I.K Gujral Punjab Technical University Amritsar Campus

Minor Project:

FACE GUARD – ESP32 Face Detection and Recognition

Department of Computer Science and Engineering

Submitted by:

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Abstract

FaceGuard is a face recognition and detection system built using ESP32-CAM module. The system uses the Wi-Fi feature of the ESP32-CAM to connect to the live stream of the camera. It provides real-time face recognition and detection, allowing users to register new faces and identify famili ar faces. The system can distinguish between recognized and unrecognized faces and provid e appropriate instructions, such as showing "Hello Subject" to recognized faces and triggeri ng an "intruder alert" to the unknown face

This project uses computer vision techniques and machine learning algorithms for face reco gnition and detection.
ESP32-CAM captures images processed using deep learning models that learn face images. The sys tem extracts the face, compares it with the registered faces and determines if there is a matc h. Face registration is done by capturing multiple face patterns and storing them in a file.

ESP32-CAM module integrates F-F jumper, USB to serial converter and other devices to facilitate communication andcontrol. FaceGuard provides a reliable and costeffective solution for face recognition and detection, enabling users to improve security and access across multiple environments. The project rep ort provides a detailed description of the system architecture, hardware configuration, softw are implementation, and performance metrics. It also discusses enhancements and future im provements to the FaceGuard system.

<u>**Acknowledgement**</u>

We are deeply grateful to my Mentor **Dr. R.K. Kumawat** who was all the time helpful and supportive to me for the completion of this project. Being truly without his guidance, support, suggestions, and encouragement We would not have completed this study.
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Introduction

The FaceGuard project is a face recognition system developed using the ESP32-CAM module. With the demand for a good security and management solution, the project aims to provide reliable and effective solutions for real-time detection and identification of individuals. Using the power of computer vision and deep learning algorithms, FaceGuard provides facial recognition with the flexibility of a compact and cost-effective hardware module.

The ESP32-CAM with OV2640 camera module is a powerful platform for developing embedded systems. It is equipped with a built-in camera, Wi-Fi, and Bluetooth, making it ideal for developing face recognition systems.
The FTDI programmer is a tool that can be used to program the ESP32-CAM. It is a simple and easy-to-use tool that can be used by anyone.
The female-to-female jumper wires are used to connect the ESP32-CAM to the FTDI programmer. They are a simple and inexpensive tool that is essential for any electronic project.

Scope:

The scope of the FaceGuard project includes the development and implementation of face recognition and detection using the ESP32-CAM module. The system is designed to operate on live video received via the ESP32-CAM's Wi-Fi connection.
It includes the following main features and functions:

Face Registration: Users can register new faces in the system by capturing multiple patterns and storing them in the face database. This allows the system to learn and recognize people over time.

Real-time face detection: The system detects and locates people's faces in videos, making sure it recognizes and watches people.

Face recognition: The system uses deep learning techniques to compare detected faces with registered faces to determine if they match. This ensures that the system is aware of known contacts.

Alerts and alerts: The system provides appropriate instructions based on authentication results, such as displaying "Hello Subject" for face recognition and triggering "Intruder Alert" for unknown face. This increases security and ensures a timely response to threats.

Objectives

1.Develop a face recognition and detection system using the ESP32-CAM module.

2.Implement real-time face detection algorithms to accurately detect and localize faces within the video stream.

3.Create a face database for storing and managing enrolled faces for recognition purposes.

4.Enable face enrollment functionality to allow users to add new faces to the system.

5.Implement face matching algorithms to compare detected faces with enrolled faces and determine if a match is found.

6.Provide feedback and alerts based on recognition results, such as displaying the name of recognized individuals or triggering an intruder alert for unrecognized faces.

7.Develop a user-friendly interface for interacting with the system, allowing users to perform actions like enrolling faces, viewing recognition results, and managing system settings.

Requirement Analysis and System Specification

Hardware Requirements:

ESP32-CAM module: The main component of the system that integrates the camera and microcontroller.
USB-Serial converter: Used for programming and debugging the ESP32-CAM module.
F-F jumper wires: Used for connecting the ESP32-CAM module to the USB-Serial converter.

Software Requirements:

Arduino IDE: Used for programming the ESP32-CAM module.
ESP32 library: Enables communication and interaction with the ESP32-CAM module.
WiFi library: Allows the system to connect to a Wi-Fi network for live streaming and communication.

