ISBN: 978-981-94-1156-6
2024 the 14th International Workshop on Computer Science and Engineering (WCSE 2024)
doi: 10.18178/wcse.2024.06.048

Design of Vehicle Accident Prevention System Based on GPS

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Abstract. The system utilizes Keil µVision IDE, Android SDK, and Visual Studio Code for software development, realizing a multifunctional vehicle collision prevention system. With GPS as the core, combined with functions such as image processing, gas sensing, and temperature monitoring, it comprehensively monitors the vehicle's internal status. Innovative features include illegal intrusion detection, gravity pressure sensing system, facial recognition anti-theft, voice assistant, flame sensor, and gyroscope detection. Real-time GPS positioning is achieved through the 4G DTU gateway Cat1 module, enabling real-time positioning and voice soothing via the mobile app. It realizes visualization of vehicle data presentation, cloud synchronization, and data analysis, providing an integrated safety protection and intelligent control experience.

Keywords: GPS, Unauthorized intrusion detection, Facial Recognition, App.

1. Introduction

Traffic accidents pose significant threats to life and property. According to WHO, about 13.5k die annually, with millions injured, a leading cause of youth deaths. In the US, accidents incur $400B losses yearly, 10% due to fatigue and distractions.

To address this, Design of Vehicle Accident Prevention System Based on GPS have emerged, using advanced sensors to monitor vehicle surroundings and provide real-time warnings, effectively preventing accidents[1]. The goal is to ensure comprehensive vehicle safety and contribute to traffic safety efforts.

2. System Architecture

The STM32F407ZGT6 microcontroller serves as the core controller in the system, responsible for managing and coordinating various modules, including sensor data acquisition, processing, and analysis, as well as actuator control. Its powerful processing capabilities and peripheral interfaces enable efficient data processing and algorithm execution, ensuring rapid and accurate response to environmental changes. Additionally, it communicates with external devices such as displays, buzzers, and network modules, facilitating user interaction and data transmission. As the central hub of system control, it monitors status, diagnoses faults, and provides self-protection functions, ensuring stable and secure system operation. The specific allocation design is depicted in Figure 1.

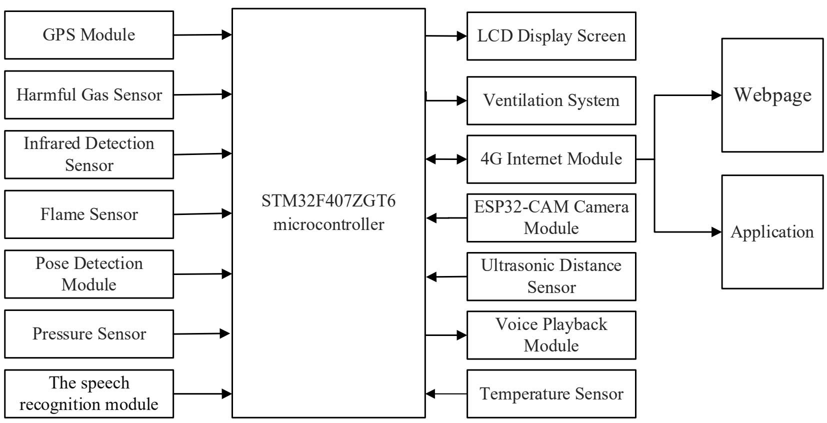

Fig. 1: System structure

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2.1. Microcontroller System

The STM32F407ZGT6 microcontroller serves as the core control unit of the system, responsible for managing the operation of various modules, including sensor data acquisition, processing, and actuator control. Its processing capability and peripheral interfaces efficiently handle data and algorithms, ensuring the system can rapidly and accurately respond to environmental changes and events. It communicates with peripherals of the vehicle safety system to enable user interaction and data transmission. Additionally, it monitors system status, diagnoses faults, and implements self-protection mechanisms to ensure the stable and secure operation of the system.

2.2. Carbon Dioxide Sensor

The SGP30 module is utilized for monitoring the air quality inside the vehicle. Through this module, the system continuously monitors the concentrations of carbon dioxide (CO2) and total volatile organic compounds (TVOC), providing precise air quality information in real-time. Employing digital optical sensor technology, it communicates with the microcontroller via the I2C interface, delivering accurate CO2 and TVOC concentration values to support crucial data for the system[2]. Its interface design is depicted in Figure 2.

