Learning Report – Embedded C

L&T Technology Services

Document History

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Contents

Activity 1 – COMPILATION APROACH

This is the complete compilation process of the sample program for ARM Cortex Mx processor based boards. Following are the compilation stages of a C program:

1. Preprocessor stage
2. Compilation stage
3. Assembly stage
4. Linking stage

1.1- MAKE FILE

Below is the make file for the sample program:

```
CC=arm-none-eabi-gcc
MACH=cortex-m4
CFLAGS= -c -mcpu=$(MACH) -mthumb -std=gnu11 -Wall -O0
LDFLAGS= -nostdlib -T stm32_ls.ld -Wl,-Map=final.map

all:main.o stm32_startup.o

main.o:main.c
	$(CC) $(CFLAGS) -o $@ $^

stm32_startup.o:stm32_startup.c
	$(CC) $(CFLAGS) -o $@ $^

final.elf: main.o stm32_startup.o
	$(CC) $(LDLAGS) -o $@ $^

```

Fig 1.1.1 make file

The command to run this make file in the command prompt is:

Fig 1.1.2 Make command

- **-mcpu=cortex-m4** is used to select our cortex-m4 processor which is used
- **-mthumb** is used to generate the code that executes in ARM state
- **main.o** is the target file
- **main.c** is the dependency

1.2- STARTUP CODE

- The startup file is responsible for setting up the right environments to run the code in main.c file.
- Some part of the startup code is target (processor) dependent.
- Role of startup file:
  1. Create a MCU specific vector table for microcontroller.
  2. To write a startup code which initializes .data and .bss section in SRAM.
  3. Call main()

```c
#include<stdint.h>

#define SRAM_START  0x20000000U
#define SRAM_SIZE   (128U * 1024U) //128KB
#define SRAM_END    ((SRAM_START) + (SRAM_SIZE))

#define STACK_START   SRAM_END

extern uint32_t _etext;
extern uint32_t _sdata;
extern uint32_t _edata;
extern uint32_t _la_data;

extern uint32_t _sbss;
extern uint32_t _ebss;

//prototype of main

int main(void);

void __libc_init_array(void);


/* function prototypes of STM32F407x system exception and IRQ handlers */

void Reset_Handler(void);

void NMI_Handler                   (void) __attribute__ ((weak, alias("Default_Handler")));
void HardFault_Handler             (void) __attribute__ ((weak, alias("Default_Handler")));
void MemManage_Handler             (void) __attribute__ ((weak, alias("Default_Handler")));
void BusFault_Handler              (void) __attribute__ ((weak, alias("Default_Handler")));
void UsageFault_Handler            (void) __attribute__ ((weak, alias("Default_Handler")));
void SVC_Handler                   (void) __attribute__ ((weak, alias("Default_Handler")));
void DebugMon_Handler              (void) __attribute__ ((weak, alias("Default_Handler")));
void PendSV_Handler                (void) __attribute__ ((weak, alias("Default_Handler")));
void SysTick_Handler               (void) __attribute__ ((weak, alias("Default_Handler")));
void WWDG_IRQHandler               (void) __attribute__ ((weak, alias("Default_Handler")));
void PVD_IRQHandler                (void) __attribute__ ((weak, alias("Default_Handler")));
void TAMP_STAMP_IRQHandler         (void) __attribute__ ((weak, alias("Default_Handler")));
void RTC_WKUP_IRQHandler           (void) __attribute__ ((weak, alias("Default_Handler")));
void RCC_IRQHandler                (void) __attribute__ ((weak, alias("Default_Handler")));
void EXTI0_IRQHandler              (void) __attribute__ ((weak, alias("Default_Handler")));
void EXTI1_IRQHandler              (void) __attribute__ ((weak, alias("Default_Handler")));
void EXTI2_IRQHandler              (void) __attribute__ ((weak, alias("Default_Handler")));
void EXTI3_IRQHandler              (void) __attribute__ ((weak, alias("Default_Handler")));
void EXTI4_IRQHandler              (void) __attribute__ ((weak, alias("Default_Handler")));
void DMA1_Stream0_IRQHandler       (void) __attribute__ ((weak, alias("Default_Handler")));
void DMA1_Stream1_IRQHandler       (void) __attribute__ ((weak, alias("Default_Handler")));
void DMA1_Stream2_IRQHandler       (void) __attribute__ ((weak, alias("Default_Handler")));
void DMA1_Stream3_IRQHandler       (void) __attribute__ ((weak, alias("Default_Handler")));
void DMA1_Stream4_IRQHandler       (void) __attribute__ ((weak, alias("Default_Handler")));
void DMA1_Stream5_IRQHandler       (void) __attribute__ ((weak, alias("Default_Handler")));
void DMA1_Stream6_IRQHandler       (void) __attribute__ ((weak, alias("Default_Handler")));
void ADC_IRQHandler                (void) __attribute__ ((weak, alias("Default_Handler")));
void CAN1_TX_IRQHandler            (void) __attribute__ ((weak, alias("Default_Handler")));
void CAN1_RX0_IRQHandler           (void) __attribute__ ((weak, alias("Default_Handler")));
void CAN1_RX1_IRQHandler           (void) __attribute__ ((weak, alias("Default_Handler")));
```

```c
    (uint32_t)DMA2_Stream3_IRQHandler,
    (uint32_t)DMA2_Stream4_IRQHandler,
    (uint32_t)ETH_IRQHandler,
    (uint32_t)ETH_WKUP_IRQHandler,
    (uint32_t)CAN2_TX_IRQHandler,
    (uint32_t)CAN2_RX0_IRQHandler,
    (uint32_t)CAN2_RX1_IRQHandler,
    (uint32_t)CAN2_SCE_IRQHandler,
    (uint32_t)OTG_FS_IRQHandler,
    (uint32_t)DMA2_Stream5_IRQHandler,
    (uint32_t)DMA2_Stream6_IRQHandler,
    (uint32_t)DMA2_Stream7_IRQHandler,
    (uint32_t)USART6_IRQHandler,
    (uint32_t)I2C3_EV_IRQHandler,
    (uint32_t)I2C3_ER_IRQHandler,
    (uint32_t)OTG_HS_EP1_OUT_IRQHandler,
    (uint32_t)OTG_HS_EP1_IN_IRQHandler,
    (uint32_t)OTG_HS_WKUP_IRQHandler,
    (uint32_t)OTG_HS_IRQHandler,
    (uint32_t)DCMI_IRQHandler,
    (uint32_t)CRYP_IRQHandler,
    (uint32_t)HASH_RNG_IRQHandler,
    (uint32_t)FPU_IRQHandler,
};


void Default_Handler(void)
{
    while(1);
}

void Reset_Handler(void)
{
    //copy .data section to SRAM
    uint32_t size = (uint32_t)&_edata - (uint32_t)&_sdata;

    uint8_t *pDst = (uint8_t*)&_sdata; //sram
    uint8_t *pSrc = (uint8_t*)&_la_data; //flash

    for(uint32_t i =0 ; i < size ; i++)
    {
        *pDst++ = *pSrc++;
    }

    //Init. the .bss section to zero in SRAM
    size = (uint32_t)&_ebss - (uint32_t)&_sbss;
    pDst = (uint8_t*)&_sbss;
    for(uint32_t i =0 ; i < size ; i++)
    {
        *pDst++ = 0;
    }

    //__libc_init_array();

    main();

}
```

Fig 1.2.1 Startup code

In startup code we use variable attributes to store some variables in the user defined function.
Function attributes:

- Weak: Lets programmer override already defined weak function (dummy function) with the same function name.
- Alias: Lets programmer give any alias name for same function.

