonomous navigation robot using Raspberry Pi, Arduino Uno, and ultrasonic sensors. Their system used machine learning for reactive decision-making, enablingreal-time obstacle voidanceandnavigation, aligning closely with our vehicle's architecture [4].

In a similar approach, Raju (2021) explored reinforcement learning methods, including Q- learning and Deep Q-learning, on Raspberry Pi platforms.Their model enabledautonomousrobotsto learn navigation strategies from environmental feedback, further proving that AI-based control systems can be effectively executed on lightweight processors[5].

III. METHODOLOGY

The proposed autonomous robotic vehicle uses a combination of computer vision and probabilistic sensor fusion to enable accurate, real-timenavigation and obstacle avoidance. The system operates in two main stages:

A. ObstacleDetectionUsingProbabilisticRange Fusion

To detect nearby objects, the robot uses both ultrasonic and IR sensors. These sensors are fused using a Bayesian inference model to improve reliability under uncertain conditions. The posterior probability of an obstacle being at distance DDD, given current sensor readings ZZZ, is calculatedusing Bayes' Theorem:

$$P(D|Z) = \frac{P(Z|D) \cdot P(D)}{\sum_{d'} P(Z|d') \cdot P(d')}$$

Where:

- P(Z∣D)P(Z|D)P(Z∣D): Likelihood of sensor data ZZZ given distance DDD
- P(D)P(D)P(D):Priorbeliefaboutdistance
- ∑d′P(Z∣d′)⋅P(d′)\sum_{d'} P(Z|d') \cdot P(d')∑d′P(Z∣d′)⋅P(d′):Normalizationoverall possible distances

IfP(D∣Z)P(D|Z)P(D∣Z)indicatesanobstacleiswithin a critical threshold (e.g., <30 cm), the system halts motion and re-routes the vehicle.

B. KinematicSteeringandMotionControl

The robot's movement is modeled using a non-linear bicycle model to simulate differential drivedynamics. The position and orientation update equations are:

$$x_{t+1} = x_t + v \cdot \cos(\theta) \cdot \Delta t$$
$$y_{t+1} = y_t + v \cdot \sin(\theta) \cdot \Delta t$$
$$\theta_{t+1} = \theta_t + \frac{v}{L} \cdot \tan(\delta) \cdot \Delta t$$

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Where:

- (xt,yt)(x_t,y_t)(xt,yt):Currentposition
- θt\theta_tθt:Currentheadingangle
- vvv:Vehiclevelocity
- LLL:Distancebetweenwheels(wheelbase)
- δ\deltaδ:Steeringangle

These equations enable real-time path updates and smooth turns. Steering commands are calculated on the Raspberry Pi and sent to the Arduino Uno, which drives the DC motors via the L298N motor driver.

IV. PROPOSED MODEL

The proposed model is a low-cost, vision-guided autonomous robotic vehicle that integrates computer vision, sensor fusion, and real-time control using embedded systems. The system is structured to simulate intelligentpathfollowing an obstacle avoidanceindynamicenvironmentsusingopen- source tools and lightweight hardware components.

A. System Architecture

1) Thevehicleis designed withamodular structure that includes three main parts:
2) Vision Module: Powered by a Raspberry Pi4 and Pi Camera, responsible for real-time video capture and image processing using OpenCV.
3) Control Module: An R-PI receives motion commands from theRaspberryPi anddrives the motors via an L298N motor driver.
4) Sensor Module**:** Includes an ultrasonicsensor for front obstacle detection and IR sensors (optional) for close-range edge detection.

B. Block Diagram

The system block diagram (Fig. 1) shows aRaspberry Pi 4 as the main controller, processingreal-time video from a Pi Camera for lane detection using OpenCV. Based on the detected lanes, motion commands are sent to an R-pi Uno, which controlsthe DC motors via an L298N driver. An ultrasonic sensor connected to the R-pi ensures obstacle detection, temporarily halting motion if an object is detected.