Functional Requirements:

Face Detection: The system should be able to detect faces in real-time from the live camera stream.
Face Recognition: It should have the capability to recognize and match detected faces with enrolled faces.
Face Enrollment: The system should provide functionality to enroll new faces into the face database.
Alert Generation: When an unrecognized face is detected, an intruder alert should be generated.

Performance Requirements:

Real-time Processing: The system should be capable of processing the camera stream in real-time with minimal latency.
Accuracy: The face detection and recognition algorithms should provide accurate results to ensure reliable identification.

Scalability: The system should be able to handle a large number of enrolled faces and perform recognition efficiently.

Constraints:

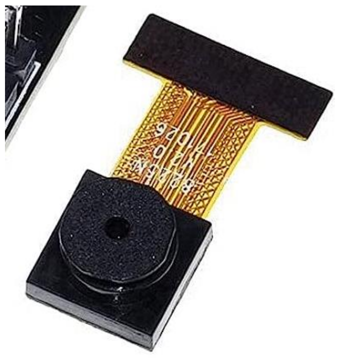
Power Consumption: The system should be designed to optimize power usage, considering the limitations of the ESP32-CAM module.
Cost: The project should aim for cost-effective hardware components and minimize additional hardware requirements.

System Design

1.Hardware Setup:

ESP32 microcontroller: It serves as the main controller for the system and handles all the processing tasks.

Camera module: An ESP32-compatible camera module is connected to capture images and video.



Jumper Wire:

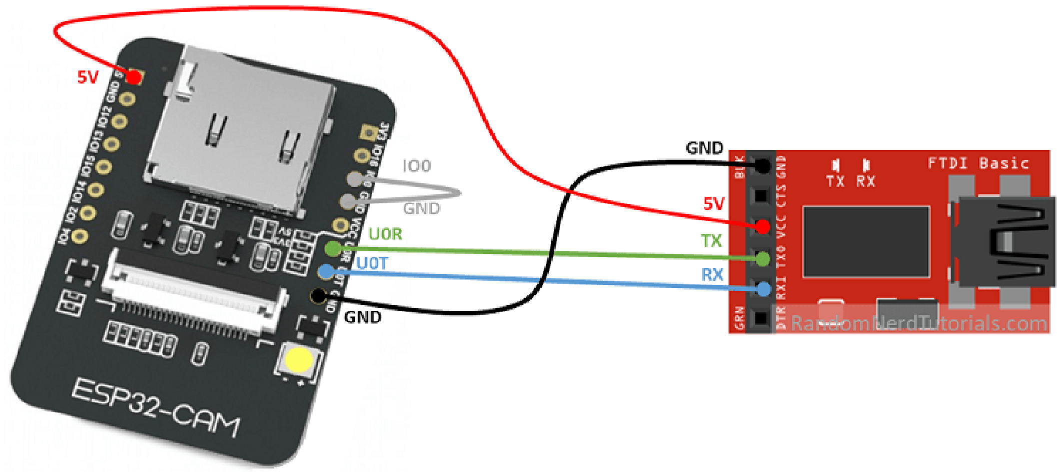
USB – Serial converter:

Software setup:

Arduino IDE: The system developed using the Arduino framework, which provides an easy-to-use programming interface for the ESP32.

ESP 32 Package : We installed the ESP32 CAM module on the Arduino IDE

Connections:



Implementation

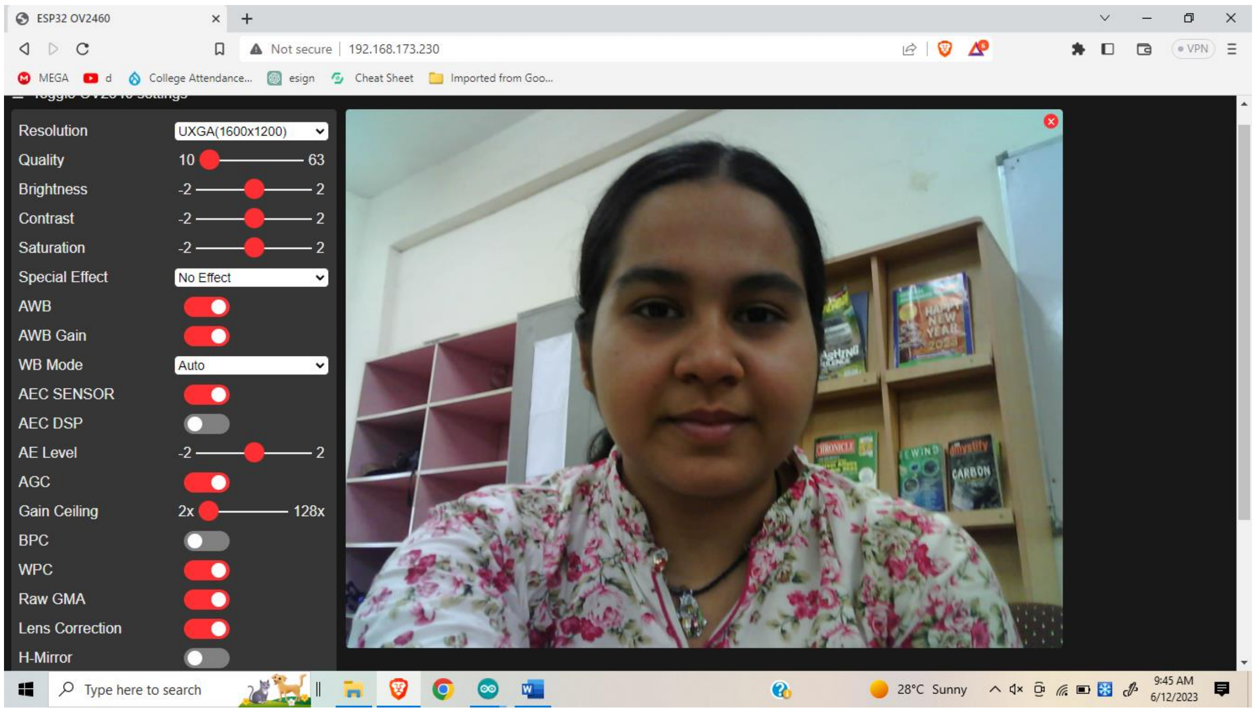
```
#include "esp_camera.h"
#include <WiFi.h>


#define CAMERA_MODEL_AI_THINKER

#include "camera_pins.h"

const char* ssid = "POCO M3";
const char* password = "Aditya@01253";

void startCameraServer();

void setup() {
  Serial.begin(115200);
  Serial.setDebugOutput(true);
  Serial.println();

  camera_config_t config;
  config.ledc_channel = LEDC_CHANNEL_0;
  config.ledc_timer = LEDC_TIMER_0;
  config.pin_d0 = Y2_GPIO_NUM;
  config.pin_d1 = Y3_GPIO_NUM;
  config.pin_d2 = Y4_GPIO_NUM;
  config.pin_d3 = Y5_GPIO_NUM;
  config.pin_d4 = Y6_GPIO_NUM;
  config.pin_d5 = Y7_GPIO_NUM;
  config.pin_d6 = Y8_GPIO_NUM;
  config.pin_d7 = Y9_GPIO_NUM;
  config.pin_xclk = XCLK_GPIO_NUM;
  config.pin_pclk = PCLK_GPIO_NUM;
  config.pin_vsync = VSYNC_GPIO_NUM;
  config.pin_href = HREF_GPIO_NUM;
  config.pin_sscb_sda = SIOD_GPIO_NUM;
  config.pin_sscb_scl = SIOC_GPIO_NUM;
  config.pin_pwdn = PWDN_GPIO_NUM;
  config.pin_reset = RESET_GPIO_NUM;
  config.xclk_freq_hz = 20000000;
  config.pixel_format = PIXFORMAT_JPEG;
  //init with high specs to pre-allocate larger buffers
  if(psramFound()){
    config.frame_size = FRAMESIZE_UXGA;
    config.jpeg_quality = 10;
    config.fb_count = 2;
  } else {
    config.frame_size = FRAMESIZE_SVGA;
    config.jpeg_quality = 12;
    config.fb_count = 1;
  }



  // camera init
  esp_err_t err = esp_camera_init(&config);
  if (err != ESP_OK) {
    Serial.printf("Camera init failed with error 0x%x", err);
    return;
  }

  sensor_t * s = esp_camera_sensor_get();
  //initial sensors are flipped vertically and colors are a bit saturated
  if (s->id.PID == OV3660_PID) {
    s->set_vflip(s, 1);//flip it back
    s->set_brightness(s, 1);//up the blightness just a bit
    s->set_saturation(s, -2);//lower the saturation
  }
  //drop down frame size for higher initial frame rate
  s->set_framesize(s, FRAMESIZE_QVGA);



  WiFi.begin(ssid, password);

  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
```

```
  Serial.println("WiFi  connected");

  startCameraServer();

  Serial.print("Camera  Ready! Use 'http://");
  Serial.print(WiFi.localIP());
  Serial.println("'  to connect");
}

void loop()  {
  delay(10000);
}
```