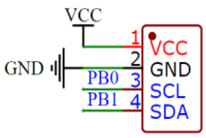

Fig. 2: SGP30 sensor schematic

2.3. Ultrasonic Ranging Module

The HC-SR04 module is employed to implement the distance detection function in front of the vehicle. By emitting ultrasonic waves and measuring the echo time, it accurately calculates the distance to obstacles ahead. When an obstacle is detected too close, it triggers an alarm, enhancing driving safety. The digital signal output can be directly recognized and processed by the system control unit, enabling fast and reliable obstacle recognition, providing robust support for navigating complex road conditions. Its interface design is illustrated in Figure 3.

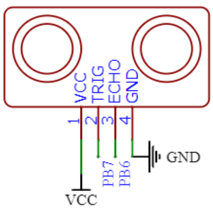

Fig. 3: HC-SR04 ultrasonic sensor schematic diagram

2.4. Vibration Sensor

The SW18101P vibration sensor collects data by monitoring changes in ADC values to assess the vehicle's vibration status, accurately perceiving vibration intensity and frequency to detect intrusion attempts. Upon detecting abnormal vibrations, the system promptly initiates safety measures such as triggering alarms, locking the doors, or activating the tracking system to safeguard the vehicle's security. Its interface design is illustrated in Figure 4.

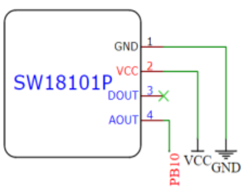

Fig. 4: Vibration sensor interface schematic diagram

2.5. Pressure Sensor

The FSR402 pressure sensor collects data by monitoring changes in ADC values to detect seat pressure changes, determining whether there is someone seated or any abnormal activity. Once it surpasses a threshold or detects anomalies, the system initiates safety measures such as sounding alarms or deploying safety airbags to ensure passenger safety. Its interface design is depicted in Figure 5.

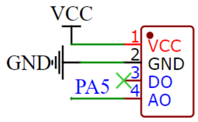

Fig. 5: Pressure sensor schematic diagram

2.6. Display Module

The HMI serial screen serves as the human-machine interface, providing real-time display of vehicle environmental parameters and allowing users to control vehicle devices. It allows modification of emergency contact numbers, enhancing safety measures. It offers a convenient operating experience, improving vehicle safety and driving comfort. Its interface design is illustrated in Figure 6.

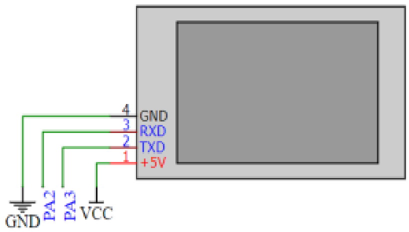

Fig. 6: Schematic diagram of the serial screen interface

2.7. Voice Module

The LD3320 voice recognition module interfaces with the system via serial communication. It enables voice command control inside the vehicle, such as adjusting windows or the ventilation system. By accurately recognizing voice commands, it enhances the driving experience and safety, allowing the driver to focus on driving. The module plays a critical role in intelligent control and user experience. Its interface design is depicted in Figure 7.

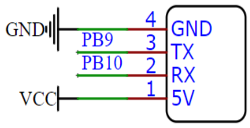

Fig. 7: Voice module schematic diagram

2.8. Internet of Things (IoT) Module

The 4G communication module is crucial in the system, interfacing with the system via a serial port. It configures communication parameters to initialize 4G communication and set up network connections, ensuring stable communication between the vehicle and the cloud server. It utilizes built-in GPS or Beidou positioning to obtain the vehicle's real-time location and transmits it along with other sensor data through 4G to the cloud server. Real-time monitoring of vehicle location and sensor data enhances vehicle safety and management efficiency. Its interface design is depicted in Figure 8.

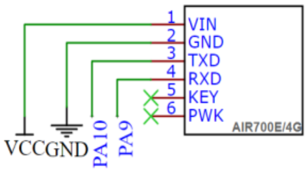

Fig. 8: 4G communication module

2.9. Face Recognition Module

The ESP32-CAM camera module plays a vital role in the system, interfacing with the system via a serial port. Its main functions include remote video transmission and facial recognition, enabling real-time capture of surrounding environment images transmitted to a remote server for remote monitoring. Additionally, it integrates facial recognition functionality, swiftly and accurately identifying the identities of individuals inside the vehicle, enhancing security measures[3]. Its interface design is illustrated in Figure 9.