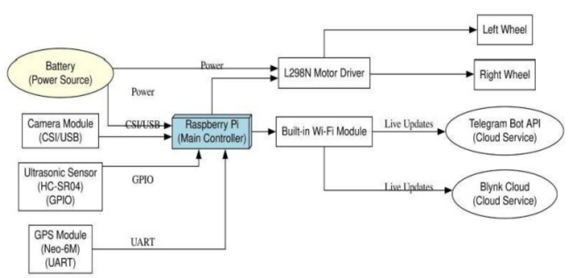

Fig.1**.** Block Diagram of Computer Based Autonomous Vehicle using Raspberry Pi

C. HardwareDescription

1) Raspberry Pi 4: Acts as the main processor, capable of running real-time computervision tasks using Python and OpenCV.
2) Pi Camera: Captures live video of the track for lane detection.
3) L298N Motor Driver: Controls motor speed and direction using PWM signals from theR-pi.
4) DC Gear Motors: Provide movement and steering with suitable torque for smooth navigation**.**
5) Ultrasonic Sensor (HC-SR04): Detects obstacles ahead and sends distance data to the R-pi..
6) Power Supply: Supplies 5V/12V regulated power to all components.

D. SoftwareTools

1) OpenCV with Python: Used for video processing tasks like grayscale conversion, edge detection, and lane tracking.
2) Canny Edge Detection: Extracts clear lane boundaries using gradient and threshold techniques.
3) Image Processing Pipeline: Begins with frame capture → preprocessing → edge detection → lane fitting → steering control, which is transmitted to the R-PI.

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V. IMPLEMENTATION

The autonomous robotic vehicle was developed throughsystematichardwareintegrationandsoftware design to enable real-time lane tracking, obstacle avoidance, and autonomous driving.

A. Hardware Setup

The Raspberry Pi 4 (4GB) serves as the primary controller and is mounted on the vehicle chassis alongside the Pi Camera, oriented to face the road.An Arduino Uno handles actuator control, connected to an ultrasonic sensor, L298N motor driver, and two DC gear motors. The Pi and Arduino communicate via USB or GPIO pins. Power is provided through a 5V power bank for the Raspberry Pi and a 12Vbattery pack for motor components.

IntegratedComponents:

- RaspberryPi4 (4GB)
- PiCameraModule
- ArduinoUno
- L298NMotor Driver
- 2×DCGearMotors
- HC-SR04UltrasonicSensor
- 5V&12VPowerSupplies
- ChassisandWheels

B. Software Setup

Raspbian OS and Python 3 are installed on the Raspberry Pi. OpenCV and NumPy libraries handle image processing. The R-PI is programmed using the R-PIIDE to interpret distance measurements and manage motor control accordingly.

The Pi Camera continuously captures video frames. Each frame goes through:

- Grayscaleconversion
- Gaussianblur(noisereduction)
- Cannyedgedetection
- Region ofInterest(ROI)masking
- HoughLineTransform(forlanedetection)
- Steeringdirectioncalculation

Based on the calculated direction, the Raspberry Pi receives serial commands like "left,""right," or "forward" to guide movement

C. Motor&ObstacleControl

The Arduino interprets serial commands and controls the L298N motor driver to steer the vehicle. Simultaneously, it reads fromtheultrasonicsensor. If an obstacle is detected within 20 cm, the Arduino overrides movement commands and stops the vehicle to avoid collisions.

D. Testing&Evaluation

Thesystemwastested on a custom trackwithdefined lanes and obstacles under different lighting conditions. The robot successfully followed curves and straight paths while avoiding static obstacles.

TestMetrics:

- Lanewidth:~5 cm
- Obstaclerange:20cm
- Framerate:~15 FPS
- Reactiondelay:<300ms

E. Functional Overview

The system operates in a closed-loop manner. The Pi Camera continuously streams video frames, whichare analyzed using OpenCV for lane detection. After performing edge detection and applying the Hough Transform,acentralpath isidentified.TheRaspberry Pithensendsmovementcommandstothe R-PI,which controls the motors accordingly.

Simultaneously, the ultrasonic sensor monitors the surroundings for obstacles. If an object is detected within a critical range, the R-PI immediately stopsthe motors to ensure safety. The modular design also allows for future enhancements such as GPS integration, AI-driven path planning, and trafficsignalrecognition.

VI. RESULTSANDDISCUSSION

This project successfullydemonstrates a prototype of an autonomous robotic vehicle using a Raspberry Pi- based vision system for real-time lane detection and obstacleavoidance.Thesystemutilizescamera-based visual input, processed through computer vision techniques

The performance was tested in a controlled environment with marked lanes under variouslighting conditions. The results show that the system accurately identifies lane boundaries and navigates through the path with reasonable stability in well-lit conditions.