The startup.o file generated is of elf executable format, various sections of which are shown below:

```
C:\Windows\System32\cmd.exe

C:\Users\Training\STM32CubeIDE\workspace_1.5.0\new\Src>make -f Makefile.mak
arm-none-eabi-gcc -c -mcpu=cortex-m4 -mthumb -std=gnu11 -Wall -O0  -o stm32_startup.o stm32_startup.c

C:\Users\Training\STM32CubeIDE\workspace_1.5.0\new\Src>arm-none-eabi-objdump.exe -h stm32_startup.o

stm32_startup.o:     file format elf32-littlearm

Sections:
Idx Name          Size      VMA       LMA       File off  Algn
  0 .text         00000090  00000000  00000000  00000034  2**2
                  CONTENTS, ALLOC, LOAD, RELOC, READONLY, CODE
  1 .data         00000000  00000000  00000000  000000c4  2**0
                  CONTENTS, ALLOC, LOAD, DATA
  2 .bss          00000000  00000000  00000000  000000c4  2**0
                  ALLOC
  3 .isr_vector   00000188  00000000  00000000  000000c4  2**2
                  CONTENTS, ALLOC, LOAD, RELOC, DATA
  4 .comment      0000004e  00000000  00000000  0000024c  2**0
                  CONTENTS, READONLY
  5 .ARM.attributes 0000002e  00000000  00000000  0000029a  2**0
                  CONTENTS, READONLY

C:\Users\Training\STM32CubeIDE\workspace_1.5.0\new\Src>
```

Fig 1.2.2: Startup command

1.3- LINKER SCRIPT

- Linkers take one or more object files or libraries as input and combines them to create a single executable file as output.
- Linker scripts decide how different sections of object file should be merged to create an output file.
- Reset handler is the entry point to the application
- Entry command is used to set the “Entry point address” information in the header of final elf file generated.
  Syntax: Entry(symbol_name)
  Entry(Reset_Handler)

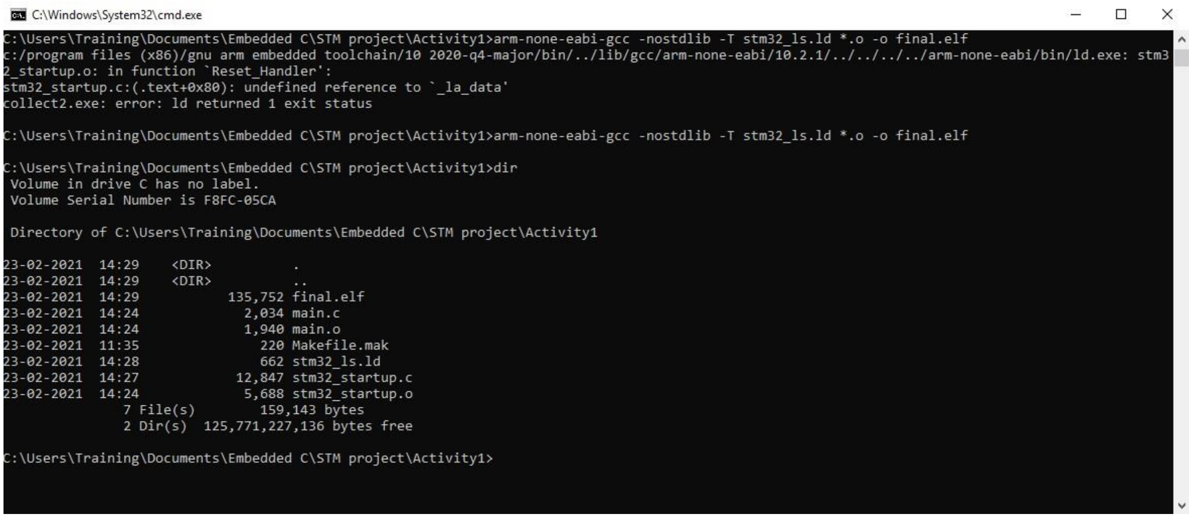
```
{
  FLASH(rx):ORIGIN =0x08000000,LENGTH =1024K
  SRAM(rwx):ORIGIN =0x20000000,LENGTH =128K
}


SECTIONS
{
  .text :
  {
    *(.isr_vector)
    *(.text)
    *(.text.*)
    *(.init)
    *(.fini)
    *(.rodata)
    *(.rodata.*)
    . = ALIGN(4);
    _etext = .;
  }> FLASH

  _la_data = LOADADDR(.data);

  .data :
  {
    _sdata = .;
    *(.data)
    *(.data.*)
    . = ALIGN(4);
    _edata = .;
  }> SRAM AT> FLASH

  .bss :
  {
    _sbss = .;
    __bss_start__ = _sbss;
    *(.bss)
    *(.bss.*)
    *(COMMON)
    . = ALIGN(4);
    _ebss = .;
    __bss_end__ = _ebss;
       . = ALIGN(4);
    end = .;
    __end__ = .;
  }> SRAM
```



```
C:\Windows\System32\cmd.exe
C:\Users\Training\Documents\Embedded C\STM project\Activity1>arm-none-eabi-gcc -nostdlib -T stm32_ls.ld *.o -o final.elf
c:/program files (x86)/gnu arm embedded toolchain/10 2020-q4-major/bin/../lib/gcc/arm-none-eabi/10.2.1/../../../../arm-none-eabi/bin/ld.exe: stm3
2_startup.o: in function `Reset_Handler':
stm32_startup.c:(.text+0x80): undefined reference to `_la_data'
collect2.exe: error: ld returned 1 exit status

C:\Users\Training\Documents\Embedded C\STM project\Activity1>arm-none-eabi-gcc -nostdlib -T stm32_ls.ld *.o -o final.elf

C:\Users\Training\Documents\Embedded C\STM project\Activity1>dir
 Volume in drive C has no label.
 Volume Serial Number is F8FC-05CA

 Directory of C:\Users\Training\Documents\Embedded C\STM project\Activity1

23-02-2021  14:29    <DIR>          .
23-02-2021  14:29    <DIR>          ..
23-02-2021  14:29           135,752 final.elf
23-02-2021  14:24             2,034 main.c
23-02-2021  14:24             1,940 main.o
23-02-2021  11:35               220 Makefile.mak
23-02-2021  14:28               662 stm32_ls.ld
23-02-2021  14:27            12,847 stm32_startup.c
23-02-2021  14:24             5,688 stm32_startup.o
               7 File(s)        159,143 bytes
               2 Dir(s)  125,771,227,136 bytes free

C:\Users\Training\Documents\Embedded C\STM project\Activity1>
```

Fig 1.3.1 command to generate final.elf file

1.4- DEBUGGING TECHNIQUES

- The STM32F407VG is embedded with on chip debugger for debugging the code.
- The OCD ON-Chip Debugger aims to provide debugging, in system programming and boundary scan testing for embedded target devices.
- OCD is a free and opensource host application allows you to program, debug, and analyze your applications using GDB.
- It supports various target boards based on different processor architecture.

Activity 2 – IMPLEMENTATION OF PROTOCOLS USING STM IDE

Implementation of protocols for STM32F407VG microcontroller featuring ARM32 bit ARM-cortex M4 with FPU core using HAL library.

2.1 GPIO:

Toggling LED at pin PD12 at GREEN_LED_GPIO_PORT. Serial wire is enabled at pin PA13.

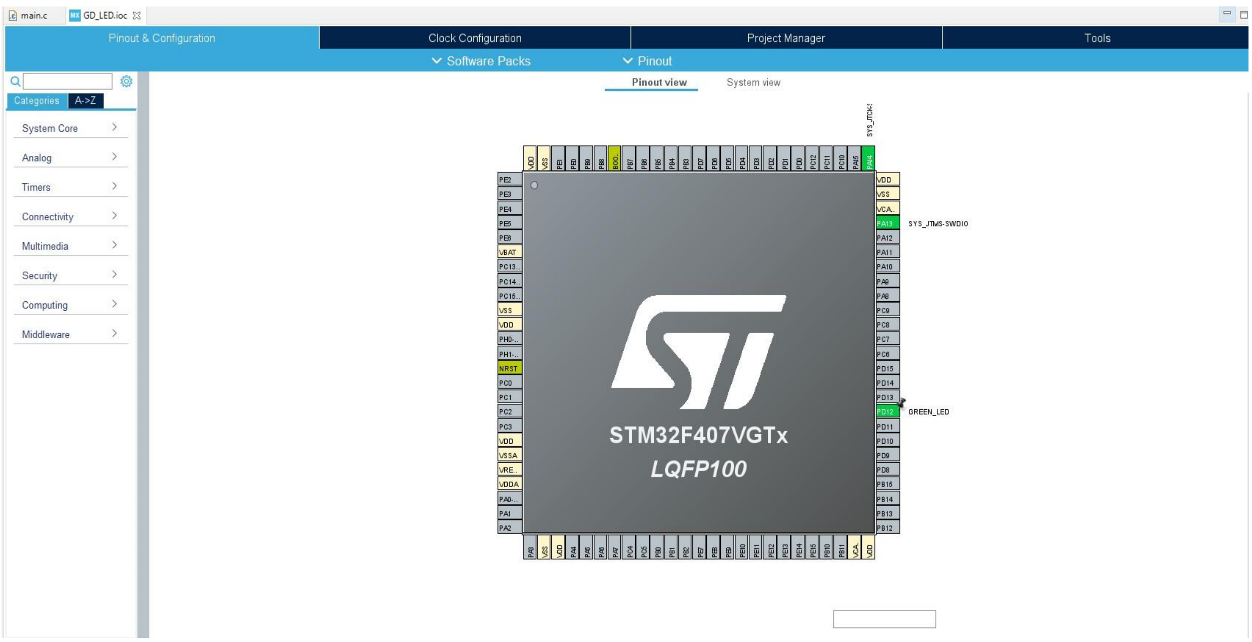


Fig: 2.1.1 GPIO pin configuration

```
/* Initialize all configured peripherals */
MX_GPIO_Init();
/* USER CODE BEGIN 2 */

/* USER CODE END 2 */

/* Infinite loop */
/* USER CODE BEGIN WHILE */
while (1)
{
    HAL_GPIO_TogglePin(GREEN_LED_GPIO_Port, GREEN_LED_Pin);
    HAL_Delay(500);
  /* USER CODE END WHILE */

  /* USER CODE BEGIN 3 */
}
/* USER CODE END 3 */
}
```

