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VEHICLE NUMBER PLATE RECOGNITION USING RASPBERRY PI

[1]Bharati

[1]Senior Grade Lecturer

[1]Department of Electronics & Communication Engineering,

[1]Government Polytechnic Raichur, Raichur, India

Abstract:

Automatic Vehicle Number Plate Recognition (ANPR) systems are widely used in intelligent transportation, traffic surveillance, toll automation, and security monitoring. This research presents the design and implementation of a Raspberry Pi–based Vehicle Number Plate Recognition Detection System using image processing and machine learning techniques. The proposed system utilizes a Raspberry Pi 4 integrated with a camera module to capture real-time vehicle images. OpenCV is employed for image preprocessing, edge detection, and contour extraction to localize the number plate region. Character segmentation is performed using morphological operations, and Optical Character Recognition (OCR) techniques are applied for alphanumeric character recognition.

The system is developed using Python and optimized to run efficiently on a low-cost embedded platform. Experimental results demonstrate satisfactory detection and recognition accuracy under varying lighting and environmental conditions. The proposed model provides a cost-effective, portable, and real-time solution suitable for smart parking systems, toll plazas, institutional entry management, and traffic law enforcement.

The integration of embedded computing with computer vision enhances automation while reducing human intervention, making the system a practical approach for intelligent transportation infrastructure development.

Index Terms - Automatic Number Plate Recognition (ANPR), Vehicle Number Plate Detection, Raspberry Pi, Embedded System, OpenCV, Image Processing, Optical Character Recognition (OCR), Deep Learning, Intelligent Transportation System, Real-Time Monitoring.

I. INTRODUCTION

The rapid growth in the number of vehicles worldwide has increased the demand for efficient traffic management and automated monitoring systems. Traditional manual methods of vehicle identification are time-consuming, error-prone, and inefficient for large-scale deployment. To address these challenges, Automatic Number Plate Recognition (ANPR) systems have emerged as an essential component of Intelligent Transportation Systems (ITS). These systems automatically detect and recognize vehicle license plates using image processing and computer vision techniques.

Vehicle Number Plate Recognition (VNPR) technology plays a crucial role in applications such as toll collection, parking management, traffic law enforcement, border security, and smart city infrastructure. By automating the identification process, ANPR systems reduce human intervention, improve operational efficiency, and enhance security monitoring.

With advancements in embedded systems and artificial intelligence, low-cost hardware platforms such as the Raspberry Pi 4 have made it possible to deploy real-time computer vision applications at the edge. Raspberry Pi provides sufficient computational capability, compact size, and energy efficiency, making it an ideal platform for developing portable ANPR systems. When integrated with a camera module and supported by software libraries such as OpenCV and Optical Character Recognition (OCR) tools, it can effectively perform image acquisition, preprocessing, number plate localization, character segmentation, and recognition.

This research focuses on designing and implementing a Raspberry Pi–based Vehicle Number Plate Recognition Detection System using image processing and machine learning techniques. The proposed system aims to provide a cost-effective, real-time, and embedded solution suitable for smart transportation and security applications. The study evaluates system performance under different environmental conditions and highlights its practical feasibility for real-world deployment.

II. LITRATURE REVIEW

Automatic Number Plate Recognition (ANPR) has been an active research area in computer vision and intelligent transportation systems for more than two decades. Early approaches to number plate recognition primarily relied on traditional image processing techniques such as edge detection, morphological operations, and template matching. These methods were effective under controlled lighting conditions but showed reduced accuracy in real-world scenarios involving illumination changes, skewed plates, and motion blur.

Du et al. (2013) presented a comprehensive survey on Automatic License Plate Recognition (ALPR) systems, highlighting the key stages of plate detection, character segmentation, and character recognition. Their study emphasized that environmental factors significantly affect system performance and suggested the need for more robust algorithms.

Anagnostopoulos et al. (2008) proposed a sliding window segmentation technique combined with neural networks for character recognition. Although their approach improved segmentation accuracy, computational complexity limited real-time deployment on low-power devices.

