



Security system based on ESP32 2021/2022

Microprocessors and Embedded Systems
Project documentation

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1 Introduction

This project aims to create a simple security system that consists of one PIR sensor and a camera. The system should also have WiFi AP capabilities to view captured pictures on the webserver running in this internal network.

For this, we will be using WeMos D1 R32 UNO ESP32, AM312 PIR Motion sensor and AI-Thinker's ESP32-CAM.

1.1 WeMos D1 R32 UNO ESP32

WeMos D1 R32 UNO ESP32 is par of ESP32 series. This is a series low-cost, low-power MCUs with integrated Wi-Fi and Bluetooth.¹

1.2 AI-Thinker's ESP32-CAM

AI-Thinker's ESP32-CAM is ESP32-based small sized camera with integrated Wi-Fi and support for TF cards.²

2 Design

The system will consist of two parts that will be interconnected.

- Motion detection
- Camera and AP

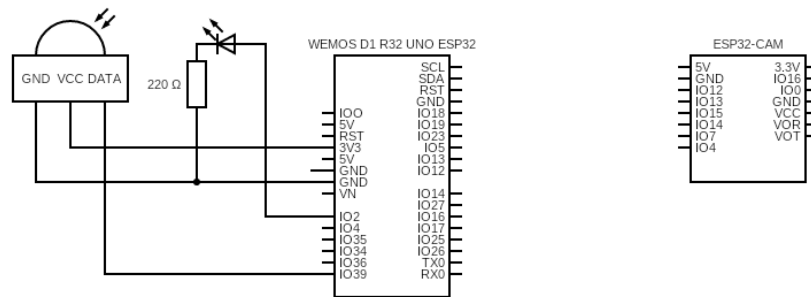


Figure 1: Connection diagram

¹<https://en.wikipedia.org/wiki/ESP32>

²<https://docs.ai-thinker.com/en/esp32-cam>

2.1 Motion detection

Motion detection will be realized using `AM312 PIR Motion sensor` and a `WeMos D1 R32 UNO ESP32`.

The motion detection model attempts to connect to a local WiFi created by a camera module as a first step. This will allow it to send information about a detected motion to the camera.

Detected motion sends a signal from a PIR sensor to an ESP32 unit that creates an HTTP request for a second ESP32 unit (Camera), informing it about this event.

2.1.1 Process of detecting movement

- Wait for a movement (loop waiting)
- Receive signal from a PIR sensor
- Blink debug LED to let us know about detection
- Send signal over HTTP to camera
- Process response and go back to waiting

2.2 Camera and AP

The camera module is responsible for creating a local WiFi network . This module also serves as a web server that displays the latest captured photo.

Another functionality of the camera module and its primary purpose is capturing and saving a photo after receiving the signal from a motion detection module.

2.2.1 Process of capturing a photo

- Receive signal over HTTP about a movement
- Capture a photo (do not retry if failed)
- Save a photo to a memory
- Send a response to the motion detection module (information about the status of photo capture)

2.2.2 Process of presenting a photo

- Listens for requests to a web server
- Receive a request for a latest photo
- Load the photo from a memory
- Display it on the main page (or send to a requester depends on request URL)

3 Implementation

3.1 Used technologies

Implementation of this system was realized using [ESP-IDF](https://docs.espressif.com/projects/esp-idf/en/latest/esp32/) ³, programming language [C](https://www.iso.org/standard/74528.html) ⁴ and [PlatformIO in VSCode](https://docs.platformio.org/en/latest/integration/ide/vscode.html) ⁵.

3.2 Motion detection

3.2.1 PIR sensor

GPIO first had to be chosen and configured as an input to use PIR sensor. For this, GPIO39 was selected. At the same time, debug LED output was configured on GPIO2.

```
1 #include <driver/gpio.h>
2
3 #define LED_GPIO GPIO_NUM_2
4 #define PIR_GPIO GPIO_NUM_39
5
6 // Setup OUTPUT
7 gpio_pad_select_gpio(LED_GPIO);
8 gpio_set_direction(LED_GPIO, GPIO_MODE_OUTPUT);
9 gpio_set_level(LED_GPIO, 0);
10 // Setup INPUT
11 gpio_pad_select_gpio(PIR_GPIO);
12 gpio_set_direction(PIR_GPIO, GPIO_MODE_INPUT);
13
```