Fig: 2.1.2 GPIO configuration code

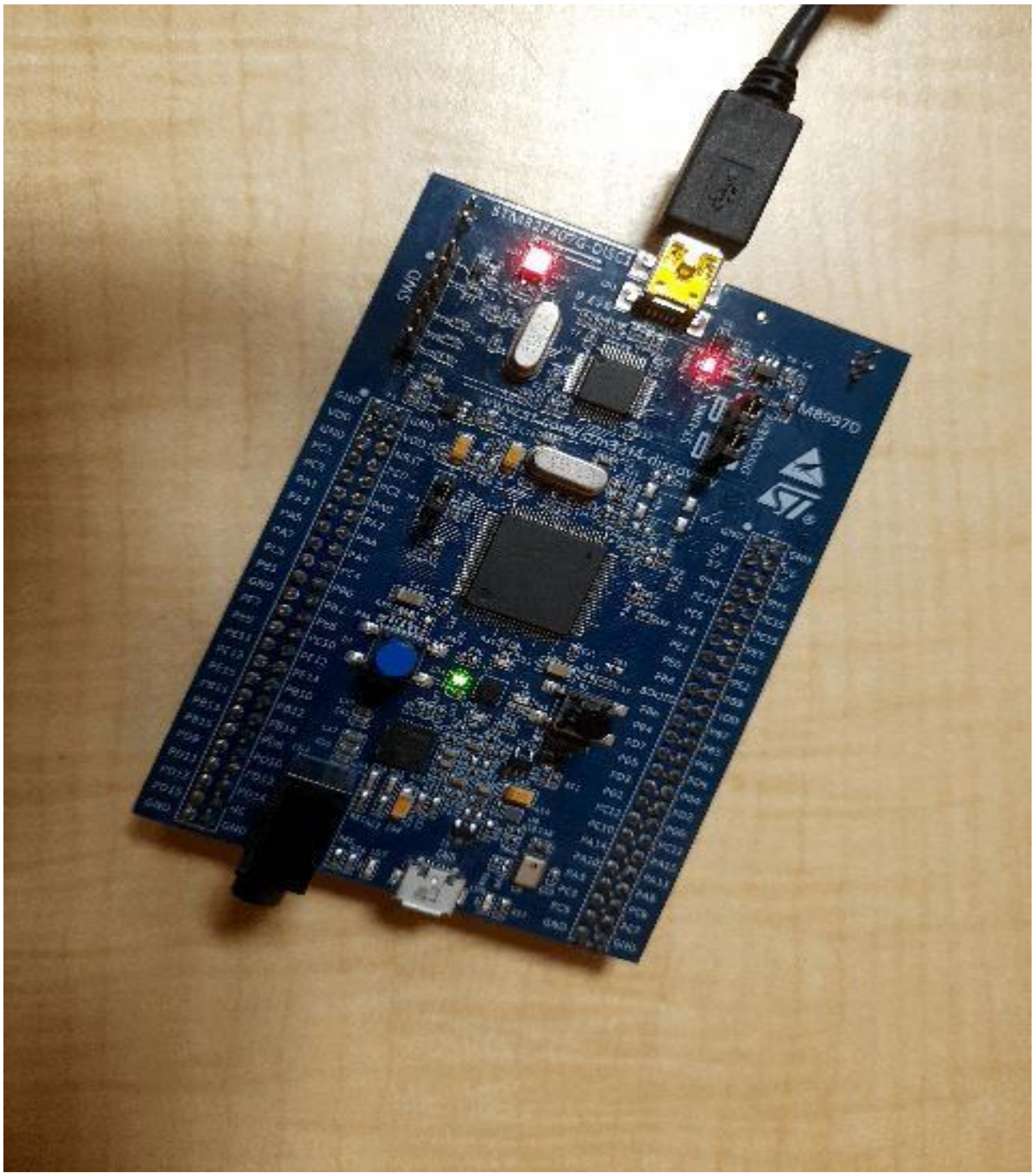


Fig: 2.1.2 LED toggling

2.2 EXTI :-

Blue button at PA0 works as an external interrupt.
When the blue button is pressed the Green LED at pin PD12 toggles.

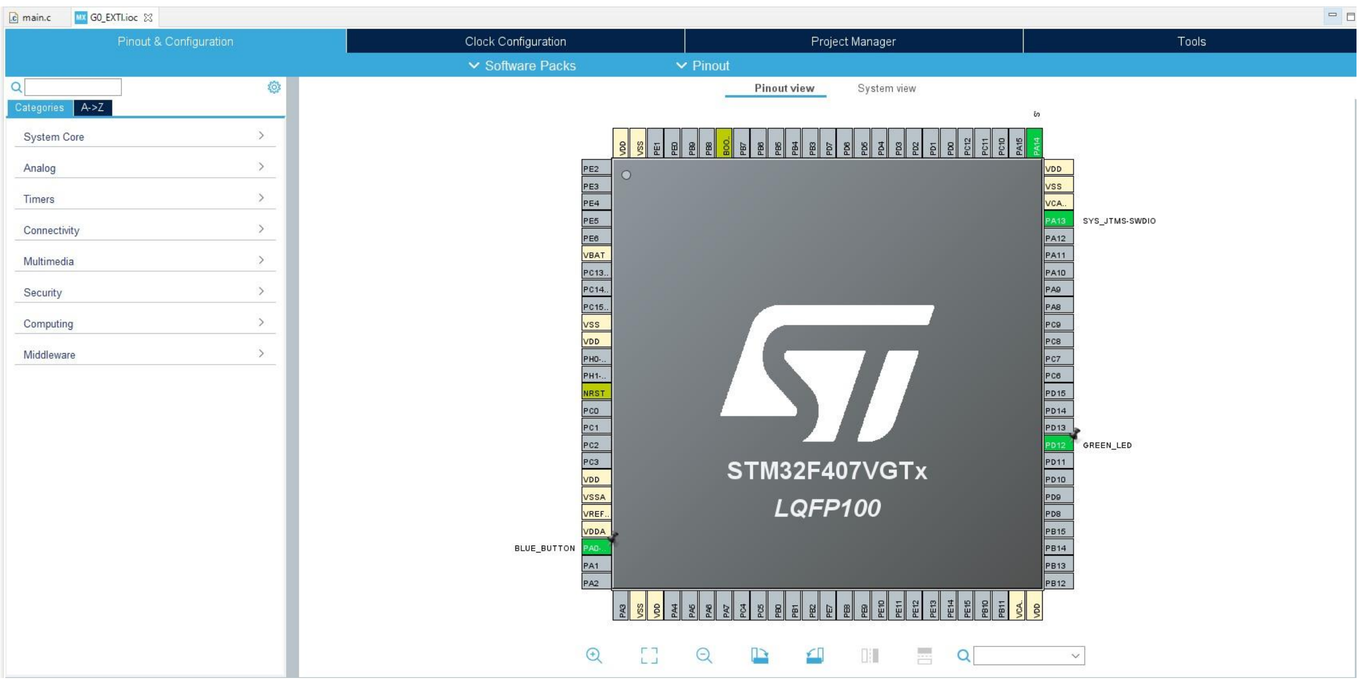


Fig: 2.2.1 EXTI pin configuration

In the main.c file a flag is initialized and if the flag == 1, the condition under the if loop executed to toggle the LED at PD12.