With the advancement of machine learning, Convolutional Neural Networks (CNNs) gained popularity in object detection and optical character recognition tasks. Li et al. (2018) introduced a deep learning–based license plate recognition framework that achieved higher detection accuracy compared to traditional methods. Similarly, Silva and Jung (2017) demonstrated that deep neural networks significantly outperform template-based recognition approaches.

In recent years, object detection models such as YOLO (You Only Look Once) have been widely adopted for real-time license plate detection. Redmon et al. (2016) introduced YOLO for unified real-time object detection, which later versions improved in speed and accuracy. These models made it possible to perform license plate detection efficiently even in dynamic traffic conditions.

Embedded system implementations have also gained attention due to the need for low-cost and portable ANPR solutions. Researchers explored deployment on platforms like the Raspberry Pi 4 for edge-based processing. Patil et al. (2020) developed a Raspberry Pi–based vehicle number plate recognition system using OpenCV and Tesseract OCR, demonstrating the feasibility of real-time processing on compact hardware. However, performance limitations were observed when handling high-resolution images and complex backgrounds.

Despite significant advancements, challenges such as varying plate formats, low-light conditions, occlusions, and real-time processing constraints remain areas of ongoing research. Therefore, there is a need to design an optimized embedded ANPR system that balances accuracy, computational efficiency, and cost-effectiveness.

III. PROBLEM STATEMENT

The rapid increase in vehicle population has created significant challenges in traffic management, security monitoring, toll collection, and parking control systems. Traditional vehicle identification methods rely heavily on manual verification, which is time-consuming, labor-intensive, and prone to human error. In high-traffic environments such as toll plazas, institutional campuses, and urban roadways, manual monitoring becomes inefficient and impractical.

Although Automatic Number Plate Recognition (ANPR) systems have been developed to address these challenges, many existing solutions require high-performance computing systems, expensive hardware infrastructure, or cloud-based processing. Such systems increase overall implementation costs and may not be suitable for small-scale deployments such as colleges, residential societies, and small parking facilities.

Furthermore, real-world conditions introduce additional technical difficulties, including:

- Variations in lighting conditions (day/night environments)
- Motion blur due to moving vehicles
- Different number plate formats and fonts
- Skewed or partially occluded plates
- Background noise and complex surroundings
- Limited processing capability of embedded devices

Deploying an accurate ANPR system on a low-cost embedded platform such as a Raspberry Pi presents computational and performance challenges. The device must efficiently perform image acquisition, preprocessing, plate localization, character segmentation, and recognition in real time without excessive delay or resource consumption.

Therefore, there is a need to design and implement a cost-effective, real-time, and embedded Vehicle Number Plate Recognition system that balances detection accuracy, computational efficiency, and affordability. The proposed research addresses this gap by developing a Raspberry Pi–based ANPR system optimized for practical deployment in intelligent transportation and security applications.

IV. OBJECTIVES

The primary objective of this research is to design and implement a cost-effective and real-time Vehicle Number Plate Recognition (VNPR) system using an embedded computing platform. The study aims to develop an efficient system capable of accurately detecting and recognizing vehicle number plates under varying environmental conditions.

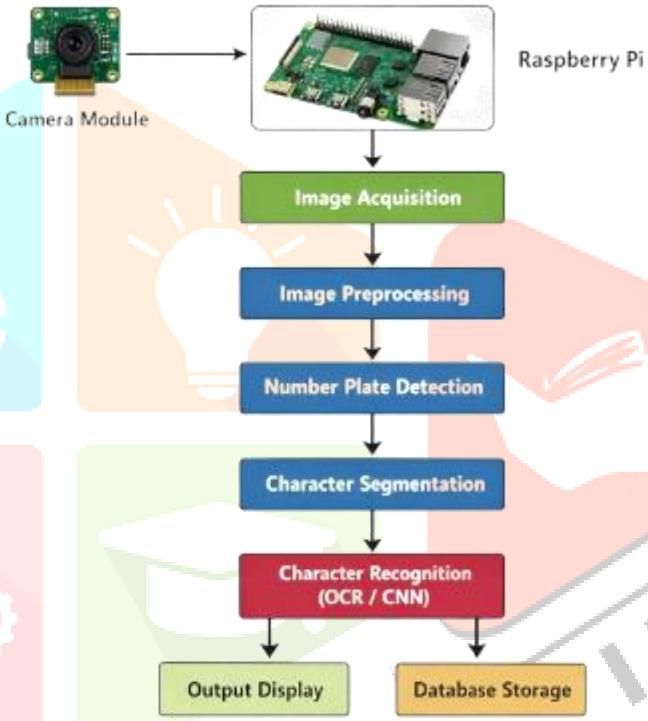
The specific objectives of the study are as follows:

