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Speed Control Technology Using Image Processing Method for an Autonomous Electric Go-Kart

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Abstract

This thesis explores the design and implementation of a speed control system for an autonomous electric Go-Kart using computer vision. It addresses the challenges of safety, efficiency, and reliability in autonomous vehicle technology. The study covers the evolution, advancements in autonomous vehicles and sensor technologies. The main objective is to create a system that uses face detection to control the Go-Kart's speed, ensuring safe object tracking. The research involves using a Raspberry Pi, Logitech webcam, and Arduino Pro Mini, with Python and OpenCV for face detection. Results show successful face detection and speed adjustment, contributing to safer autonomous systems. The study suggests further improvements, such as additional sensors and advanced algorithms, to enhance system robustness and efficiency.

1. Introduction

Autonomous electric vehicles are a rapidly advancing technology that combines electric propulsion with self-driving capabilities to enhance transportation safety, efficiency, and sustainability [1]. These vehicles rely on sensors, such as the ESP32, and programming to enable autonomous operation. To achieve optimal energy efficiency, affordability, comfort, and safety, a well-structured information and communication technology architecture is crucial [2]. Speed control technology plays a key role in regulating the speed of vehicles, utilizing mechanical components, instructions, and electronic circuits. It is vital in various industries, including automotive, manufacturing, and aerospace, as it improves performance, safety, energy efficiency, and overall operational effectiveness [3].

2. Literature Review

A literature review is a comprehensive synthesis and evaluation of existing research and publications on a specific topic. It involves analyzing academic journals, books, and other relevant resources to understand the current knowledge and identify research gaps. This chapter focuses on the importance of speed control technology advancements for autonomous electric vehicles, specifically examining how an autonomous electric Go-Kart can recognize and follow a leading vehicle while matching its speed. It will discuss the challenges in developing effective speed control systems for autonomous driving applications, considering factors such as energy optimization, performance, and safety.

2.1 Scenario-Based Testing

Scenario-based testing is a crucial method for evaluating the intelligence and performance of autonomous vehicles [4]. It involves testing the vehicle's ability to safely and legally navigate through specially designed regions within a limited time frame. These tests, such as the Grand Challenge and Urban Challenge, assess the vehicle's ability to recognize static environments, such as roads and stationary obstacles, and dynamic participants, such as other vehicles and pedestrians. Additionally, the vehicle must demonstrate appropriate decision-making and actions to interact effectively with its surroundings. Vehicles that fail these tests are considered insufficiently intelligent.

2.2 Functionality-Based Testing

Functionality-based testing evaluates specific subsystems or components of autonomous vehicles, such as lane marking recognition, vehicle recognition, object detection, lane-keeping systems, and obstacle recognition [4]. By isolating individual functions, this method facilitates targeted evaluation and debugging, allowing issues to be identified and resolved at the component level before system integration. This approach ensures each module functions correctly, reducing the risk of failures during full-system operation.

2.3 Simulation-Based Testing

Simulation-based testing is a cost-effective and scalable approach for evaluating autonomous vehicles in virtual environments [5]. Advanced simulation platforms replicate various driving scenarios, weather conditions, and traffic patterns, enabling extensive testing without the risks and costs of physical trials. Fuzzy logic enhances this method by managing uncertainties in sensor data and decision-making algorithms. This approach accelerates the testing cycle and provides a safe platform to assess hazardous scenarios, such as extreme weather or high-speed emergencies, that are impractical to recreate in real-world settings.

2.4 Battery Electric Vehicle (BEV)

Battery Electric Vehicles (BEVs) rely solely on batteries to power their drivetrains, with their range directly related to the battery's capacity. Top-tier BEVs can travel 300 to 500 kilometers per charge, while others typically range from 100 to 250 kilometers [6]. Factors such as driving habits, car settings, weather, road conditions, and battery type and age influence these ranges. Recharging a BEV also takes longer than refueling an internal combustion engine (ICE) vehicle.

2.5 Fuel Cell Electric Vehicle

Fuel Cell Electric Vehicles (FCEVs), also known as Fuel Cell Vehicles (FCVs), use fuel cells that generate electricity through chemical reactions. Hydrogen is the primary fuel for these cells, leading to the term "hydrogen fuel cell vehicles." FCVs store hydrogen in high-pressure tanks and obtain oxygen from ambient air. The fuel cells generate electricity to power an electric motor that drives the wheels. Excess energy can be stored in batteries or supercapacitors, with commercially available FCVs like the Honda Clarity and Toyota Mirai using batteries for storage [7].