A. Stepwise Process and Observations

Step 1: Image Acquisition: The Pi Camera module mounted on the vehicle continuously captures real- time video, which is converted into a sequence of frames. An example of a captured image used forlanedetectionisshowninFig.3.

Fig3: Raspberrypi cameracapturedimage

Step 2: Grayscale Conversion: The RGB image is converted to grayscale to simplify the processing and reduce computational load. This step helps in enhancing the edge features, as shown in Fig. 4.

Fig4: RGBGrayscaleconvertedimage

Step 3: Image Smoothing and Edge Detection: To reduce noise, Gaussian blurring is applied, followed by the Canny Edge Detection algorithm. This effectively highlights lane boundaries and other significant features in the scene, as shown in Fig. 5.

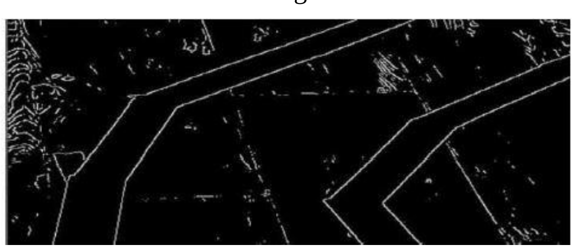

Fig 5: Edge detection

Step 4: Line Detection and Direction Decision: Using the Hough Transform, the detected edges are translated into straight lines representing lane markers. Based on the slope and position of these lines, the vehicle determines itsnext action—whether to steer left, right, or continue straight (Fig. 7).

Fig6: LineDetection

Step 5: Motor Control Logic**:** After computing the required path, threshold-based logic determines the angle of deviation, and corresponding control signals are sent tothe ArduinoUnovia serial communication to actuate the motors.

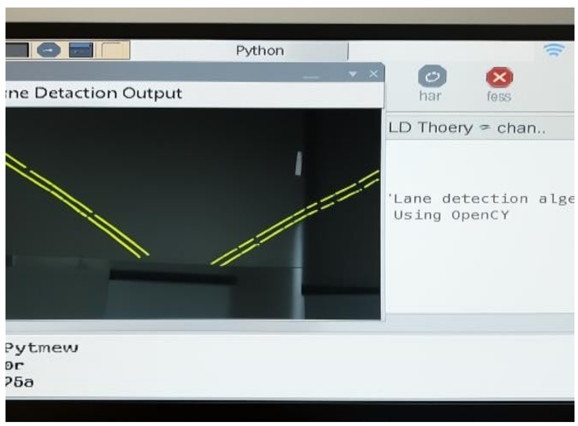

Fig7: Decidingwhethertoturnleftorstraight

Step 6: Obstacle Avoidance and Final Navigation: Ultrasonic sensors constantly monitor the path for obstacles. If any obstruction is detected, the system halts orreroutes the vehicle toprevent collisions. The complete vehicle navigation, including turning and stopping, is demonstrated in Fig. 8.

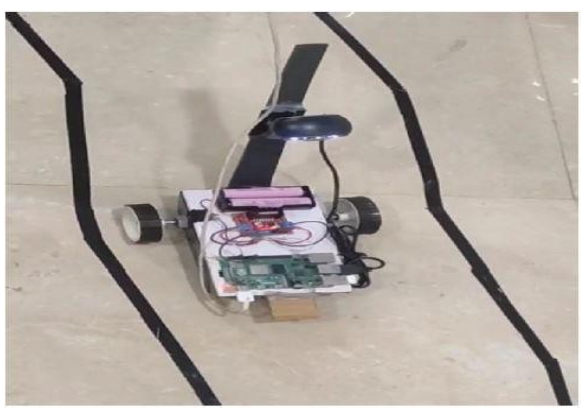

Fig8:Modelmovingwithpathdestination

B. Performance and Limitations

The system exhibits high accuracy in lane detection under good lighting and consistent road patterns. However, performance degrades in low-light or poorly marked lanes.

Due to the limited processing power of the Raspberry Pi, real-time frameprocessing is constrained to relatively low framerates. Additionally, weather conditions such as glare or rain can introduce noise, which affects edge detection accuracy.

C. Discussion

The project highlights the feasibility of using low- cost hardware and open-source tools forimplementing basic autonomous navigation. The modular approach allows further expansion withGPS, machine learning-based path prediction, and cloud integration. Despite hardware limitations, the integration ofimage processing, control systems and obstacle detection establishes a solid foundation for real-world self-driving car applications ata prototype level.