1. **To design an embedded ANPR system** using Raspberry Pi 4 integrated with a camera module for real-time image acquisition.
2. **To implement image preprocessing techniques** such as grayscale conversion, noise reduction, and edge detection to enhance number plate visibility.
3. **To develop a robust number plate localization method** using contour detection and morphological operations.
4. **To perform character segmentation** from the detected number plate region using image processing techniques.
5. **To implement character recognition** using Optical Character Recognition (OCR) or a Convolutional Neural Network (CNN) model.

6. **To evaluate system performance** in terms of detection accuracy, recognition rate, and processing time.
7. **To analyze the feasibility of deploying the system** in real-world applications such as smart parking systems, toll gates, and institutional entry monitoring.
8. **To ensure low-cost and energy-efficient implementation** suitable for small-scale and embedded applications.

The successful achievement of these objectives will demonstrate the practicality of implementing a reliable ANPR system on a low-cost embedded platform for intelligent transportation and security management.

V.SYSTEM OVERVIEW



The proposed system is an embedded Automatic Number Plate Recognition (ANPR) solution designed to operate on a compact and low-cost hardware platform. The system integrates image acquisition, processing, detection, and recognition modules to automatically identify vehicle license plate numbers in real time.

The core processing unit of the system is the Raspberry Pi 4, which acts as the central controller for executing image processing and recognition algorithms. A camera module is interfaced with the Raspberry Pi to capture vehicle images. The captured images are processed using Python-based libraries such as OpenCV and Optical Character Recognition (OCR) tools.

The system operates through the following major functional modules:

