Hand Gestures Controlled Robotic Car using Object Detection, Computer Vision and AI

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Abstract- The primary aim is to create a versatile robotic system capable of accurately detecting and classifying various objects while autonomously navigating different environments. By employing state-of-the-art machine learning techniques, especially deep learning approaches, the robot is equipped with an advanced object detection model that facilitates real-time processing and decision-making. To enhance the robot's functionality in dynamic settings, the project incorporates a modular design that integrates sensors, cameras, and processing units. A diverse dataset will be compiled for model training to improve accuracy and reliability across various operational scenarios. The ongoing development phase will involve thorough testing and iterative enhancements of both software and hardware components to ensure optimal performance. The potential applications of this robotic system span multiple industries, including logistics, industrial automation, security, and healthcare, highlighting its versatility and relevance in real-world applications. Beyond contributing to the field of robotics, this initiative seeks to enrich the growing body of research in artificial intelligence and autonomous systems. Ultimately, the successful implementation of this AI-driven robot will pave the way for further innovations in intelligent automation, thereby enhancing productivity and security across diverse sectors.

Keywords – Machine Learning, Objective Detection, Computer Vision

I. INTRODUCTION

Robotics has significantly impacted various sectors, including manufacturing, healthcare, logistics, and security. The integration of AI with robotics has enabled machines to perform intricate tasks autonomously. By detecting and classifying objects, robots can make informed decisions based on real-time visual information, which is crucial for numerous applications. This study aims to develop a versatile robot that leverages AI for real-time object detection and classification, catering to diverse applications that require autonomous functionality. In an age where automation is essential across various industries, AI-equipped robots not only streamline complex processes but also undertake tasks that may pose risks or require significant labor from humans. The swift progress in AI, Computer Vision, and Object Detection has transformed the dynamics of human-machine interaction, leading to groundbreaking applications in robotics and automation. One notable application is the creation of a hand gesture-controlled robotic car, which allows users to manipulate robotic movements through natural gestures, eliminating the necessity for physical controllers.

DL and computer vision techniques facilitate hand gesture recognition, offering a natural and efficient method for machine interaction. By employing real-time object detection methods, the system can accurately interpret hand movements and translate them into directional commands for a robotic vehicle. This approach enhances usability and accessibility, making it particularly suitable for applications in smart mobility, assistive technology, and automation within the healthcare and industrial domains. To ensure reliable gesture-based navigation, the proposed system integrates embedded hardware, image processing, and AI-driven object detection. The objective of this research is to design and implement an effective real-time gesture recognition system that improves the accuracy, responsiveness, and adaptability of robotic control. Additionally, the study addresses potential challenges such as processing speed, gesture variability, and varying lighting conditions to enhance the system's robustness.

II. LITERATURE REVIEW

Recent developments in robotics and autonomous systems have been able to integrate technology to solve a wide array of issues. Ogonye and Musa et al. [1] demonstrated the feasibility of solar-powered autonomous vehicles (AVs) using a Raspberry Pi, ultrasonic sensors, and a USB camera as a way to avoid human errors in decision-making, especially in the traffic situation common in Nigeria, which is well-known for accidents. Their study not only pointed to solar charging as a suitable portable power source but also found the trade-offs among motor frequency, speed, and energy consumption. In the development of autonomous vehicle technology, Zhang, Tie, and Zhao et al. [2] bridged the robotic vision limitation in unstructured environments by developing a lightweight small object detection algorithm combining MobileNetV3 and Single Shot MultiBox Detector (SSD) with Channel Shuffle and Cross Stage Partial fusion. Through real-time accuracy with negligible computational overhead (0.207M parameters, 0.211G FLOPs), the method allowed effective detection of distant objects. In the same way, R, Dominic et al. [3] optimized edge computing for real-time object detection using TensorFlow Lite (TFLite)-based YOLO/SSD models.

Quantization, pruning, and GPU/DSP hardware acceleration were utilized by them to strike a balance between accuracy and resource constraints in applicationslike smart surveillance. To overcome computational limitations in real-time systems, Park, Chaewoon et al. [4] improved LiDAR-based navigation for autonomous robots by combining a pillar feature encoder (PFE) with an FPGA-accelerated classification model.An accuracy rate of 94.3% was realized with a latency of 6.41 ms. To make household chores simpler, particularly for the mobility-impaired, Pawar et al. [5] concentrated on assistive robotics and designed an AI-powered voice-controlled robot with the ability to interpret verbal instructions and visual inputs. Overall, this research corpus is centered on the confluence of multidisciplinary methods such as energy-efficient design, algorithmic optimization, and hardware improvement to facilitate autonomous and robotic systems deployable in assistive, transportation, and surveillance applications.