After correct configuration of INPUT GPIO it is left running in infinite while loop where it checks if a signal has been received. If it detects signal it blinks with debug LED and calls function to send HTTP request to camera.

```
1 while(1) {
2     if (gpio_get_level(PIR_GPIO)) {
3         timestamp = esp_timer_get_time();
4         gpio_set_level(LED_GPIO, 1);
5         send_request_to_camera();
6         vTaskDelay(delay);
7         gpio_set_level(LED_GPIO, 0);
8     } else {
9         gpio_set_level(LED_GPIO, 0);
10        vTaskDelay(delay);
11    }
12 }
13
```

To prevent it from sending too much requests processing is delayed for 1s using function `vTaskDelay()` and const `delay`.

```
1 const TickType_t delay = 1000 / portTICK_PERIOD_MS;
2
```

³<https://docs.espressif.com/projects/esp-idf/en/latest/esp32/>

⁴<https://www.iso.org/standard/74528.html>

⁵<https://docs.platformio.org/en/latest/integration/ide/vscode.html>

3.2.2 Wireless connection (WiFi STA)

Connection to existing WiFi AP is realized using library "`esp_wifi.h`" and official example code⁶. Default SSID for AP is hardcoded. Our IP and a gateway are saved for further use later in a program during connection.

```
1 #define WIFI_SSID          "ESP32-Cam AP"
2 .
3 my_ip = event->ip_info.ip;
4 gateway = event->ip_info.gw;
5
```

3.2.3 HTTP requests

Sending of a signal to a camera is realized using HTTP request. This functionality can be implemented using library "`esp_http_client.h`". For this project was used modified official example code⁷. Here comes a previously saved gateway address into play - in this system, the gateway is always the camera module. The gateway address is taken as a host and appended `/pir` path. HTTP client is configured with this newly created URL, initiated and called. (Called only on PIR event)

```
1 char temp_url[50];
2 sprintf(temp_url, "http://%d.%d.%d.%d/take-photo", IP2STR(&gateway)
3 );
4 esp_http_client_config_t config = {
5     .url = temp_url,
6     .method = HTTP_METHOD_GET,
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```

3.3 Camera and AP

3.3.1 Wireless connection (WiFi AP)

Camera module servers as the main hub of the system as such it's this module that creates WiFi AP. Library "esp_wifi.h" is used here as well but this time during configuration we chose AP mode.

```
1 esp_netif_create_default_wifi_ap();
2
3
4
5
6
7
8
9
10 wifi_config_t custom_config = {
11     .ap = {
12         .ssid = WIFI_SSID,
13         .ssid_len = strlen(WIFI_SSID),
14         .channel = WIFI_CHAN,
15         .max_connection = WIFI_MSC0,
16         .authmode = WIFI_AUTH_OPEN // Do not require password
17     },
18 };
19 ESP_ERROR_CHECK(esp_wifi_set_mode(WIFI_MODE_AP));
20 ESP_ERROR_CHECK(esp_wifi_set_config(WIFI_IF_AP, &custom_config));
21 ESP_ERROR_CHECK(esp_wifi_start());
22
```

3.3.2 Storage

Due to problems encountered when trying to store pictures on an SD card or SPIFFS⁸, I decided to implement the last taken photo storage as a temporary global variable that is rewritten when a new photo is taken. This decision also makes it easier to serve this photo on the webserver.

```
1 /**
2  * Latest photo store
3  */
4 size_t taken_photo_len = 0;
5 size_t taken_photo_width = 0;
6 size_t taken_photo_height = 0;
7 pixformat_t taken_photo_format = PIXFORMAT_JPEG;
8 uint8_t *taken_photo_buf = NULL;
9
10
11 if (taken_photo_buf != NULL) {
12     free(taken_photo_buf);
13 }
14 taken_photo_buf = malloc(photo->len);
15 memcpy(taken_photo_buf, photo->buf, photo->len);
16
17 taken_photo_format = photo->format;
18 taken_photo_len = photo->len;
19 taken_photo_width = photo->width;
20 taken_photo_height = photo->height;
21
```

⁸<https://docs.espressif.com/projects/esp-idf/en/latest/esp32/api-reference/storage/spiffs.html>

3.3.3 Camera

To initialize the camera, a correct pin schema was needed. This was obtained from ESP-IDF GitHub⁹. I have also decided to enable flash when camera is taking pictures which allows for better visibility during night or in dark rooms.