3. Methodology

This section details the electric Go-Kart project by describing its specifications, tools, and development process. It includes detailed rules for the application to clarify process descriptions. The research approach involved sample preparation, experiments, and product analysis, following a consideration of the advantages and disadvantages of the chosen methods, the project focuses on designing the speed control technology, testing the electric motor Go-Kart driving mechanism, and evaluating its performance.

3.1 General Project Flowchart

The flow chart in Fig. 1 outlines the general procedure, starting with a literature review. It proceeds to analyze the operation of autonomous systems and select the appropriate controller, sensor, and motor for the project. The next step involves developing codes focused on speed control technology. Connectivity between the controller, Raspberry Pi 5 board, and code is tested using a breadboard. If successful, data collection and analysis follow, leading to documentation. If unsuccessful, the programming steps are repeated until the connection works.

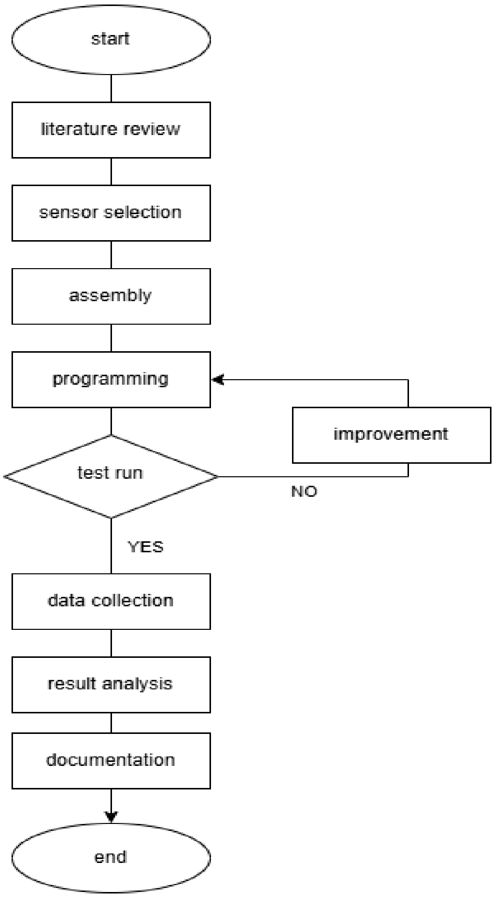

Fig. 1: General Flowchart

3.2 Raspberry Pi 5

The Raspberry Pi 5 is a high-performance single-board computer with a Broadcom BCM2712 quad-core Cortex-A76 processor running at 2.0 GHz, making it suitable for tasks such as image processing. It features a VideoCore VII GPU supporting 4K video output and dual 4K displays via two micro-HDMI ports. With 4GB or 8GB of LPDDR4-3200 RAM, it handles larger tasks and multitasking efficiently. Storage is provided via a microSD card, and USB 3.0 enables faster data transfer. Connectivity options include Gigabit Ethernet, dual-band Wi-Fi, and Bluetooth 5.0. Powered by a 5V USB-C supply, it offers 40 GPIO pins and a CSI interface for camera modules, supporting projects involving image capture or external device control.

3.3 Arduino Pro Mini

Arduino Pro Mini is a compact and lightweight microcontroller board, ideal for space and power sensitive projects. Based on the ATmega328 microcontroller, it comes in two variants: one operating at 3.3V and 8MHz and the other at 5V and 16MHz. Its small size makes it suitable for embedding in permanent installations or space constrained projects. Unlike other Arduino boards, it lacks a USB connection for programming and instead requires an external programmer, such as an FTDI adapter or a USB to serial converter. The board features 14 digital I/O pins, six of which can be used as PWM outputs, and six analog input pins for sensor data. It also includes a reset button and headers for external component connections. Its versatility makes it suitable for a wide range of applications, including robotics, wearable devices, home automation, and custom electronics.

3.4 FTDI adapter

FTDI adapter is a small device used to program microcontroller boards such as the Arduino Pro Mini. It serves as an interface between the computer's USB and the serial interface of the microcontroller, which is necessary because the Arduino Pro Mini lacks a built-in USB port for code uploading. The FTDI adapter uses the FT232RL chip to convert USB signals into TTL serial signals that the microcontroller can understand. It connects to the Arduino Pro Mini via a set of pins, typically using a 6-pin header that matches the Pro Mini’s layout. Once connected to the computer, it appears as a Virtual COM Port, enabling code uploads via the Arduino IDE. The FTDI adapter can also be used for debugging or monitoring serial data from a microcontroller, making it a versatile and essential tool for working with Arduino boards that do not have USB interfaces.