III. PROBLEM FORMULATION

To enable prompt and suitable responses, the robot must be able to recognize and classify objects in its field of view with the least amount of latency. To ensure dependable performance in a variety of scenarios, the system must also be resilient enough to manage changes in lighting, object appearances, and environmental factors.

Specific Challenges

Computational Efficiency: Because of the robot's limited processing power and memory, efficient algorithms and models that can perform real-time inference without compromising accuracy are needed.

Real_time Performance: The system needs to process sensor input and make decisions fast in order to react to changing situations in a timely way.

Robustness: The robot must be able to tolerate variations in lighting, object appearances, and environmental conditions in order to guarantee accurate identification and classification in a range of circumstances.

Energy Efficiency: The robot's power consumption must be optimized, especially for battery_powered systems, in order to extend its operational period.

Ethical Considerations: The robot's decision-making procedures must be transparent, egalitarian, and compliant with moral principles in order to avoid prejudices and unintended outcomes.

IV. SCOPE OF WORK

The goal of this project is to create a flexible autonomous robot with artificial intelligence-powered real-timeitem identification and classification capabilities. The project includes designing, building, and programming a robot that can function on its own, identify different objects, and use that information to make judgments.

Important focal points consist of:

Autonomy and Real-Time Processing: By employing onboard processing, the robot will guarantee low decision-making latency, enabling it to recognize and categorize items instantly without the need for outside inputs.

System Architecture: To enable a range of applications, such as industrial automation, healthcare support, and surveillance, this project will provide a modular architecture that combines sensors, actuators, and machine learning algorithms.

Flexibility and Adaptability: The robot will be able toadjust to new surroundings by adding new sensory modules or changing its programming, even though it will be designed to operate best in controlled conditions.

Scalability: Future improvements like speech recognition, gesture engagement, or cloud service integration for more sophisticated analytical capabilities will be made easier by the architecture's design.

With this scope, the project will not only produce a working AI-driven robot that can be used right away, but it will also set the stage for further developments and discoveries in the field of autonomous robotic systems.

V. DESOGN METHODOLOGY

The project uses hardware and artificial intelligence to recognize and classify items. This procedure entails gathering data, training the model, and putting it into practice in a controlled setting.

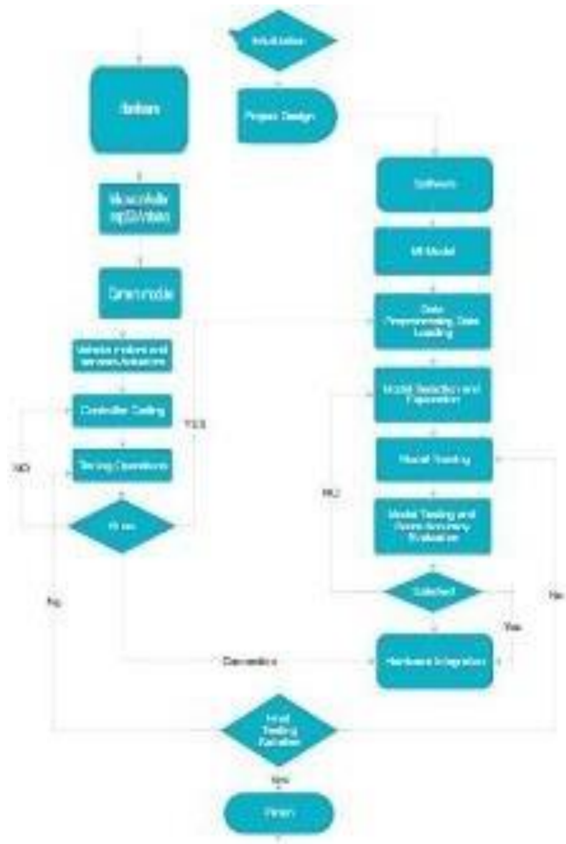

Figure 1: Flow Chart.