```
1 gpio_set_level(4, 1);
2 vTaskDelay(delay);
3 camera_fb_t *photo = esp_camera_fb_get();
4 gpio_set_level(4, 0);
5
```

3.3.4 Webserver

Webserver as de facto main 'brain' of the whole system which allows the processing of PIR event and is also serving latest taken photo is implemented using "esp_http_server.h"¹⁰ library from ESP-IDF.

The webserver is served on the default IP address of the camera module 192.168.4.1 and allows for the following paths:

- / - main page which displays latest taken photo and automatically refreshes every 5 seconds
- /latest-photo.jpg - server latest photo captured by PIR event directly
- /take-photo - captures a new photo and displays it directly; this photo is not saved anywhere and does not replace the latest photo captured by the PIR event
- /pir - is used by motion sensor module as an endpoint for sending a signal about the PIR event

All of those endpoints are calling handler functions that are responsible for providing correct data.

```
1 httpd_uri_t index_get = {
2     .uri      = "/",
3     .method   = HTTP_GET,
4     .handler  = get_handler,
5     .user_ctx = NULL
6 };
7 httpd_register_uri_handler(server, &index_get);
8 httpd_uri_t latest_get = {
9     .uri      = "/latest-photo.jpg",
10    .method   = HTTP_GET,
11    .handler  = img_handler,
12    .user_ctx = NULL
13 };
14 httpd_register_uri_handler(server, &latest_get);
```

⁹https://github.com/espressif/esp32-camera/blob/master/examples/main/take_picture.c

¹⁰https://docs.espressif.com/projects/esp-idf/en/latest/esp32/api-reference/protocols/esp_http_server.html


```
15 httpd_uri_t pir_post = {
16     .uri      = "/pir",
17     .method    = HTTP_GET,
18     .handler   = pir_handler,
19     .user_ctx  = NULL
20 };
21 httpd_register_uri_handler(server, &pir_post);
22 httpd_uri_t take_post = {
23     .uri      = "/take-photo",
24     .method    = HTTP_GET,
25     .handler   = take_handler,
26     .user_ctx  = NULL
27 };
28 httpd_register_uri_handler(server, &take_post);
29
```

4 Conclusion

In conclusion this project was a lot of fun as it allowed me to learn a lot about ESP32 lower lever programming as compared to Arduino framework. The only thing that should be fixed that I'm aware of is the lack of archiving older photos on SD card or some other media.

4.0.1 Notes

Due to problem with programmer for AI-Thinker's ESP32-CAM which cause following error to appear a lot even when following correct procedure, programming and testing anything on AI-Thinker's ESP32-CAM was incredibly difficult and time consuming.