main.c G0_EXTI.ioc

```c

/* USER CODE BEGIN PV */
uint8_t flag = 0;
/* USER CODE END PV */

/* Private function prototypes -----------------------------------------------*/
void SystemClock_Config(void);
static void MX_GPIO_Init(void);
/* USER CODE BEGIN PFP */

/* USER CODE END PFP */

/* Private user code ---------------------------------------------------------*/
/* USER CODE BEGIN 0 */

/* USER CODE END 0 */

/**
  * @brief  The application entry point.
  * @retval int
  */
int main(void)
{
  /* USER CODE BEGIN 1 */

  /* USER CODE END 1 */

  /* MCU Configuration--------------------------------------------------------*/

  /* Reset of all peripherals, Initializes the Flash interface and the Systick. */
  HAL_Init();

  /* USER CODE BEGIN Init */

  /* USER CODE END Init */

  /* Configure the system clock */
  SystemClock_Config();

  /* USER CODE BEGIN SysInit */

  /* USER CODE END SysInit */

  /* Initialize all configured peripherals */
  MX_GPIO_Init();
  /* USER CODE BEGIN 2 */

  /* USER CODE END 2 */

  /* Infinite loop */
  /* USER CODE BEGIN WHILE */
  while (1)
  {
    /* USER CODE END WHILE */
      if(1==flag){
              HAL_GPIO_TogglePin(GREEN_LED_GPIO_Port, GREEN_LED_Pin);
              HAL_Delay(500);
              flag = 0;
          }
    /* USER CODE BEGIN 3 */
  }
```

Fig: 2.2.1 EXTI configuration code

2.3 ADC

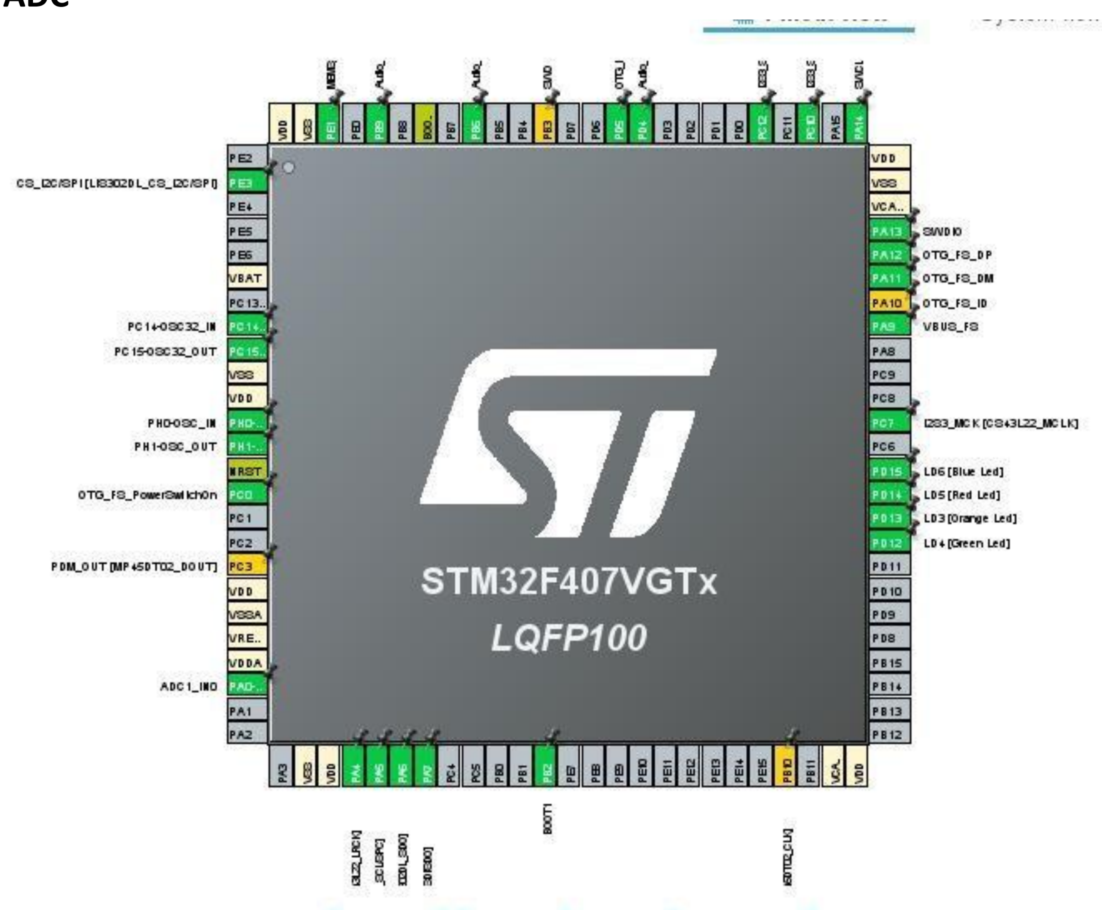


Fig: 2.3.1 ADC pin configuration

2.4 SPI

```c
/* USER CODE END Header */
/* Includes ------------------------------------------------------------------*/
#include "main.h"
#include "usb_host.h"


ADC_HandleTypeDef hadc1;

I2C_HandleTypeDef hi2c1;

I2S_HandleTypeDef hi2s3;

SPI_HandleTypeDef hspi1;


/* Private function prototypes -----------------------------------------------*/
void SystemClock_Config(void);
static void MX_GPIO_Init(void);
static void MX_I2C1_Init(void);
static void MX_I2S3_Init(void);
static void MX_SPI1_Init(void);
static void MX_ADC1_Init(void);
void MX_USB_HOST_Process(void);


uint32_t adc_value;

int main(void)
{

  HAL_Init();

  SystemClock_Config();

  MX_GPIO_Init();
  MX_I2C1_Init();
  MX_I2S3_Init();
```

```c

  MX_GPIO_Init();
  MX_I2C1_Init();
  MX_I2S3_Init();
  MX_SPI1_Init();
  MX_USB_HOST_Init();
  MX_ADC1_Init();

  while (1)
  {

    MX_USB_HOST_Process();


    HAL_ADC_Start(&hadc1);


    if(HAL_ADC_PollForConversion(&hadc1, 5)== HAL_OK){

        adc_value= HAL_ADC_GetValue(&hadc1);

    }


    HAL_ADC_Stop(&hadc1);
    HAL_Delay(100);

  }

}


void SystemClock_Config(void)
{
  RCC_OscInitTypeDef RCC_OscInitStruct = {0};
  RCC_ClkInitTypeDef RCC_ClkInitStruct = {0};
  RCC_PeriphCLKInitTypeDef PeriphClkInitStruct = {0};
```