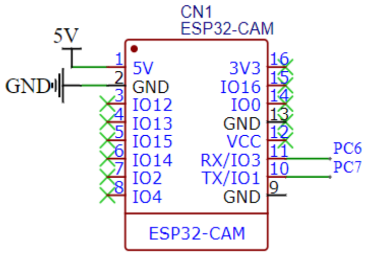

Fig. 9: Schematic diagram of ESP32-CAM interface

3. Data Transmission Platform and Communication Protocol

The cloud platform utilized for data transmission between the mobile application (APP) and the lower-level device in this system is OneNet[4]. This platform not only offers extensive data storage and analysis capabilities but also employs advanced encryption technology to ensure communication security between devices and the platform. The platform boasts powerful cloud computing and application development capabilities. The system achieves intelligent IoT (Internet of Things) through the development of custom applications using APIs and SDKs on the OneNet platform.

4. The Positioning System

The system retrieves WGS84 coordinates using the GPS module and then utilizes conversion functions to transform them into GCJ02 coordinates, enabling accurate acquisition of the vehicle's position. The GCJ02 coordinates are interfaced with the system via serial communication, transmitted in digital form to the control center, providing real-time geographic location information of the vehicle.

5. System Design and Implementation

The system first comprehensively monitors the vehicle environment through various internal sensors, including gas concentration, temperature, and gravity pressure[5]. Data is regularly uploaded to the cloud for storage and analysis. Facial recognition and flame sensors are utilized to monitor vehicle safety, preventing intrusion, self-ignition, or rollover events. When abnormal situations are detected, alert messages are sent to the user. Users can monitor the vehicle's status in real-time, set thresholds, and receive alert notifications through a mobile app or web page. The system includes a voice assistant feature, allowing users to control doors, windows, and ventilation through voice commands. Real-time GPS positioning of the vehicle is achieved via the 4G DTU gateway Cat1 module, enhancing safety and management efficiency. The system flowchart is shown in Figure 10.

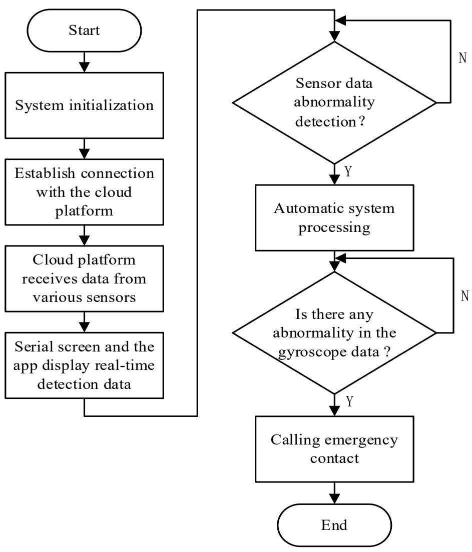

Fig. 10: System design implementation flow chart

6. Face Detection Based on MTCNN

6.1. Core Algorithm of MTCNN Model

1. Face Detection:

Face detection is essentially a classification task, so the cross-entropy loss function is utilized to accomplish this functionality[6].

$$L_i^{det} = -(y_i^{det}\log(P_i)) + (1 - y_i^{det})(1 - \log(P_i))$$

In the above formula, P_i represents the predicted probability of the sample being a face by the model, while $y_i^{det} \in \{0,1\}$ represents the actual label, typically taking values of 0 or 1, where 1 indicates the sample is a face and 0 indicates the sample is not a face. As the cross-entropy loss function decreases, indicating smaller loss, it means the model's predicted probability for the sample being a face is higher.

In design, the cross-entropy loss function is widely applied in deep learning classification tasks. By minimizing the cross-entropy loss function, the model can better learn the classification features of samples, thereby improving its ability to accurately recognize faces.

2. Bounding Box Regression:

Its main purpose is to calculate the deviation between the predicted values and the ground truth for each candidate box. Since its learning objective is a regression problem, the Euclidean loss function is applied to each sample[7].

$$L_i^{box} = \left\|\hat{y}_i^{box} - y_i^{box}\right\|_2^2$$

In the design, $\hat{y}_i^{box}$ represents the regression target obtained from the network, which is the ground truth. Using the Euclidean distance function, we can measure the gap between the regression target and the ground truth, i.e, L_i^{box}. When the Euclidean distance is smaller, it indicates that the regression target is closer to the ground truth, meaning the model's predictions are more accurate. In a face recognition system, minimizing the Euclidean distance helps the model better learn the features of samples, thereby improving the accuracy of face recognition and enhancing the performance and reliability of the system.