3.5 XL6009 Voltage Regulator

The voltage regulator is an essential component used in Arduino projects to provide a constant and steady power supply to the microcontroller and attached components. It takes a variable input voltage and converts it into a stable output voltage that the Arduino can safely use. Voltage regulators are especially useful for the Arduino Pro Mini, which requires a specific input voltage of either 3.3V or 5V, depending on the model. Linear voltage regulators, such as the LM7805 (5V) and LM317 (adjustable), are commonly used for this purpose. These regulators maintain a steady output even when the input voltage fluctuates. They also protect the Arduino from overvoltage or power surges, working alongside capacitors to further stabilize the voltage. The voltage regulator ensures the Arduino operates reliably without hardware failure in projects powered by batteries or high voltage sources.

3.6 MG995 Servo Motor

MG995 servo motor is a versatile and widely used electromechanical tool suitable for various applications, including robotics, remote control systems, and mechanical projects. Renowned for its positioning accuracy and high torque, it is a popular choice among engineers and hobbyists. The MG995 offers a reliable solution for achieving controlled movement in diverse mechanical and electronic projects.

3.7 C270 HD Webcam Logitech

Logitech C270 HD Webcam served as the primary visual input component for the autonomous electric Go-Kart, supporting image processing and algorithm execution. This webcam was chosen for its wide field of view and ability to deliver clear images. It captures video at a resolution of 1280 x 720 pixels and supports full HD video and still photos, with an HDR mode offering up to 3 megapixels. Additionally, it automatically adjusts to varying lighting conditions, producing brighter images in low light. The webcam's ease of use and advanced features make it suitable for both beginners and experienced users.

3.8 Raspbian OS

Raspbian OS, a Debian-based operating system optimized for Raspberry Pi devices, was utilized in this project. It provides a lightweight yet robust platform for running the image processing and speed control algorithms required for the autonomous electric Go-Kart. Raspbian OS supports various programming languages and libraries, including Python and OpenCV, essential for implementing computer vision tasks. Its user-friendly interface and extensive community support make it an ideal choice for beginners and experts. Additionally, the OS is highly efficient, ensuring reliable performance while managing the hardware resources of the Raspberry Pi.

3.9 Arduino IDE

The Arduino IDE was used to program the Arduino Pro Mini in this project. It provides a simple interface for writing, compiling, and uploading code to the microcontroller. The IDE supports programming in C and includes built in libraries that help with tasks like motor control and sensor integration. It worked well with the FTDI adapter to upload the code, ensuring the smooth operation of the Go-Kart.

3.10 Experiment Setup

The experimental setup tested the autonomous electric Go-Kart, which operates using face detection as a trigger. Key components included a DC brushless motor, Arduino Pro Mini, Raspberry Pi 5, motor controller module, FTDI module, and voltage regulator. The Raspberry Pi processed images from a Logitech webcam to detect faces. When a face was detected, it signaled the Arduino to activate the motor controller and engage the accelerator. If no face was detected, the motor controller deactivated the accelerator, stopping the Go-Kart. A battery powered the system, with the voltage regulator ensuring a stable power supply. Testing was conducted in a controlled environment to assess accuracy and response. Fig. 2 (a) shows the top view of the Go-Kart, and Fig. 2 (b) depicts the back view of the Go-Kart.


(a) (b)

Fig. 2: Experiment Setup (a) Top view of full Go-Kart (b) Back view of Go-Kart for Acceleration part

4. Result and Discussion

This chapter discusses the experimental results for developing a speed control system for an autonomous electric Go-Kart using camera-based image processing. The system detects a human face to activate the accelerator, allowing the Go-Kart to move, while the absence of a face keeps it stationary. It runs on an eco-friendly electric battery and integrates Raspberry Pi and Arduino for image processing and accelerator control, respectively. The Raspberry Pi uses Python to process images and make decisions, which are executed by the Arduino to ensure proper operation. This project represents progress in speed control for autonomous vehicles.

4.1 Camera Feed Testing

Camera feed testing was performed to validate the functionality of Python coding and associated face detection libraries. The process began by executing the Python script, which displayed the camera feed, confirming its functionality. Successful camera operation ensured real-time video feed manipulation for face detection. Fig.3 illustrates the live feed during testing, serving as a foundation for further development of the speed control mechanism for the autonomous Go-Kart.