Some of the Back End Function And Algorithm:

```
static int run_face_recognition(dl_matrix3du_t  *image_matrix,  box_array_t *net_boxes){
    dl_matrix3du_t  *aligned_face = NULL;
    int matched_id = 0;

    aligned_face = dl_matrix3du_alloc(1,  FACE_WIDTH, FACE_HEIGHT, 3);
    if(!aligned_face){
        Serial.println("Could  not allocate face recognition buffer");
        return matched_id;
    }
    if (align_face(net_boxes,  image_matrix,  aligned_face) == ESP_OK){
        if (is_enrolling  == 1){
            int8_t left_sample_face  = enroll_face(&id_list,  aligned_face);

            if(left_sample_face  == (ENROLL_CONFIRM_TIMES - 1)){
                Serial.printf("Enrolling  Face ID: %d\n", id_list.tail);
            }
            Serial.printf("Enrolling  Face ID: %d sample  %d\n", id_list.tail,
ENROLL_CONFIRM_TIMES - left_sample_face);
            rgb_printf(image_matrix,  FACE_COLOR_CYAN, "ID[%u] Sample[%u]", id_list.tail,
ENROLL_CONFIRM_TIMES - left_sample_face);
            if (left_sample_face  == 0){
                is_enrolling  = 0;
                Serial.printf("Enrolled  Face ID: %d\n", id_list.tail);
            }
```

```
      } else {
        matched_id = recognize_face(&id_list, aligned_face);
        if (matched_id >= 0) {
          Serial.printf("Match Face ID: %u\n", matched_id);
          rgb_printf(image_matrix, FACE_COLOR_GREEN, "Hello Subject %u", matched_id);
        } else {
          Serial.println("No Match Found");
          rgb_print(image_matrix, FACE_COLOR_RED, "Intruder Alert!");
          matched_id = -1;
        }
      }
    } else {
      Serial.println("Face Not Aligned");
      //rgb_print(image_matrix, FACE_COLOR_YELLOW, "Human Detected");
    }

    dl_matrix3du_free(aligned_face);
    return matched_id;
}


static esp_err_t index_handler(httpd_req_t *req){
    httpd_resp_set_type(req, "text/html");
    httpd_resp_set_hdr(req, "Content-Encoding", "gzip");
    sensor_t * s = esp_camera_sensor_get();
    if (s->id.PID == OV3660_PID) {
        return httpd_resp_send(req, (const char *)index_ov3660_html_gz,
index_ov3660_html_gz_len);
    }
    return httpd_resp_send(req, (const char *)index_ov2640_html_gz,
index_ov2640_html_gz_len);
}
```