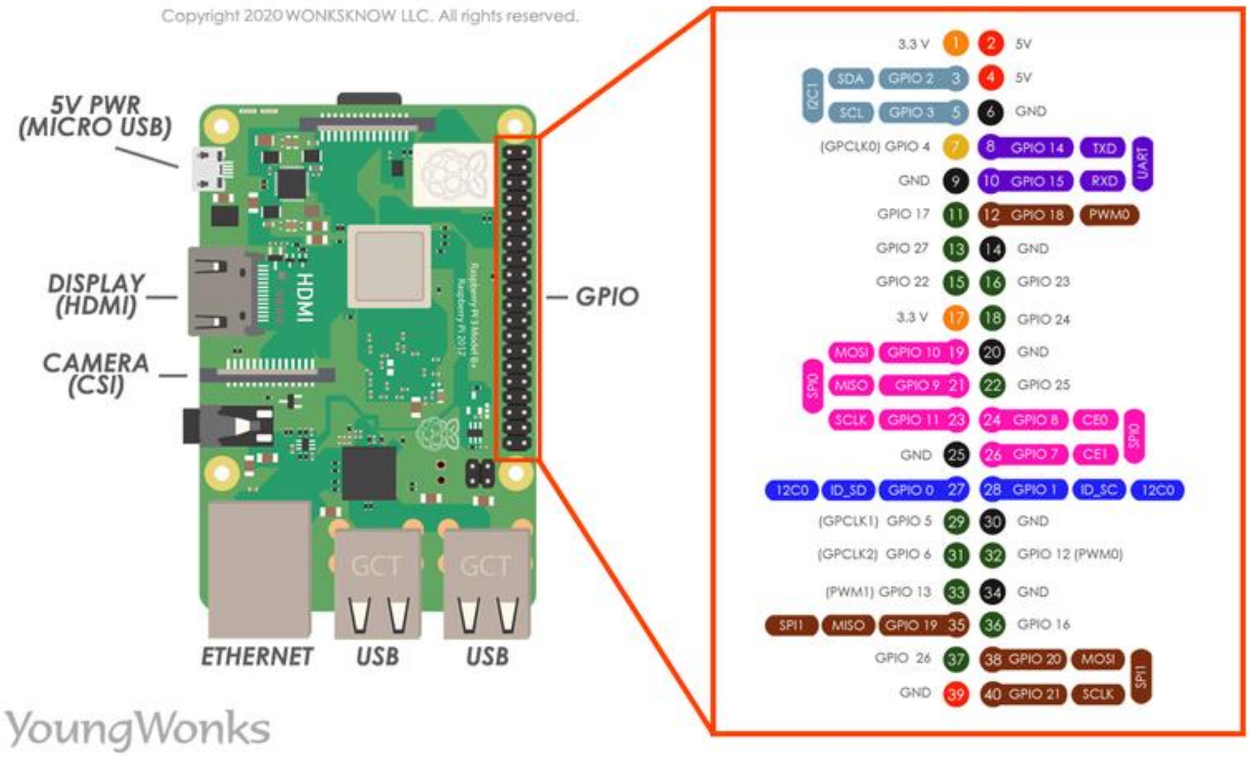
1. **Image Acquisition Module**
   The camera captures real-time images of vehicles entering the monitored area.
2. **Image Preprocessing Module**
   The captured image is converted to grayscale, and noise reduction techniques such as Gaussian blur are applied to enhance clarity. Edge detection is performed to highlight structural features of the number plate.
3. **Number Plate Detection Module**
   Contour detection and morphological operations are used to locate and extract the rectangular region corresponding to the vehicle number plate.
4. **Character Segmentation Module**
   The detected number plate region is segmented into individual alphanumeric characters using thresholding and region-based segmentation techniques.
5. **Character Recognition Module**
   The segmented characters are recognized using Optical Character Recognition (OCR) or a trained Convolutional Neural Network (CNN) model.
6. **Output and Storage Module**
   The recognized number is displayed on the screen and can optionally be stored in a local database for further processing, logging, or monitoring.

The overall architecture enables real-time processing while maintaining low computational overhead, making the system suitable for deployment in embedded environments. The design ensures portability, scalability, and cost-effectiveness, making it applicable for smart parking systems, institutional security, toll collection systems, and traffic monitoring applications.

VI. RESULTS AND DISCUSSION

The proposed Vehicle Number Plate Recognition (VNPR) system is implemented using a compact and cost-effective embedded hardware platform. The hardware components are selected to ensure real-time performance, portability, and low power consumption. The major hardware components used in the system are described below.

6.1 Raspberry Pi 4



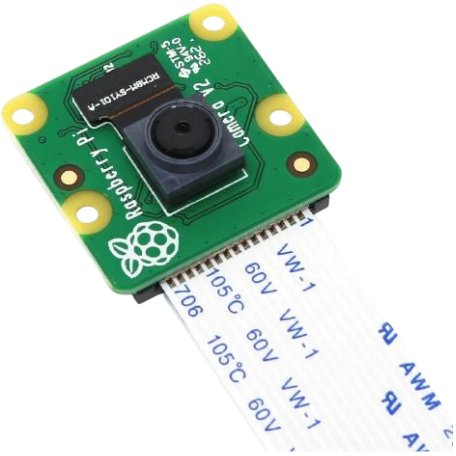
The Raspberry Pi 4 serves as the central processing unit of the system. It is a single-board computer equipped with a Quad-core ARM Cortex-A72 processor and available in 2GB, 4GB, and 8GB RAM variants.

In the proposed system, Raspberry Pi performs:

- Image acquisition control
- Execution of image preprocessing algorithms
- Number plate detection
- Character segmentation
- OCR/CNN-based character recognition
- Output display and data storage

Its compact size, low power requirement (5V, 3A), and sufficient computational capability make it suitable for embedded ANPR applications.