Fig: Configuration code

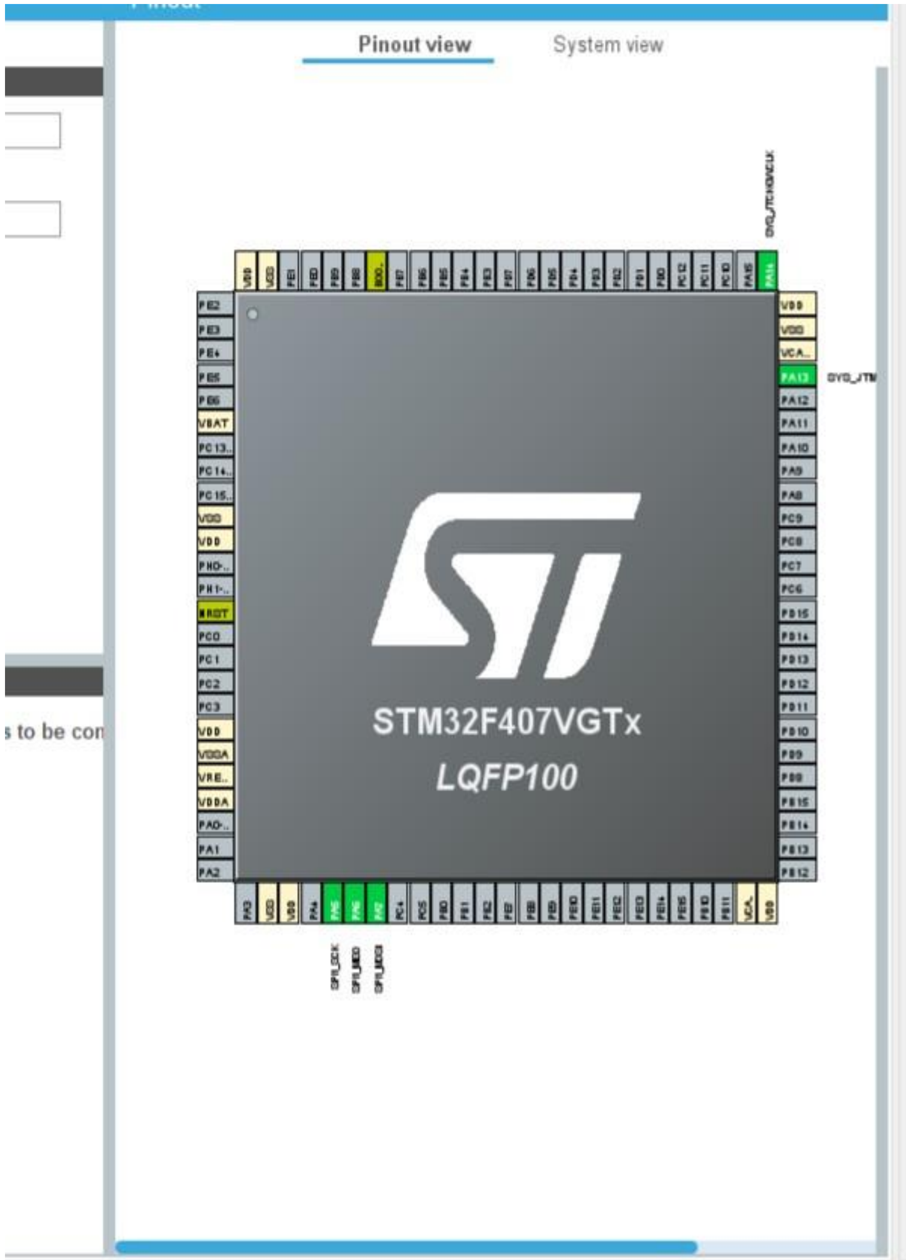
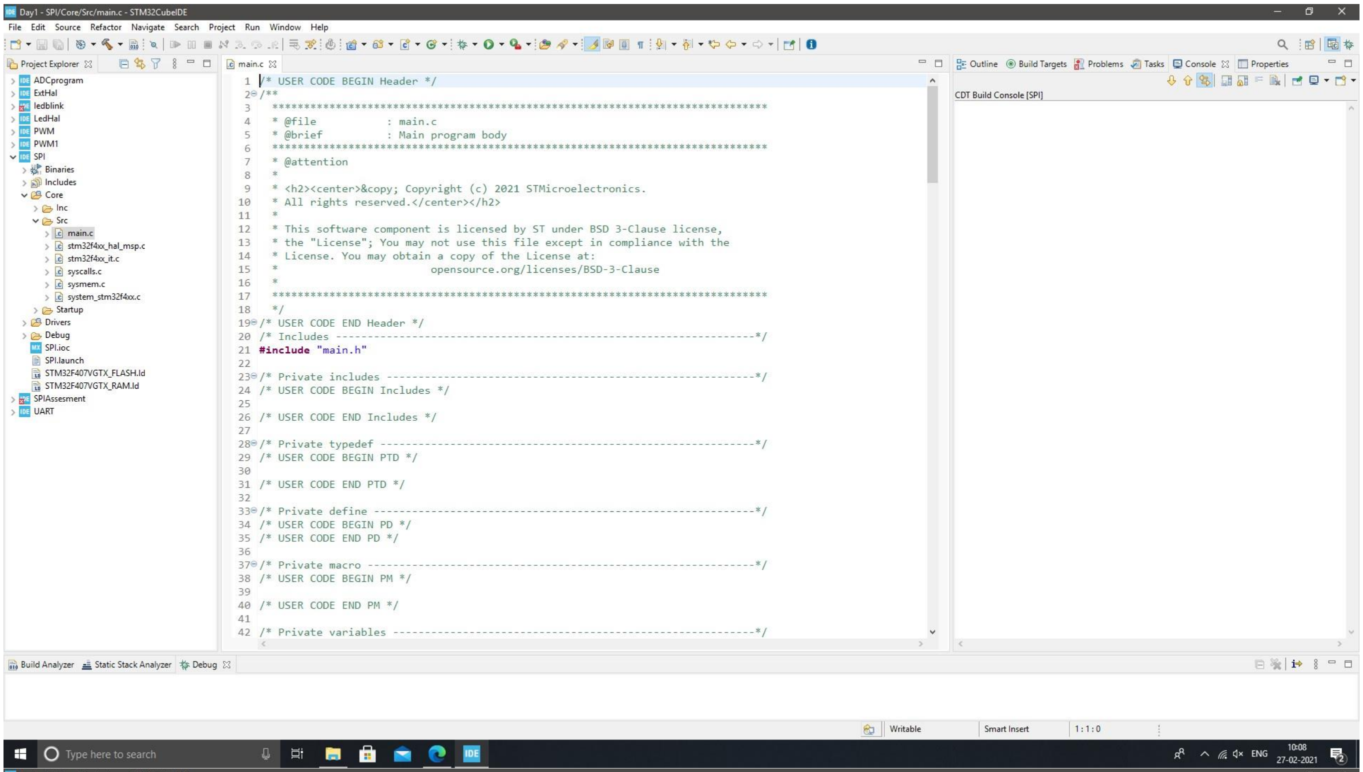
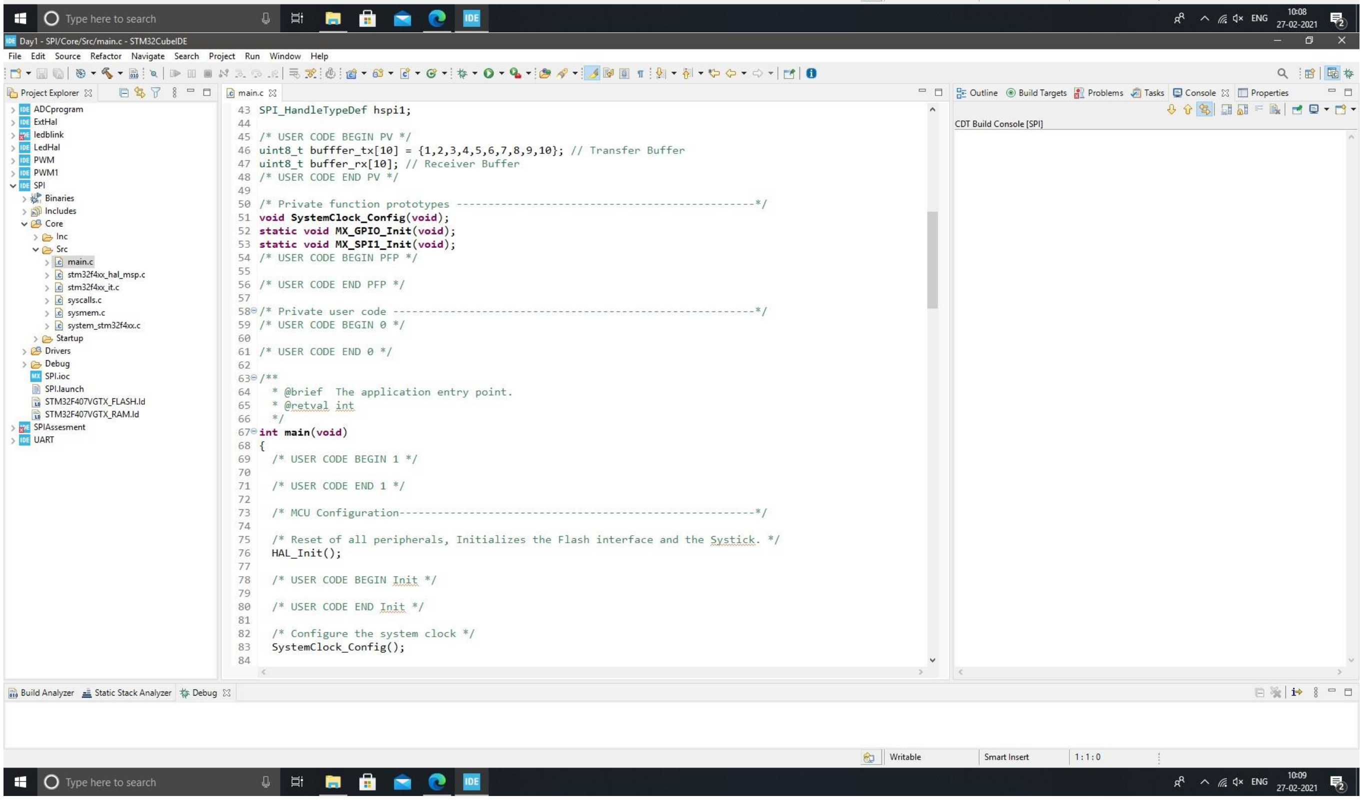


Figure: 2.4.1 SPI Pin configuration


Day1 - SPI/Core/Src/main.c - STM32CubeIDE
/* USER CODE BEGIN Header */
/**
* @file : main.c
* @brief : Main program body
* @attention
* <h2><center>© Copyright (c) 2021 STMicroelectronics.
* All rights reserved.</center></h2>
* This software component is licensed by ST under BSD 3-Clause license,
* the "License"; You may not use this file except in compliance with the
* License. You may obtain a copy of the License at:
* opensource.org/licenses/BSD-3-Clause
*/
/* USER CODE END Header */
/* Includes --*/
#include "main.h"
/* Private includes --*/
/* USER CODE BEGIN Includes */
/* USER CODE END Includes */
/* Private typedef ---*/
/* USER CODE BEGIN PTD */
/* USER CODE END PTD */
/* Private define --*/
/* USER CODE BEGIN PD */
/* USER CODE END PD */
/* Private macro ---*/
/* USER CODE BEGIN PM */
/* USER CODE END PM */
/* Private variables ---*/