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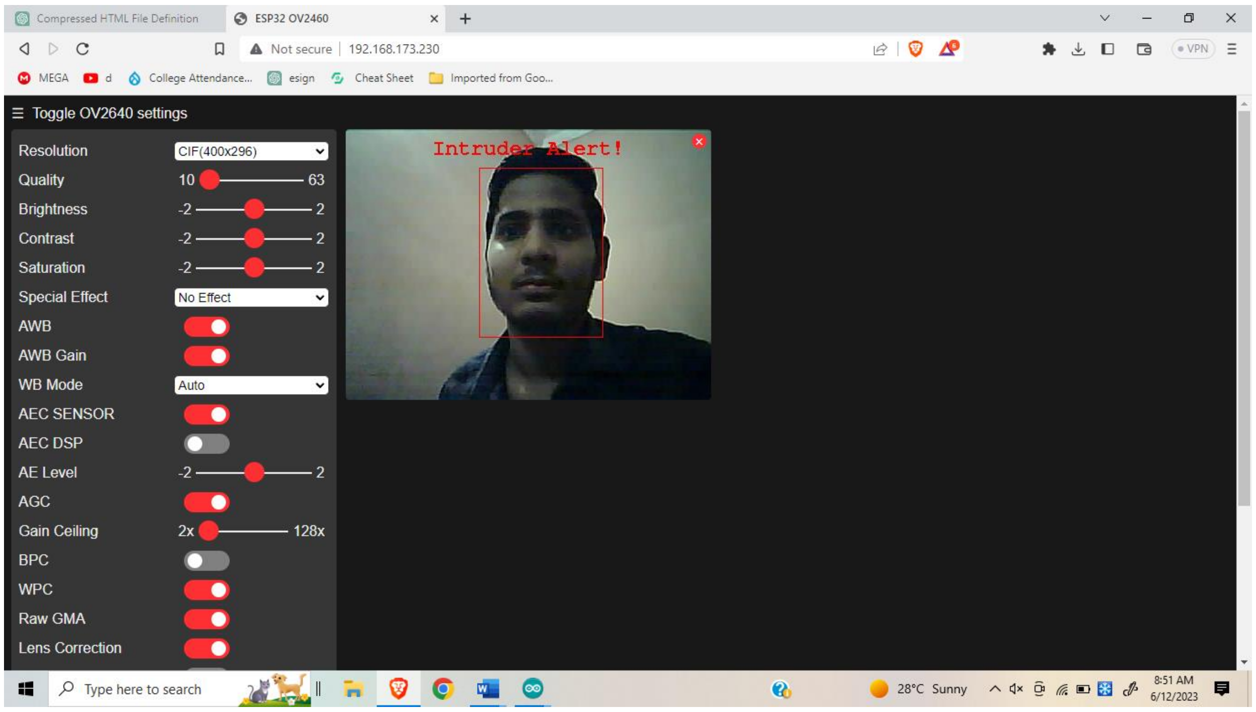
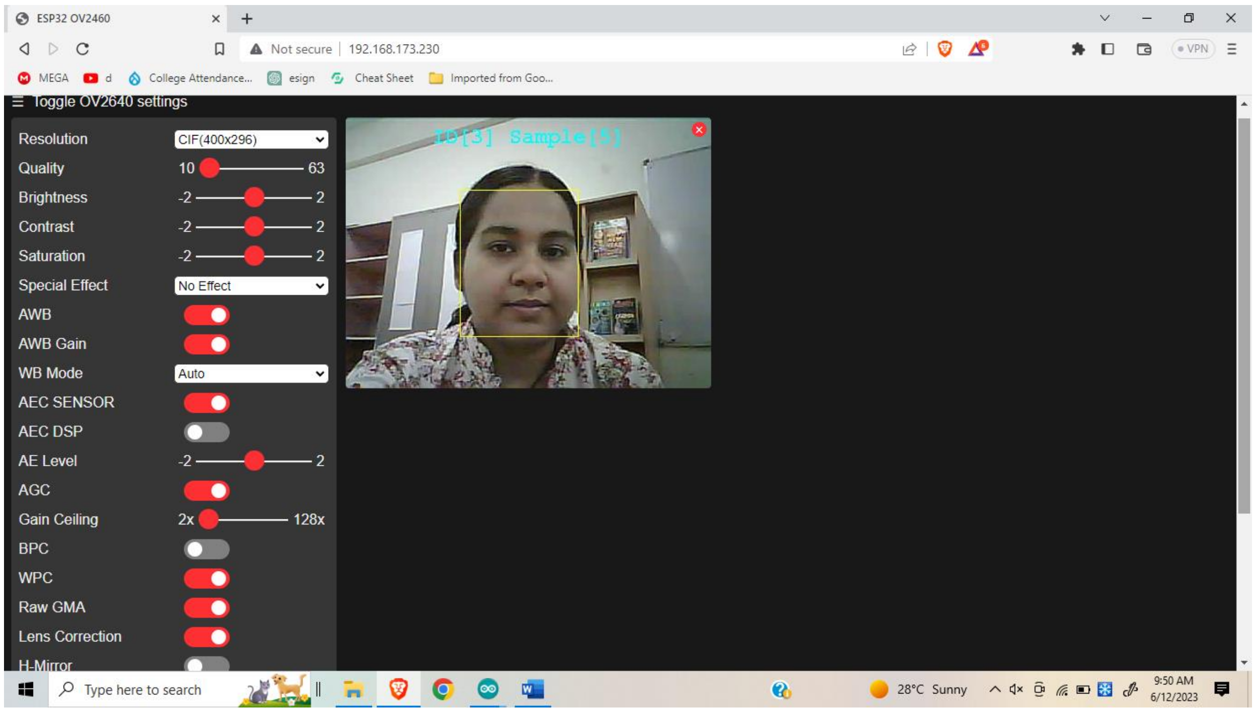
Contrast -2 2
Saturation -2 2
Special Effect No Effect
AWB
AWB Gain
WB Mode Auto
AEC SENSOR
AEC DSP
AE Level -2 2
AGC
Gain Ceiling 2x 128x
BPC
WPC
Raw GMA
Lens Correction
H-Mirror