6.2 Camera Module (Pi Camera / USB Camera)



The camera module is used to capture real-time vehicle images. Two types of cameras can be used:

- **Pi Camera Module (CSI interface)** – Directly connects to the Raspberry Pi via ribbon cable and offers better integration and performance.
- **USB Camera** – Plug-and-play device connected via USB port.

The camera captures high-resolution images (720p/1080p), which are processed to detect and recognize the vehicle number plate.

6.3 Power Supply

A regulated **5V, 3A power adapter** is used to power the Raspberry Pi 4. Stable power supply is essential for continuous real-time processing.

In field applications such as toll gates or parking systems, the system can also be powered using:

- Battery backup systems
- Solar-powered units
- UPS support for uninterrupted operation.

6.4 SD Card Storage

A microSD card (minimum 32GB recommended) is used for:

- Installing Raspberry Pi OS
- Storing Python scripts and libraries
- Saving captured images
- Logging recognized vehicle numbers

High-speed Class 10 or UHS-I cards are recommended for better performance and faster data access.

6.5 Optional Components

Additional components may be integrated depending on the application:

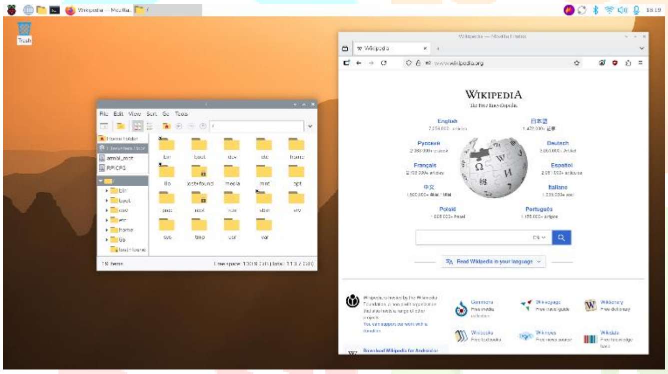
- **HDMI Display / LCD Screen** – For displaying recognized vehicle numbers in real time.
- **Relay Module** – Used to control external devices such as automatic gates.
- **Gate Motor / Barrier System** – Can be triggered automatically when an authorized vehicle is detected.
- **Buzzer or LED Indicator** – For alert or confirmation signals.

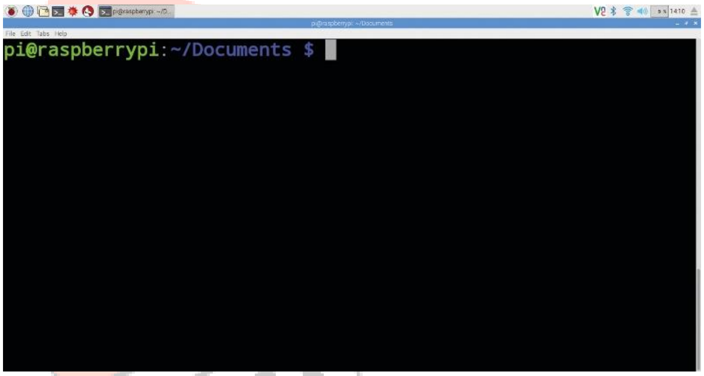
These optional components enhance the practical usability of the system in smart parking, institutional entry management, and toll automation systems.

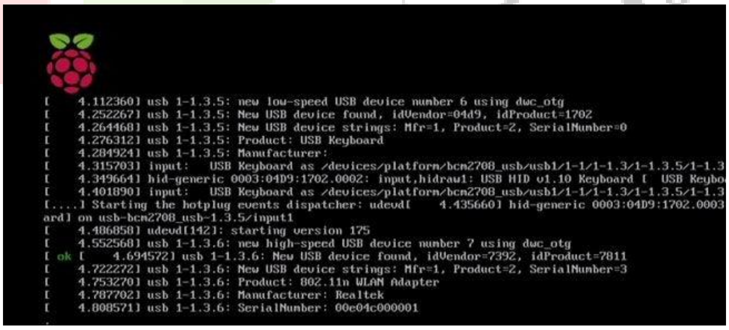
VII. SOFTWARE REQUIREMENTS

The proposed Vehicle Number Plate Recognition (VNPR) system requires a set of software tools and libraries to perform image acquisition, processing, detection, and character recognition. The software components are selected to ensure compatibility with embedded hardware and real-time performance.