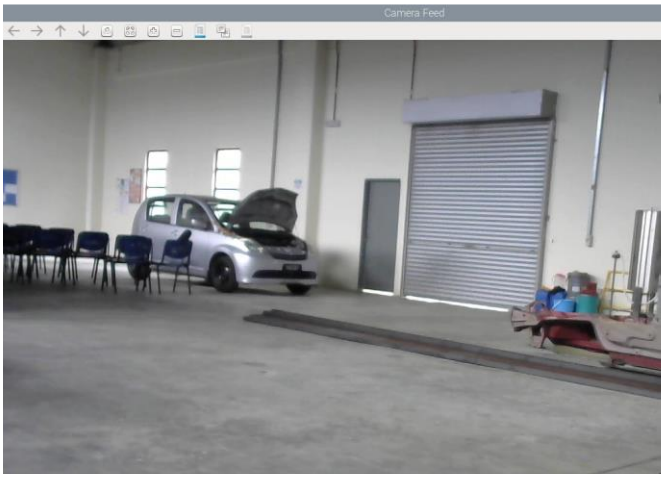

Fig. 3: Test of camera feed using Raspberry Pi 5

4.2 Camera Face Detection Testing

Face detection testing was carried out after confirming the camera feed was functioning correctly. The process began with installing the required libraries, followed by writing and running the code in the IDE to implement face detection. The system was confirmed to be working when a square-shaped detection appeared over the face in the webcam feed. This visual indicator was crucial in verifying the system's ability to detect faces. Face detection was chosen for object recognition due to its practicality and reliability. Recognizing random objects would require more complex coding and substantial effort for accuracy. Additionally, random objects could cause unstable detection due to variations in shape, size, or lighting conditions, making face detection a more efficient and reliable choice for this project. The face detection rate by using the camera is evaluated by five different distance starting form 1 meter to 5 meter. The success rate of face detection for each distance is calculated by the formula.

$$\text{Success Rate} = \left(\frac{\text{Successful Detections}}{\text{Total Tests}}\right) \times 100 \tag{1}$$

Table 1 shows the results of the camera face detection tests. There are 3 tests in total that has been carried out to evaluate the success rate of face detection for each distance. For distance 1 and 2 meters, the face detection success rate achieved a 100% success rate for all 3 total tests. For distance 3 meters, there is a decrease to 66.7% face detection success rate as it doesn't succeed 1 out of 3 tests. At the distance of 4 and 5 meters, the success rate of face detection is 33.33%.

Table 1: Success Rate Face Detection for 5 Different Distance

Distance (m)	Total tests	Successful detection	Success rate (%)
1	3	3	100
2	3	3	100
3	3	2	66.7
4	3	1	33.33
5	3	1	33.33

Fig. 4 below shows the graph of face detection success rate against distance graph. From the graph, the result for the detection success rate is the same for distances 1 and 2 meters which are 100%, and the detection rate becomes lower until it reaches 33.33% as the distance increases to 5 meters. This shows that the camera face detection is more effective at shorter distances compared to longer distances due to the decrease in resolution and smaller face size when distance is further.

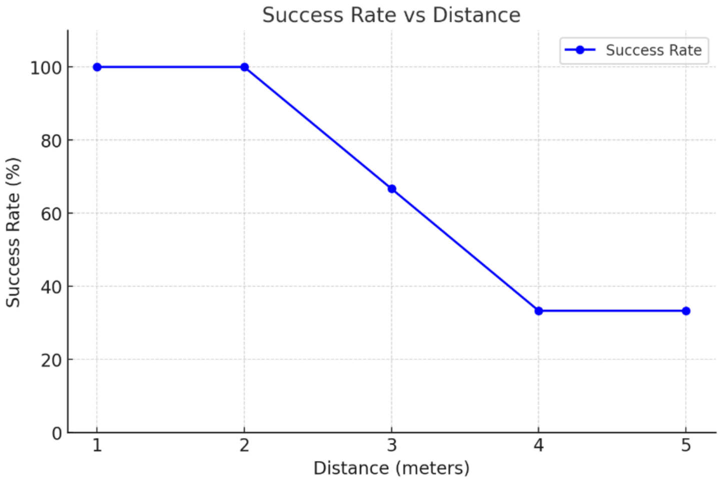

Fig. 4: Face Detection Success Rate against Distance Graph

4.3 Raspberry Pi with Camera and Accelerator Integration

This part of the project focused on integrating the Raspberry Pi, camera, and accelerator system for full interaction. The Raspberry Pi processed the camera feed using OpenCV for face detection, with detected faces triggering the servo motor to pull the accelerator pedal and activate the Go-Kart. The code used Haar Cascade Classifier for face detection, and when a face was detected, a square appeared on the screen, indicating detection. The signal was sent to the Arduino, which activated the servo motor to pull the accelerator pedal. Testing confirmed that when a face was detected, the motor responded by engaging the accelerator. Fig. 5 shows output from geany run script after face detection by the camera and sending the signal to Arduino to trigger the accelerator.