Day1 - SPI/Core/Src/main.c - STM32CubeIDE
SPI_HandleTypeDef hspi1;
/* USER CODE BEGIN PV */
uint8_t bufffer_tx[10] = {1,2,3,4,5,6,7,8,9,10}; // Transfer Buffer
uint8_t bufffer_rx[10]; // Receiver Buffer
/* USER CODE END PV */
/* Private function prototypes ---*/
void SystemClock_Config(void);
static void MX_GPIO_Init(void);
static void MX_SPI1_Init(void);
/* USER CODE BEGIN PFP */
/* USER CODE END PFP */
/* Private user code ---*/
/* USER CODE BEGIN 0 */
/* USER CODE END 0 */
/**
* @brief The application entry point.
* @retval int
*/
int main(void)
{
/* USER CODE BEGIN 1 */
/* USER CODE END 1 */
/* MCU Configuration--*/
/* Reset of all peripherals, Initializes the Flash interface and the Systick. */
HAL_Init();
/* USER CODE BEGIN Init */
/* USER CODE END Init */
/* Configure the system clock */
SystemClock_Config();

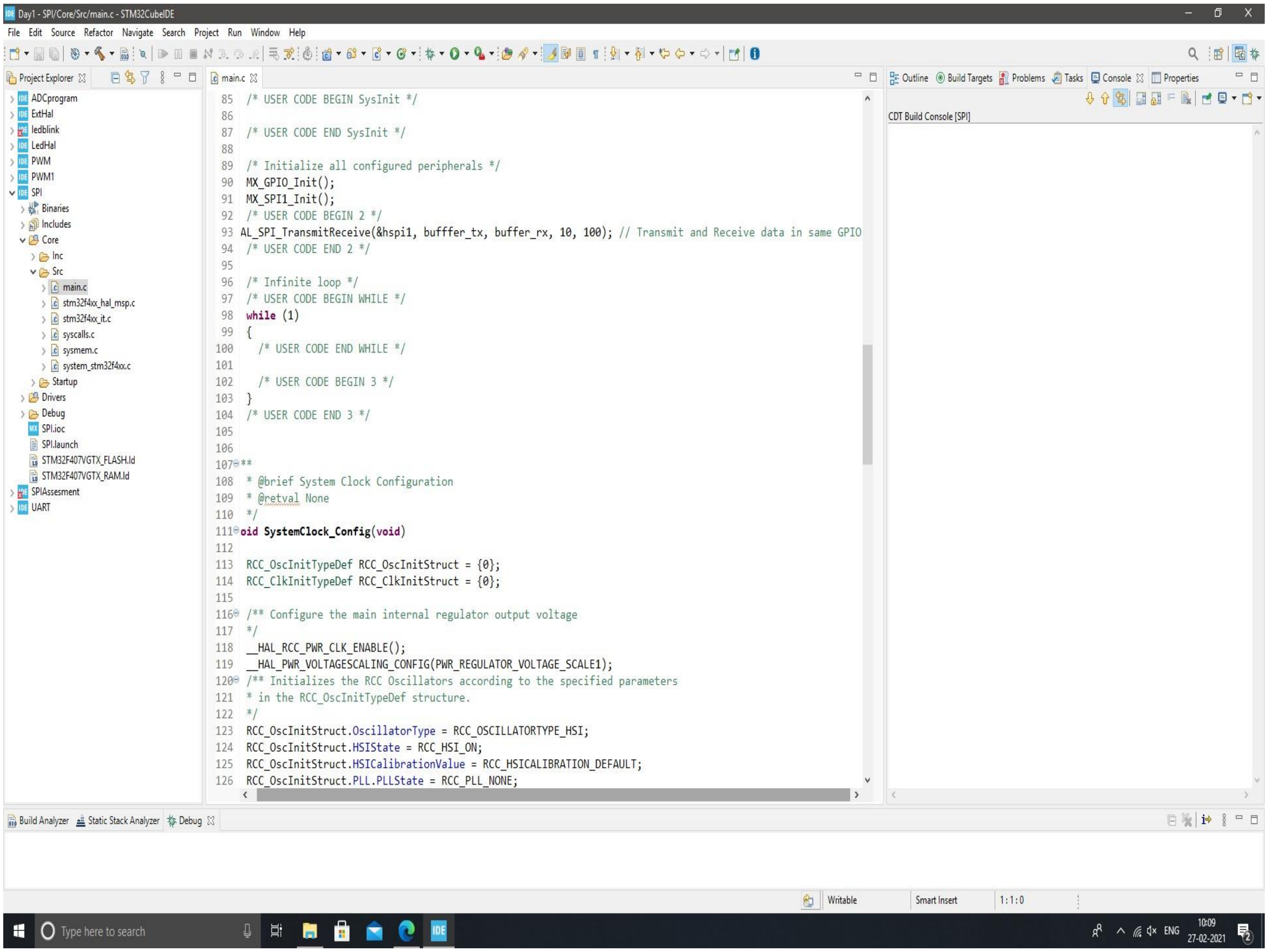


Fig: 2.4.2 SPI configuration code

2.5 UART

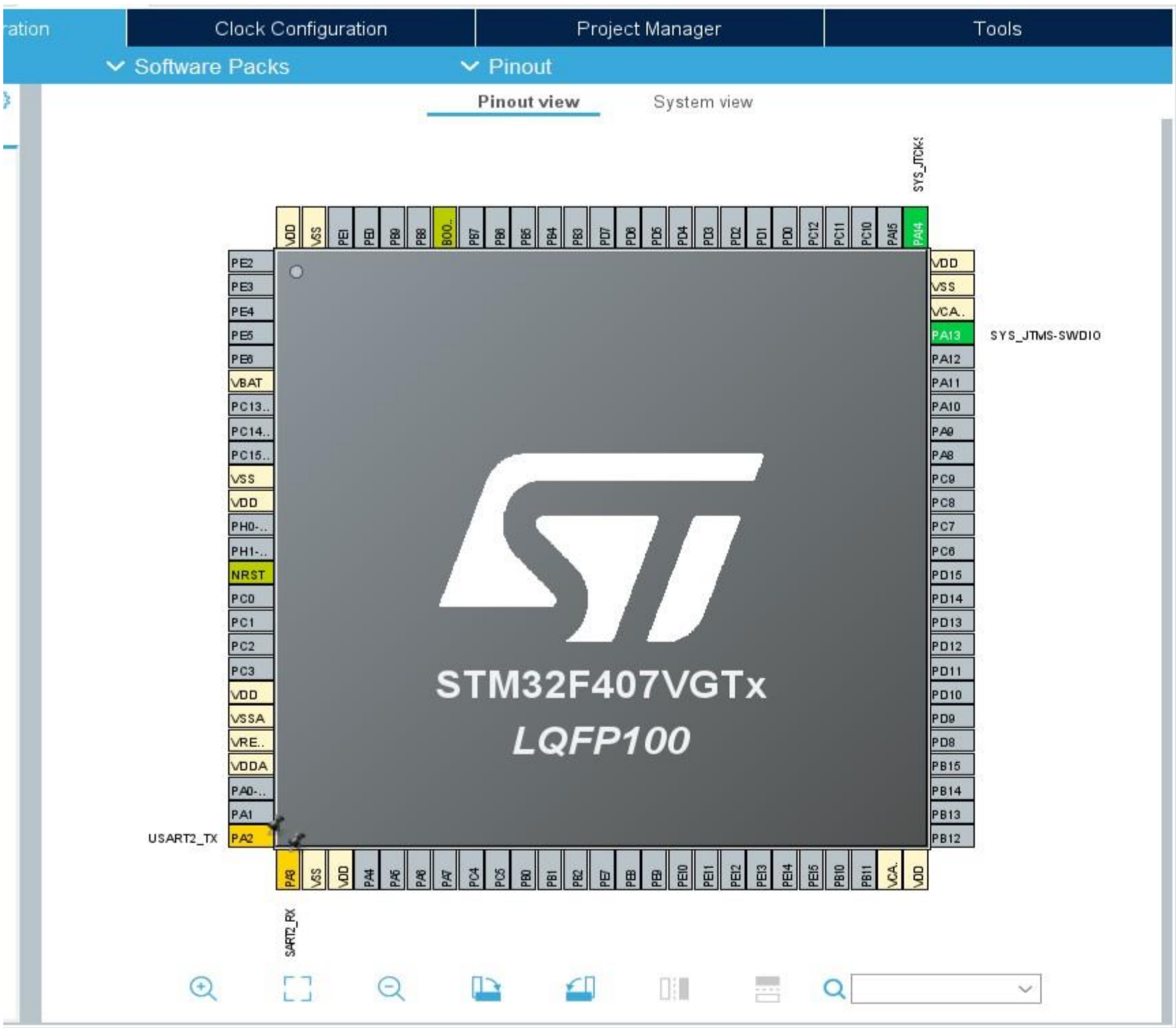


Fig: 2.5.1 UART Pin configuration

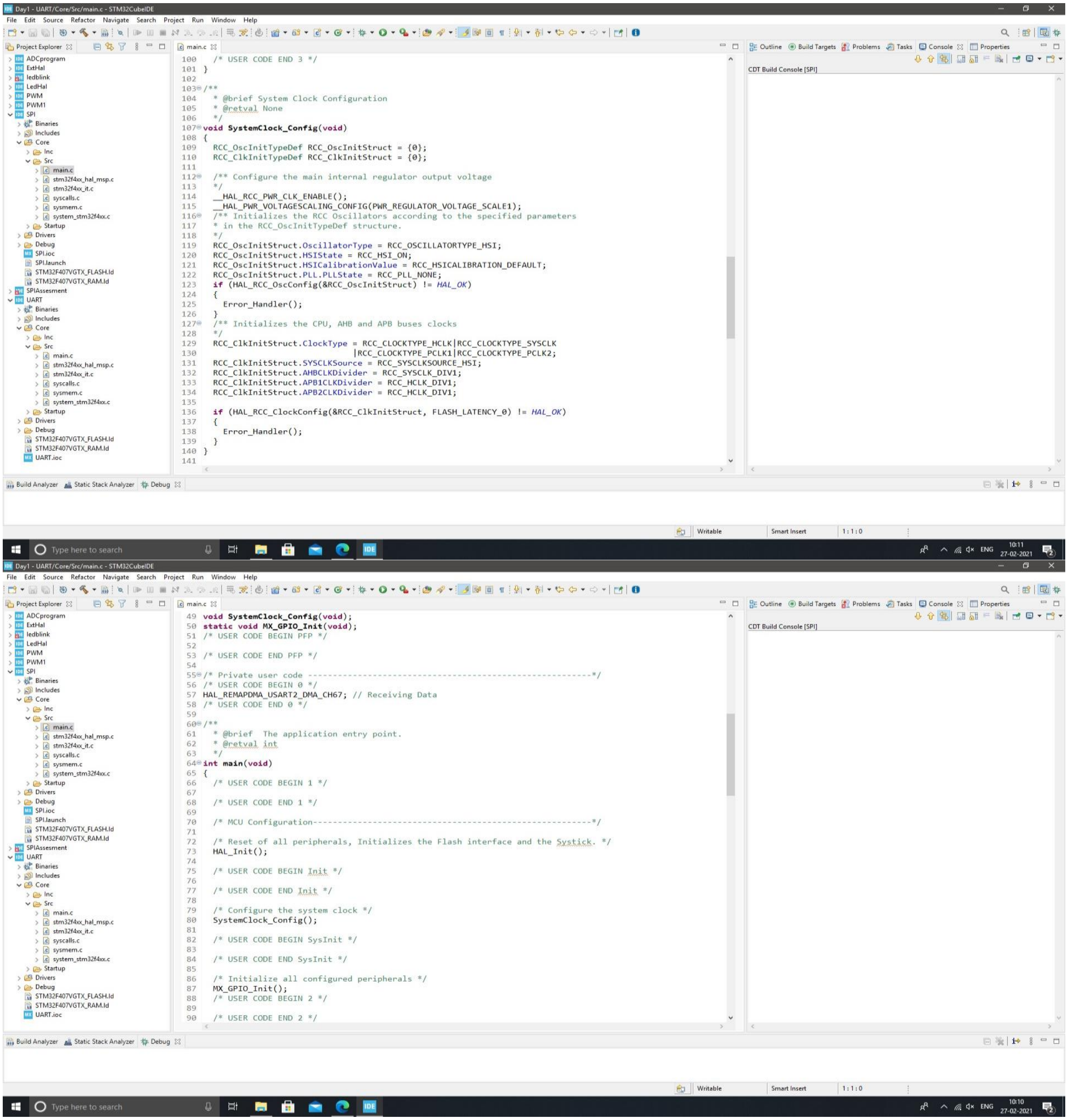


Fig: 2.5.2 UART configuration code

Activity 3 – PROJECT ON BCM MODULE

BCM module was implemented using STM32f407VG microcontroller featuring 32 bit ARM-cortex M4 with FPU core.

This BCM module have following features:

1. Seat belt System
2. Sunroof Control System

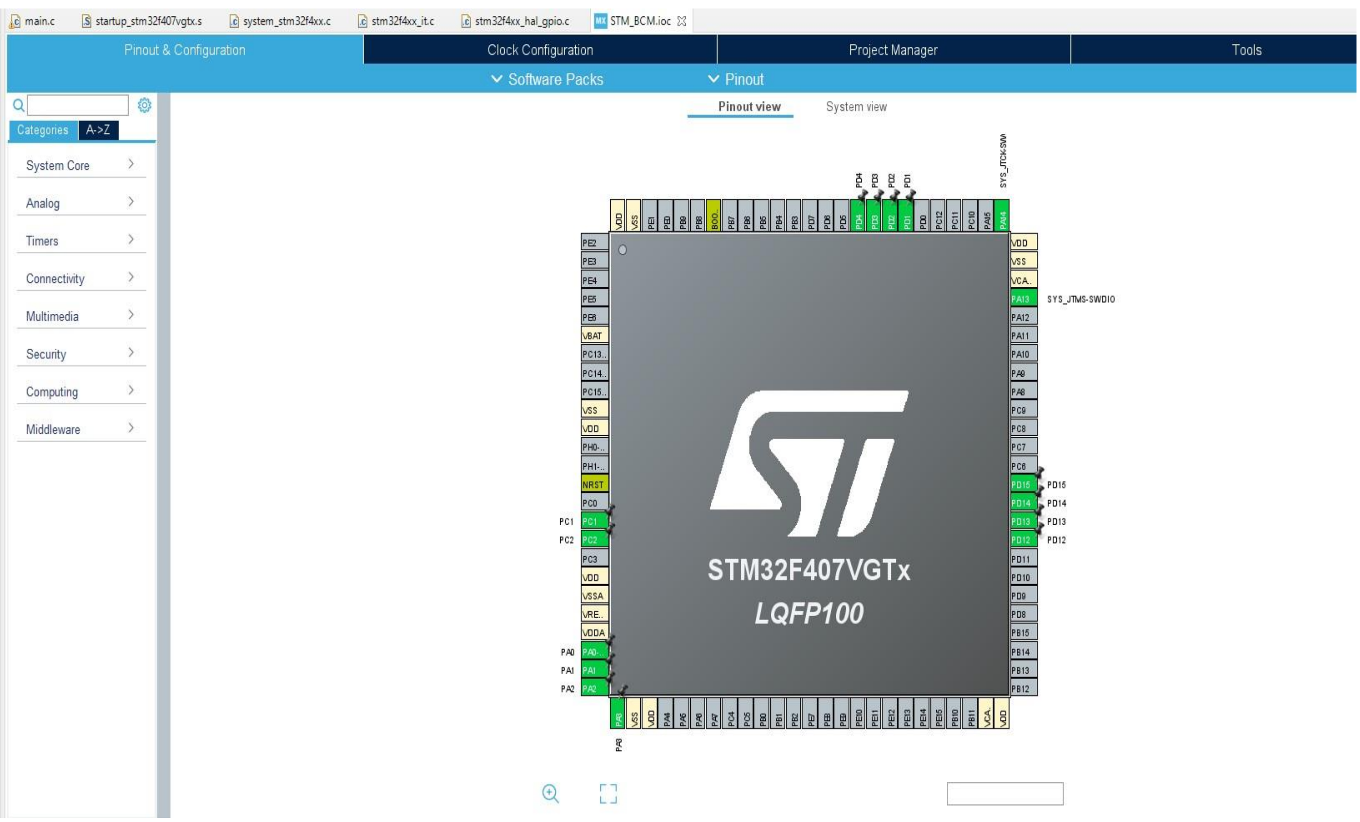


Fig 3.2 Pin configuration

Implementation

1. **Seat belt System**

Buzzer status denotes status of Seat Belt.