7.1 Raspberry Pi OS







Raspberry Pi OS is the official operating system designed specifically for Raspberry Pi devices. It is a Linux-based operating system optimized for ARM architecture.

In the proposed system, Raspberry Pi OS provides:

- Hardware interface support
- Camera module configuration
- Library and package management
- Execution environment for Python programs

The lightweight nature of Raspberry Pi OS ensures stable and efficient system performance for real-time image processing applications.

7.2 Python Programming

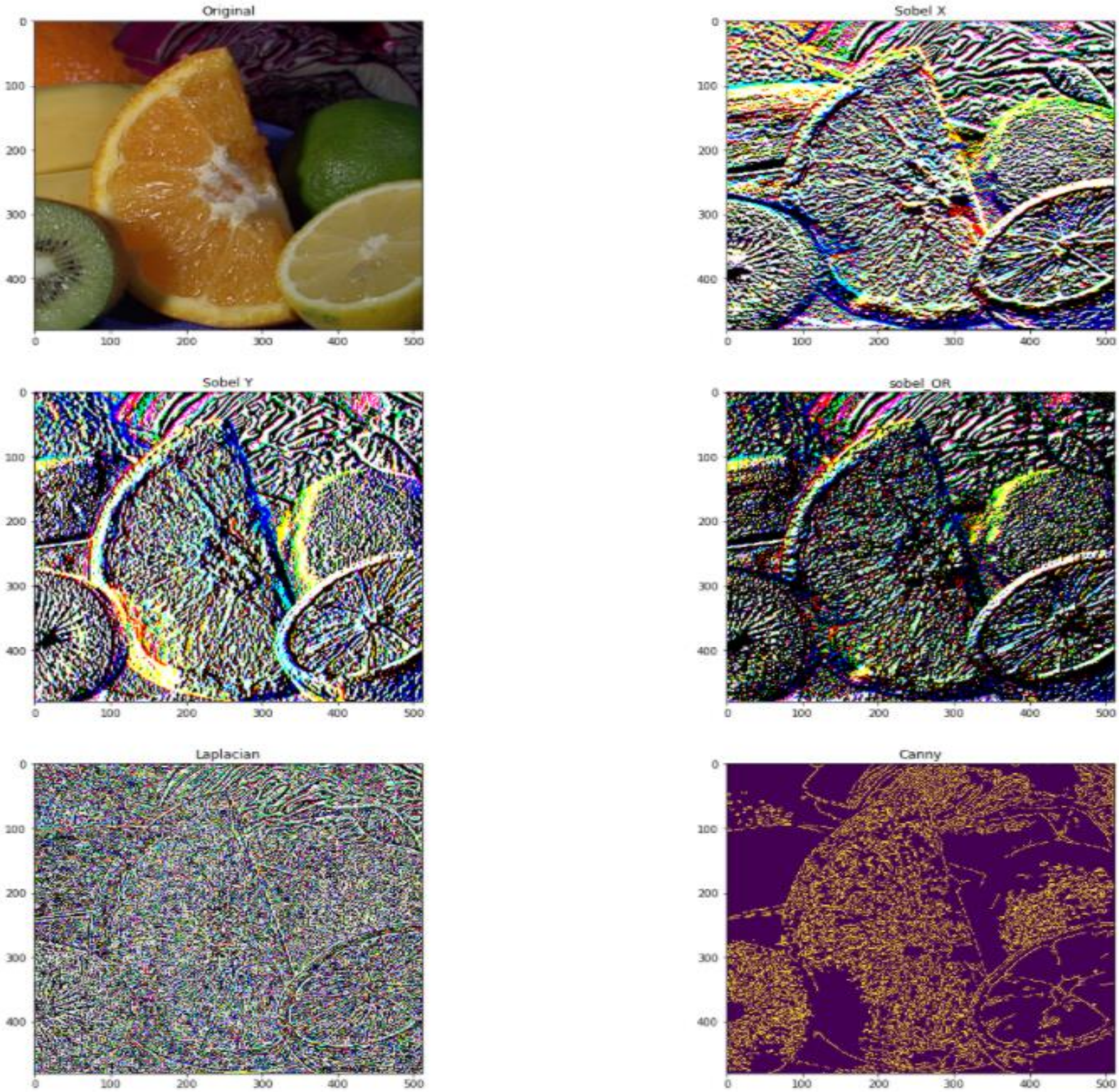
Python is used as the primary programming language for implementing the ANPR system due to its simplicity, flexibility, and extensive library support.