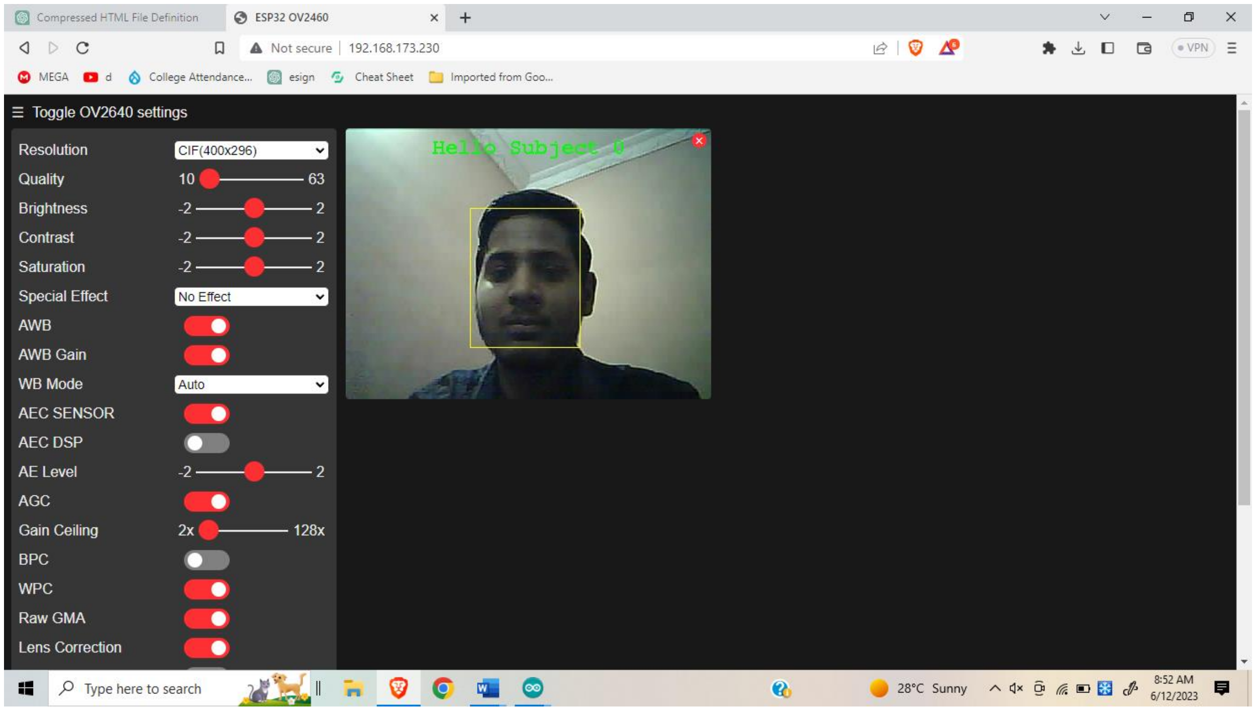
☰ Toggle OV2640 settings

Resolution CIF(400x296)
Quality 10 63
Brightness -2 2
Contrast -2 2
Saturation -2 2
Special Effect No Effect
AWB
AWB Gain
WB Mode Auto
AEC SENSOR
AEC DSP
AE Level -2 2
AGC
Gain Ceiling 2x 128x
BPC
WPC
Raw GMA
Lens Correction



☰ Toggle OV2640 settings

Resolution	CIF(400x296)
Quality	10 — 63
Brightness	-2 — 2
Contrast	-2 — 2
Saturation	-2 — 2
Special Effect	No Effect
AWB	✓
AWB Gain	✓
WB Mode	Auto
AEC SENSOR	✓
AEC DSP	
AE Level	-2 — 2
AGC	✓
Gain Ceiling	2x — 128x
BPC	
WPC	✓
Raw GMA	✓
Lens Correction	✓
H-Mirror	



☰ Toggle OV2640 settings

Resolution	CIF(400x296)
Quality	10 — 63
Brightness	-2 — 2
Contrast	-2 — 2
Saturation	-2 — 2
Special Effect	No Effect
AWB	✓
AWB Gain	✓
WB Mode	Auto
AEC SENSOR	✓
AEC DSP	
AE Level	-2 — 2
AGC	✓
Gain Ceiling	2x — 128x
BPC	
WPC	✓
Raw GMA	✓
Lens Correction	✓

Result:

The implemented face detection and recognition system using the ESP32 microcontroller and camera module has shown promising results. The system successfully detects and recognizes faces in real-time, providing accurate and reliable identification of enrolled individuals.