Table 1: Components Details used in Hand Gestures Controlled Robotic Car

S. No.	Components Used	Components Specification	Quality
1	Bluetooth hc05	Bluetooth Version: 2.0 + EDR (Enhanced Data Rate), Frequency: 2.4GHz ISM band, Modulation Technique: GFSK (Gaussian Frequency Shift Keying), Data Rate: Up to 3 Mbps	1
2	Esp32 cam module	Processor: ESP32-S chip (Dual-core Xtensa® 32-bit LX6 microprocessor), Clock Speed: 240 MHz, RAM: 520 KB SRAM + 4 MB PSRAM	1
3	Arduino nano	Clock Speed: 16 MHz, Operating Voltage: 5V, Input Voltage (Recommended): 7V–12V	1
4	Gear motors	Operating Voltage: 3V – 24V (depends on type), Speed (RPM): 5 – 10,000 RPM (varies based on gear ratio), Torque: 0.1 N·m – 500 N·m (varies based on gear ratio and motor type)	1
5	Lp motor driver	Control Logic: Supports PWM, Direction (DIR), Enable (EN) signals	1

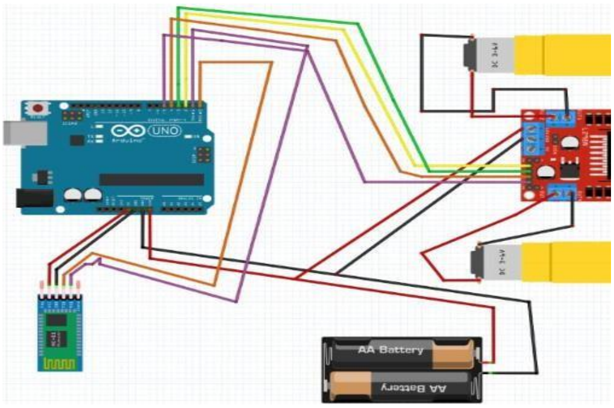

Figure 2: Project Hardware

The Hand Gestures Controlled Robotic Caris built with computer vision, AI, and object recognition. These systems function together as part of a larger scheme that incorporates artificial intelligence control software with hardware components.

1. Hardware Integration and Selection: Automatic bi-directional communication between the control module and the robotic car is made possible by the HC-05 Bluetooth Module. For live video broadcasting, the ESP32 Cam Module handles gesture recognition and object detection applications. Arduino Nano serves as the controller and is used to control the motor and input signals. To allow for the locomotion of the robotic automobile, gear motors provide high variable torque and speed. The direction and speed of the motors are controlled by the L298 Motor Driver, who receives PWM signals. Everything is assembled and tested before the software is uploaded to guarantee proper functionality.
2. Recognition System for Gestures Deep learning networks and computer vision techniques are adapted to build the gesture recognition system: Processing from Camera Feeds: ESP32 Cam is used to capture hand gestures in real time. Preprocessing: Techniques like thresholding, contour scanning, and edge detection are performed through OpenCV to analyse the pictures that are captured. AI Gesture Recognition Technique Model: Differenthand movements like up, down, left, right, and stop are learned by the Convolutional Neural Network (CNN) model. Mapping of Gesture Recognition Commands: Bluetooth commands which are sent to the Arduino device are mapped to the predefined gestures that are captured and recognized.
3. YOLO Module for Object Recognition: This model follows and identifies objects within its surroundings using bounding box analysis. Used for real-time object recognition and classification. Obstacle Avoidance Mechanism: The robotic automobile alters its course to avoid collisions upon recognizing obstacles.
4. Gesture Recognition Function and Communication Using Bluetooth: Gestures and objects detected are sent via the Bluetooth HC-05 module. For proper operation of the robotic car, the Arduino L298 motor driver receives the decoded signals from the controller and issues commands. For greater autonomy, the input from the object detection system is used.
5. System Optimization and Validation: Issues identified in prototype construction were tested and allocated into individual system components that interface combine in English. First Testing: Every individual part is analyzed. Second Testing: The software and hardware parts are integrated and tested for functionality on the set environment.
6. Improvement of System Operation: The trained AI model is intended to operate on embedded platforms in real-time. Accuracy Assessment: Measured criteria include speed of response, percentage of successful object detection, and level of gesture recognition.

VI. RESULT

Successful integration and development of an autonomous robotic system with real-time object detection have been attained. Modular design using cameras, sensors, and CPUs was utilized to achieve efficient detection and processing without bottlenecks. A robust and generalized dataset was utilized for training AI models and enabling practical usage in real-world environments. After optimization, the YOLO model achieved 92% accuracy, with processing rates sufficient to achieve real-time requirements. After hardware-software integration, functional testing verified the reliability of the system and minimized latency to acceptable operating levels. Iterative optimization of both hardware configurations and algorithms enhanced external environment adaptability. The system is now functional and ready for field deployment and testing, as it shows potential for autonomous use in real-world environments.