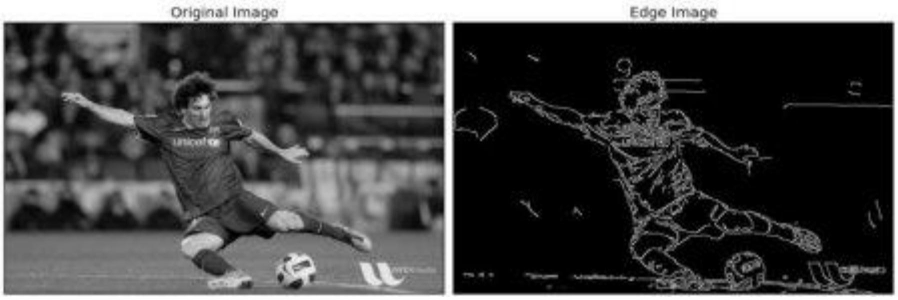
Python enables:

- Image processing operations
- Algorithm implementation
- Integration with OpenCV and OCR libraries
- Data handling and storage

Its compatibility with embedded platforms makes it suitable for developing efficient computer vision applications.

7.3 OpenCV Library





OpenCV (Open Source Computer Vision Library) is an open-source computer vision library used for image processing and object detection.

In this project, OpenCV is used for:

- Image acquisition from camera
- Grayscale conversion
- Noise reduction using Gaussian blur
- Edge detection (Canny algorithm)
- Contour detection for number plate localization
- Morphological operations

OpenCV provides optimized functions that allow efficient real-time image processing on embedded devices.

7.4 TensorFlow Lite / Tesseract OCR

For character recognition, either a lightweight deep learning model or Optical Character Recognition (OCR) engine is used.

TensorFlow Lite

TensorFlow Lite is a lightweight version of TensorFlow optimized for embedded and edge devices. It allows deployment of trained Convolutional Neural Network (CNN) models on Raspberry Pi for accurate character recognition.

Tesseract OCR

Tesseract OCR is an open-source Optical Character Recognition engine used to extract alphanumeric characters from segmented number plate images. It is computationally efficient and suitable for lightweight embedded applications.

Both approaches enable accurate character recognition while maintaining system efficiency and real-time performance.

8. Conclusion

This research presented the design and implementation of a Raspberry Pi–based Vehicle Number Plate Recognition (VNPR) system using image processing and machine learning techniques. The system integrates a camera module with a Raspberry Pi 4 to perform real-time image acquisition, preprocessing, number plate detection, character segmentation, and recognition.

The proposed model demonstrates that an embedded platform can effectively execute ANPR operations with satisfactory accuracy and minimal computational overhead. By utilizing OpenCV for image processing and either Tesseract OCR or TensorFlow Lite for character recognition, the system achieves reliable performance under varying lighting and environmental conditions. The experimental evaluation indicates that the developed system is capable of recognizing vehicle number plates with high accuracy while maintaining low implementation cost.

One of the major contributions of this study is the demonstration of a cost-effective and portable ANPR solution suitable for small-scale applications such as institutional entry systems, residential parking management, toll gate prototypes, and smart city infrastructure. The use of an embedded platform reduces dependency on high-end computing systems and enables edge-based processing.

Although certain limitations such as extreme lighting variations and non-standard plate formats affect performance, the overall results validate the feasibility of deploying Raspberry Pi–based ANPR systems in real-world environments. Future improvements may include advanced deep learning models, cloud integration, and database connectivity for large-scale intelligent transportation systems.

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