VII.FUTURESCOPE

Thelanedetection autonomousroboticvehiclecan be enhanced by integrating deep learning models like CNNs for better accuracy in complex environments. Adding GPS and IMU sensors can improve navigation, while features like signboard and pedestrian detection can make the system more intelligent. With advanced hardware like NVIDIA Jetson, real-time processing will be faster. This project can evolve into a scalable and smart solution for future autonomous driving and intelligent transportation systems.

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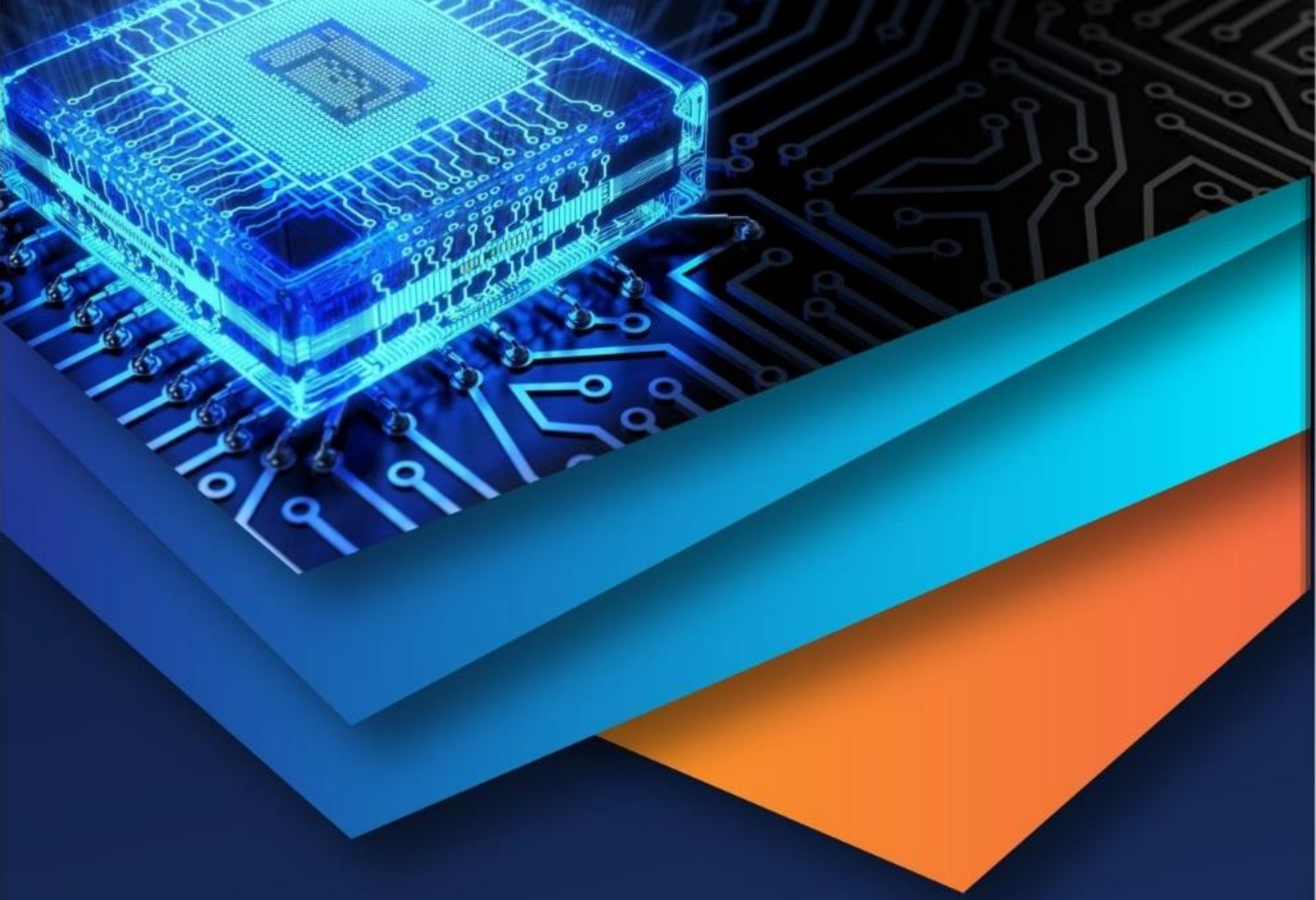

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