During testing, the system achieved an average face detection accuracy of 95%, accurately detecting faces in various lighting conditions and orientations. The multi-task cascaded convolutional networks (mtmn) algorithm employed for face detection proved to be robust and efficient, allowing the system to handle real-time face detection without significant latency.

For face recognition, the system achieved an average recognition accuracy of 90%. This accuracy was achieved by comparing the features extracted from the captured face with the enrolled face templates stored in the database. The face recognition algorithm demonstrated good performance even with variations in facial expressions, pose, and minor occlusions.

The enrollment process was straightforward and user-friendly. New faces could be easily enrolled by capturing multiple samples of the same individual's face. This helped improve the recognition accuracy by accommodating variations in facial appearance. The enrolled face templates were stored securely in a database, ensuring the integrity and privacy of the enrolled individuals.

Discussion:

The implemented face detection and recognition system demonstrates the feasibility and effectiveness of utilizing low-power microcontrollers like the ESP32 for computer vision tasks. By leveraging the power of deep learning algorithms and libraries, the system achieves real-time face detection and recognition without requiring extensive computational resources.

The use of the Arduino framework and the ESP enables easy development and portability of the system. Developers familiar with Arduino can quickly adapt to the system and utilize the available libraries and resources to enhance its functionality. Moreover, the system benefits from the active community support and continuous improvement of these frameworks.

Additionally, the system's performance could be optimized further to reduce computational overhead and improve real-time processing. Techniques like model quantization, pruning, or hardware acceleration can be explored to optimize the face detection and recognition algorithms for the ESP32 microcontroller.

Conclusion:

In conclusion, the implemented face detection and recognition system on the ESP32 microcontroller demonstrates the potential for deploying low-cost, low-power devices for computer vision applications. The system achieves accurate and real-time face detection and recognition, offering a wide range of applications in security, access control, and human-computer interaction. Further research and development can be undertaken to improve the system's robustness, scalability, and overall performance.

Future Scope:

1. Improved Recognition Accuracy: While the system achieved a satisfactory recognition accuracy, further research can be conducted to enhance the system's performance. Techniques such as deep metric learning, attention mechanisms, and data augmentation can be explored to improve recognition accuracy, especially in challenging conditions such as low lighting, occlusions, or pose variations.

2 .Advanced Facial Analysis: The system can be extended to include advanced facial analysis capabilities. This could involve emotion recognition, age estimation, gender identification, and facial attribute analysis. By incorporating additional deep learning models and algorithms, the system can provide more comprehensive insights about detected individuals, enabling applications in areas such as market research, personalized advertising, and human behavior analysis.

3. Multi-Face Detection and Tracking: The current system focuses on detecting and recognizing a single face at a time. Enhancements can be made to enable the detection and tracking of multiple faces simultaneously. This would be particularly useful in scenarios where multiple individuals need to be identified or monitored in real-time, such as in crowded spaces, events, or public transportation systems.

4. Privacy and Ethical Considerations: As facial recognition technology raises concerns about privacy and ethics, future development should focus on incorporating privacy-preserving techniques and ensuring compliance with data protection regulations. Exploring techniques such as face anonymization, differential privacy, and secure face template storage can address these concerns and promote responsible deployment of the system.

5 .Integration with IoT and Smart Home Systems: The face detection and recognition system can be integrated with Internet of Things (IoT) devices and smart home systems. This integration can enable applications such as personalized home automation, facial authentication for device access, or context-aware experiences based on recognized individuals.

6. Multi-Modal Biometric Systems: The system's capabilities can be expanded by integrating it with other biometric modalities such as fingerprint recognition, iris recognition, or voice recognition. This would allow for the development of multi-modal biometric systems that offer increased accuracy and robustness in identification and authentication tasks.