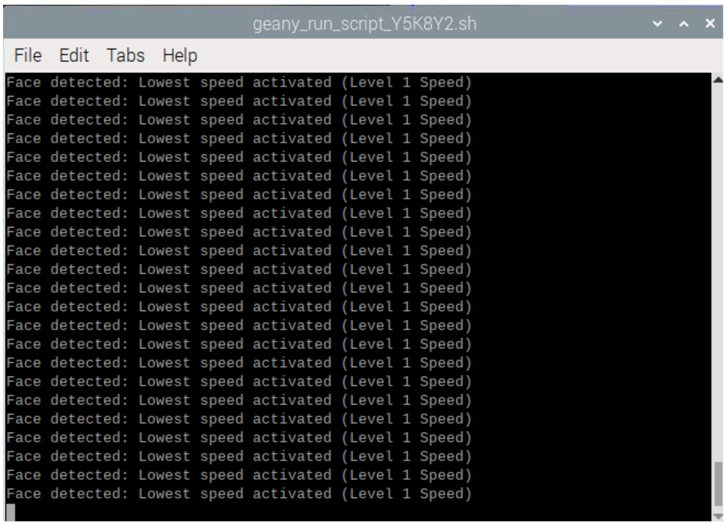

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Fig. 5: Geany run script face detection and accelerator activation

Table 2 shows the integration of Raspberry Pi and camera for accelerator control. The data was obtained by multiple tests for the camera face detection with servo motor position integration, which pulls the pedal for the accelerator between 5 different distances. There are 3 different speeds which are low speed, medium speed, and high speed. For each distance, the face detection is successful for all distances from 1 meter to 5 meters. For a distance of 1 meter, the servo angle was adjusted to 10° when the face was detected, and that resulted in the engagement of the pedal accelerator at low speed. While the distance is 5 meters, which is the longest distance, the servo angle is adjusted to 90° and pulls the pedal to engage the accelerator to high speed.

Table 2: Face Detection and Servo Motor Accelerator Integration

Distance (m)	Total tests	Successful detection	Servo angle (°)	Speed level
1	3	Yes	10	Low
2	3	Yes	45	Medium
3	3	Yes	90	Medium
4	3	Yes	90	High
5	3	Yes	90	High

The graph in Fig. 6 depicts the relation between servo angle adjustments and distance. The further the distance of Go-Kart's camera from the face, the higher the adjustment of the servo angle and the higher the level of the speed of the accelerator engaged.

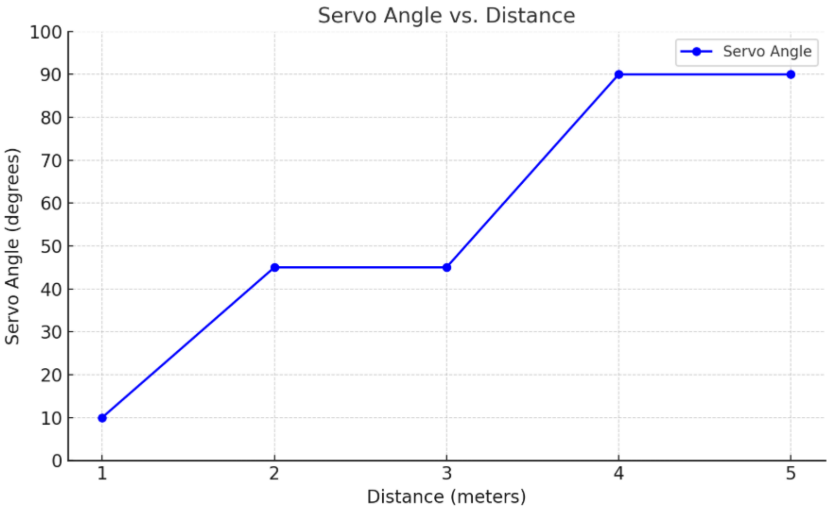

Fig. 6: Servo Angle Adjustment against Distance Graph

5. Conclusion

This project effectively used face identification via a Raspberry Pi and camera to create a speed control system for an autonomous electric go-kart. When a face appears in front of the camera of the go-kart, the system detects it and uses a servo motor to control the accelerator pedal to change the speed. Although there is always opportunity for development, such as adding more sensors and honing algorithms for increased dependability and performance, this study shows the potential of using image processing for speed control in autonomous systems.

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