Input: Push Button switch(PB14);

Output: Buzzer makes sound;

```
  ///-------------------seat belt warning system.------------------
while (1)
{
  /* USER CODE END WHILE */
  MX_USB_HOST_Process();
  /* USER CODE END WHILE */
       if(HAL_GPIO_ReadPin(GPIOB, GPIO_PIN_14)==1)
            {
                HAL_GPIO_WritePin(GPIOD, GPIO_PIN_6,GPIO_PIN_SET);
            }
            else
            {
                HAL_GPIO_WritePin(GPIOD, GPIO_PIN_6,GPIO_PIN_RESET);

            }
```

Figure :- Coding Part of Seat Belt System

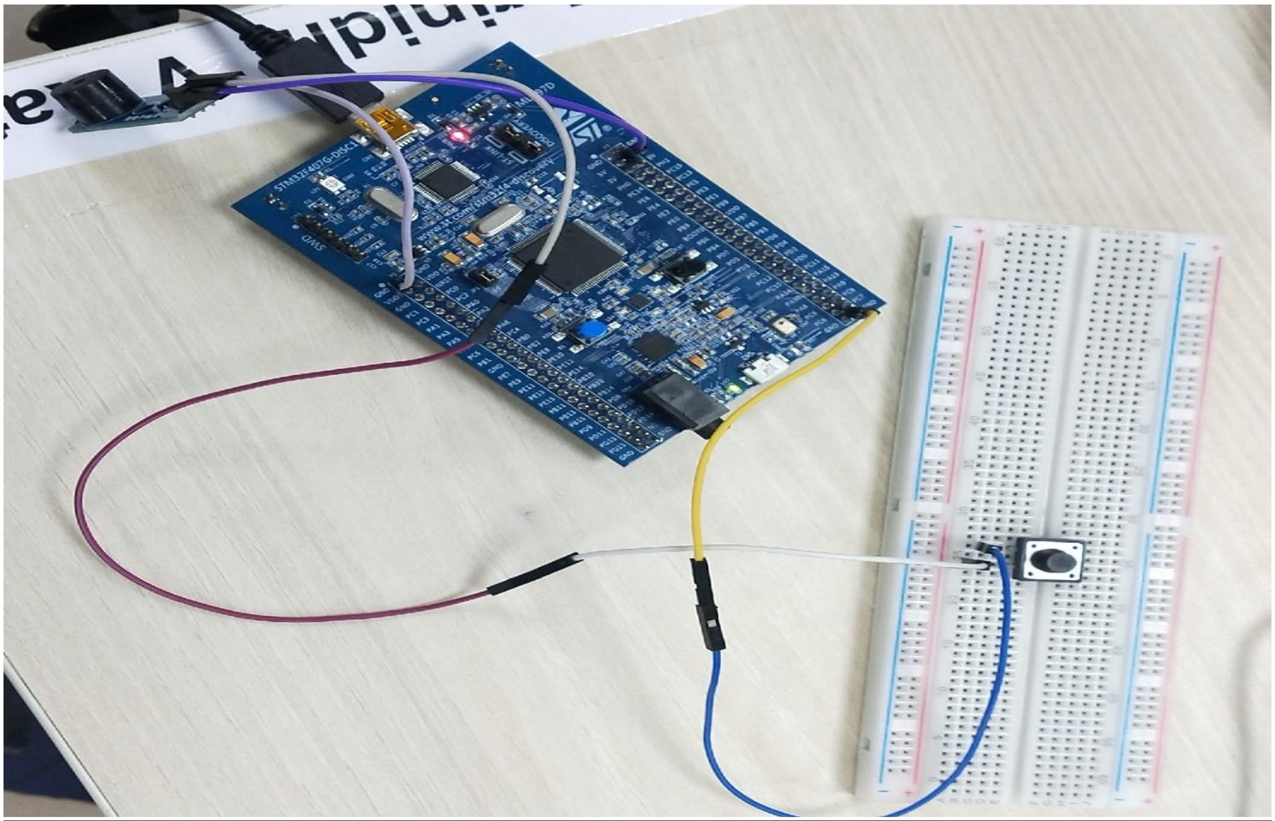


Figure :- Implementation of Seat Belt Control system

2. **Sunroof control system.**

LED status denotes OPEN/CLOSE status of sunroof.
Input: Push Button switch(PB14);
Output: GREEN LED BLINK;

```
//-------------------Sun roof control system.-------------
while(1){
     if(HAL_GPIO_ReadPin(GPIOA, GPIO_PIN_0)==1)
         {
         HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
         HAL_Delay(500);
         HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
         HAL_Delay(500);
         HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
         HAL_Delay(500);
         HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
         HAL_Delay(500);
         HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
          HAL_Delay(500);
         HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
         HAL_Delay(500);
        HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
        HAL_Delay(500);
       HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
        HAL_Delay(500);
        HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
                    HAL_Delay(500);
            HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
                                 HAL_Delay(500);
                                 HAL_GPIO_TogglePin(GPIOD, GPIO_PIN_12);
                                  HAL_Delay(500);
         }
         else
         {
             HAL_GPIO_WritePin(GPIOD, GPIO_PIN_12,GPIO_PIN_RESET);
         }

}
```

Figure :- Coding Part of Sunroof Control System

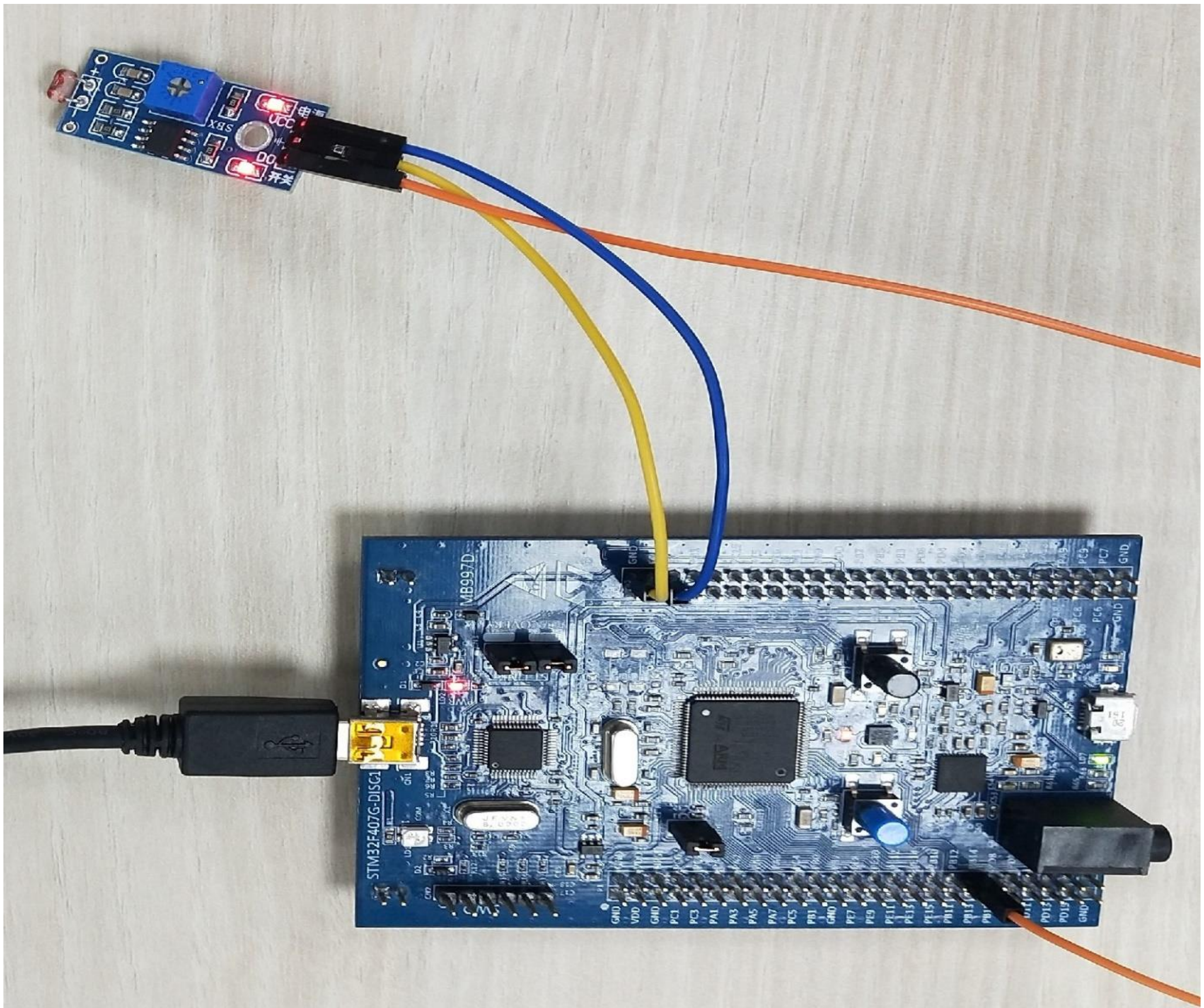


Figure :- Implementation Part of Sunroof Control System