```
1 Traceback (most recent call last):
2 File "C:\Users\roman\.platformio\packages\tool-esptoolpy\esptool.py
  ", line 4582, in <module>
3   _main()
4 File "C:\Users\roman\.platformio\packages\tool-esptoolpy\esptool.py
  ", line 4575, in _main
5   main()
6 File "C:\Users\roman\.platformio\packages\tool-esptoolpy\esptool.py
  ", line 4074, in main
7   esp = esp or get_default_connected_device(ser_list, port=args.
  port, connect_attempts=args.connect_attempts,
8 File "C:\Users\roman\.platformio\packages\tool-esptoolpy\esptool.py
  ", line 121, in get_default_connected_device
9   _esp.connect(before, connect_attempts)
10 File "C:\Users\roman\.platformio\packages\tool-esptoolpy\esptool.py
  ", line 632, in connect
11   last_error = self._connect_attempt(mode=mode, esp32r0_delay=
  True, usb_jtag_serial=usb_jtag_serial)
12 File "C:\Users\roman\.platformio\packages\tool-esptoolpy\esptool.py
  ", line 596, in _connect_attempt
13   self.sync()
14 File "C:\Users\roman\.platformio\packages\tool-esptoolpy\esptool.py
  ", line 486, in sync
15   val, _ = self.command(self.ESP_SYNC, b'\x07\x07\x12\x20' + 32 *
  b'\x55',
16 File "C:\Users\roman\.platformio\packages\tool-esptoolpy\esptool.py
  ", line 418, in command
17   self._port.timeout = new_timeout
18 File "C:\Users\roman\.platformio\penv\lib\site-packages\serial\
  serialutil.py", line 372, in timeout
19   self._reconfigure_port()
20 File "C:\Users\roman\.platformio\penv\lib\site-packages\serial\
  serialwin32.py", line 222, in _reconfigure_port
21   raise SerialException(
22 serial.serialutil.SerialException: Cannot configure port, something
  went wrong. Original message: PermissionError(13, 'Access is
  denied.', None, 5)
23 *** [upload] Error 1
24
```

5 Attachments

Latest photo captured by ESP32 Camera

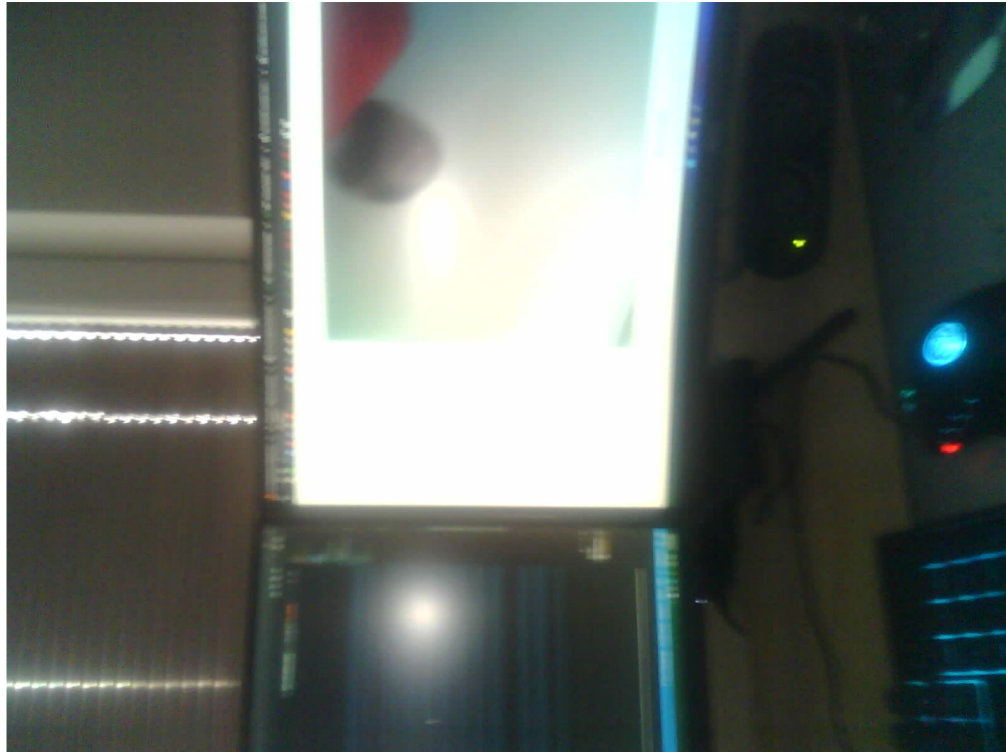


Figure 2: Main page of webserver