3. Facial feature point localization. Its learning objective is also a regression problem, therefore, the Euclidean loss function is used.

$$L_i^{landmark} = \left\|\hat{y}_i^{landmark} - y_i^{landmark}\right\|_2^2$$

In the design, $\hat{y}_i^{landmark}$ represents the predicted coordinates of the facial feature points for the i sample obtained from the network, while $y_i^{landmark}$ represents the true coordinates of the facial feature points for the i sample obtained from the network. The Euclidean loss function $L_i^{landmark}$ is used to measure the difference between the predicted coordinates and the true coordinates of the feature points, indicating the model's accuracy in localizing facial feature points.

When the Euclidean distance is smaller, it indicates that the predicted feature points are closer to the ground truth values, implying more precise localization of the facial landmarks. In facial recognition systems, minimizing the Euclidean distance helps the model to accurately locate key facial landmarks such as eyes, nose, and mouth, thereby enhancing the accuracy and stability of facial recognition. This contributes to the overall performance improvement of the system.

4. The training objective function for facial classification, bounding box regression, and facial landmark localization can be represented by the following equation:

$$\min \sum_{\mathfrak{H}=1}^{n} \sum_{j\in\{det,box,landmark\}} \alpha_j \beta_i^j L_i^j$$

In the equation, N represents the number of training samples, α_j indicating the importance of the task.

To obtain more accurate facial landmark coordinates, we use $\alpha_{det} = 1$, $\alpha_{box} = 0.5$, $\alpha_{landmarkt} = 0.5$. in the P-Net and R-Net networks.

In the O-Net network, we use $\alpha_{det} = 1$, $\alpha_{box} = 0.5$, $\alpha_{landmarkt} = 1$, and $\beta_i^j \epsilon \{0,1\}$ for the sample type detector. L_i^j represents using gradient descent to train the convolutional neural network.

Gradient descent is used to train the O-Net network in order to minimize the loss function during the training process, thereby improving the network's ability to recognize and locate facial features. This design effectively enhances the performance of the face detection system and provides more accurate facial landmark coordinates, thereby enhancing the reliability and practicality of the system.

7. Face Recognition Testing

To comprehensively evaluate the performance of the face recognition system, various testing methods such as normal, occlusion, side profile, upward angle, and downward angle were employed. Under normal conditions, clear frontal face images were collected to simulate ideal scenarios. Occlusion testing involved using objects to simulate occlusions. Side profile testing covered different side angles of the face. Upward and downward angle testing examined recognition from different angles. These tests comprehensively assess the accuracy and robustness of the system. Below are the test results and samples.

Table 1: Model test results

Recognition Conditions: Angles and Occlusions	Recognition instances/count	Successful instances/count	Recognition rate/%
Normal	40	40	100
Obstruction	40	28	70
Profile	40	30	75
Elevated angle	40	32	80
Downward angle	40	34	85

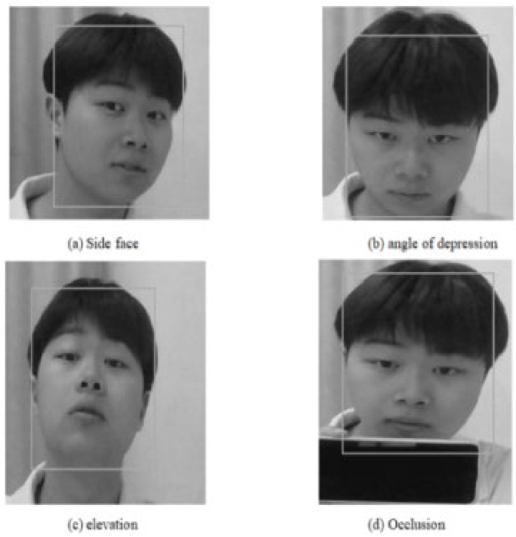

Fig. 11: Effect of face detection

8. Acknowledgement

This work was supported by the National college students innovation and entrepreneurship training program project support (Grant NO. 202310066008, 202210066021).

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