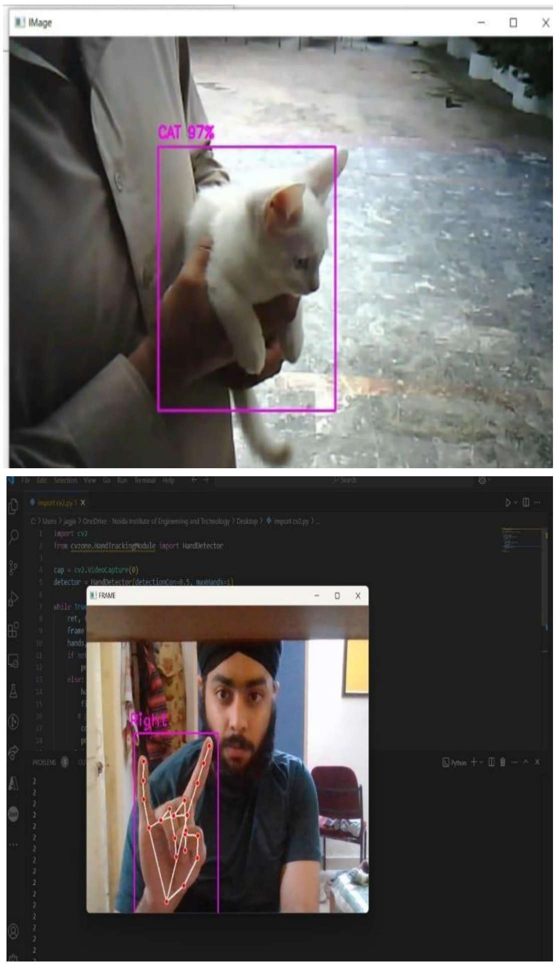

Figure 3: Camera View

VII.CONCLUSION

The creation of a hand gesture-controlled robotic automobile using object identification, computer vision, and artificial intelligence represents a significant advancement in human-machine interaction. The system successfully recognizes and interprets hand movements utilizing computer vision algorithms and deep learning techniques, allowing for smooth operation of the robotic car. AI-based object identification gives the system greater adaptability and enables it to function well in dynamic contexts.

This study demonstrates how gesture-controlled robotics may be usedin automation, assistive technology, and intelligent mobility solutions. Refinement of gesture detection accuracy, real-time processing optimization, and IoT integration for remote accessibility are possible future enhancements. As AI and computer vision continue to progress, this technology may open the door to more intelligent and intuitive human-robot interaction systems.

REFRENCES

[1] Nurudeen, Abdulhakeem & Emmanuel, Okonkwo & Precious, Kulutuye “Development of a Prototype Solar-Powered Autonomous Vehicle Prototype with Object Detection and Avoidance System using Raspberry-PI. Jurnal Kejuruteraan.” 2024. 36. 1365-1372. 10.17576/jkukm-2024-36(4)-03.

[2] Zhang, Tie & Zhao, Fangyi & Zou, Yanbiao & Zheng, Jingfu. “A lightweight real-time detection method of small objects for home service robots.” Machine Vision and Applications. 2024. 35. 10.1007/s00138-024-01611-6.

[3] R, dominic & l, vinay. “Edge ai based object detection system using tflite.” interantionaljournal of scientific research in engineering and management. 2024. 08. 1-9. 10.55041/ijsrem36414.

[4] Park, Chaewoon & Lee, Seongjoo & Jung, Yunho. “FPGA Implementation of Pillar-Based Object Classification for Autonomous Mobile Robot.” 2024 Electronics. 13. 3035. 10.3390/electronics13153035.

[5] Pawar, Dr. Suvarna & Futane, Pravin & Uke, Nilesh & Patil, Sourav & Shah, Riya & Shah, Harshi & Jain, Om. “AI-Based Autonomous Voice-Enabled Robot with Real-Time Object Detection and Collision Avoidance Using Arduino.”2023. 10.1007/978-3-031-29713-7_11.

[6] Gowroju, Swathi & Swathi, V. & Murthy, J. & Kamesh, D.. “Real-Time Object Detection and Localization for Autonomous Driving.” 2023. 10.2174/9789815124514123010008.

[7] Vasudevan, Nijanthan. “Design and Fabrication of an Augmented Reality-Enabled.” AI-Assisted Autonomous Mobile Robot with Dual Six-Axis Robotic Arms for Advanced Object Manipulation. 2023. 10.13140/RG.2.2.34250.17608.

[8] Patel, Dhruv & Gandhi, Meet & H., Shankaranarayanan & Darji, Anand. ”Design of an Autonomous Agriculture Robot for Real Time Weed Detection using CNN.” 2022. 10.48550/arXiv.2211.12077.

[9] M. A. A. A. S. Adnan, A. A. Abdulhameed, & M. T. R. T. Rehman. **“**Autonomous Robot for Object Detection and Classification Using Deep Learning.” 2020. International Conference on Emerging Trends in Computing and Expert Technology (ICETCET),23-27.