```

I (528333) [ESP32 PIR]: [PIR] Motion detected at 52345238!
I (528333) [ESP32 PIR]: [PIR] Sending signal to the camera!
W (52873) wifi:<ba-addr>idx:0 (ifx:0, 7c:9e:bd:38:3d:89), tid:0, ssn:0, winSize:64
E (57923) [ESP32 PIR]: [HTTP] Sending PIR signal to CAM failed (ESP_ERR_HTTP_FETCH_HEADER)
I (57923) [ESP32 PIR]: [HTTP] DISCONNECTED
I (65923) [ESP32 PIR]: [PIR] Motion detected at 65435238!
I (65923) [ESP32 PIR]: [PIR] Sending signal to the camera!
E (71353) [ESP32 PIR]: [HTTP] Sending PIR signal to CAM failed (ESP_ERR_HTTP_FETCH_HEADER)
I (71353) [ESP32 PIR]: [HTTP] DISCONNECTED
I (82353) [ESP32 PIR]: [PIR] Motion detected at 81865234!
I (82353) [ESP32 PIR]: [PIR] Sending signal to the camera!
I (83363) [ESP32 PIR]: [HTTP] Response from CAM to PIR signal : 200 : 47
I (83363) [ESP32 PIR]: Picture taken! (
I (83363) [ESP32 PIR]: 1600 x 1200, siz
I (83373) [ESP32 PIR]: e: 82018 bytes)
I (83373) [ESP32 PIR]: [HTTP] DISCONNECTED
I (117383) [ESP32 PIR]: [PIR] Motion detected at 116895238!
I (117383) [ESP32 PIR]: [PIR] Sending signal to the camera!
I (118373) [ESP32 PIR]: [HTTP] Response from CAM to PIR signal : 200 : 47
I (118373) [ESP32 PIR]: Picture taken! (
I (118373) [ESP32 PIR]: 1600 x 1200, siz
I (118373) [ESP32 PIR]: e: 61508 bytes)
I (118383) [ESP32 PIR]: [HTTP] DISCONNECTED
I (532393) [ESP32 PIR]: [PIR] Motion detected at 531905238!
I (532393) [ESP32 PIR]: [PIR] Sending signal to the camera!
I (533403) [ESP32 PIR]: [HTTP] Response from CAM to PIR signal : 200 : 48
I (533403) [ESP32 PIR]: Picture taken! (
I (533403) [ESP32 PIR]: 1600 x 1200, siz
I (533413) [ESP32 PIR]: e: 124800 bytes)
I (533413) [ESP32 PIR]: [HTTP] DISCONNECTED
I (544423) [ESP32 PIR]: [PIR] Motion detected at 543935234!
I (544423) [ESP32 PIR]: [PIR] Sending signal to the camera!
I (545443) [ESP32 PIR]: [HTTP] Response from CAM to PIR signal : 200 : 47
I (545443) [ESP32 PIR]: Picture taken! (
I (545453) [ESP32 PIR]: 1600 x 1200, siz
I (545453) [ESP32 PIR]: e: 62020 bytes)
I (545453) [ESP32 PIR]: [HTTP] DISCONNECTED
I (3455463) [ESP32 PIR]: [PIR] Motion detected at 3454975234!
I (3455463) [ESP32 PIR]: [PIR] Sending signal to the camera!
I (3456483) [ESP32 PIR]: [HTTP] Response from CAM to PIR signal : 200 : 47
I (3456483) [ESP32 PIR]: Picture taken! (
I (3456483) [ESP32 PIR]: 1600 x 1200, siz
I (3456483) [ESP32 PIR]: e: 81962 bytes)
I (3456493) [ESP32 PIR]: [HTTP] DISCONNECTED
I (5326493) [ESP32 PIR]: [PIR] Motion detected at 5326005234!
I (5326493) [ESP32 PIR]: [PIR] Sending signal to the camera!
I (5327263) [ESP32 PIR]: [HTTP] Response from CAM to PIR signal : 200 : 47
I (5327263) [ESP32 PIR]: Picture taken! (
I (5327263) [ESP32 PIR]: 1600 x 1200, siz
I (5327263) [ESP32 PIR]: e: 80327 bytes)
I (5327273) [ESP32 PIR]: [HTTP] DISCONNECTED
I (10503273) [ESP32 PIR]: [PIR] Motion detected at 10502785234!
I (10503273) [ESP32 PIR]: [PIR] Sending signal to the camera!
I (10504283) [ESP32 PIR]: [HTTP] Response from CAM to PIR signal : 200 : 47
I (10504283) [ESP32 PIR]: Picture taken! (
I (10504283) [ESP32 PIR]: 1600 x 1200, siz
I (10504293) [ESP32 PIR]: e: 84861 bytes)
I (10504293) [ESP32 PIR]: [HTTP] DISCONNECTED

```

Figure 3: Logged PIR event on motion detection module