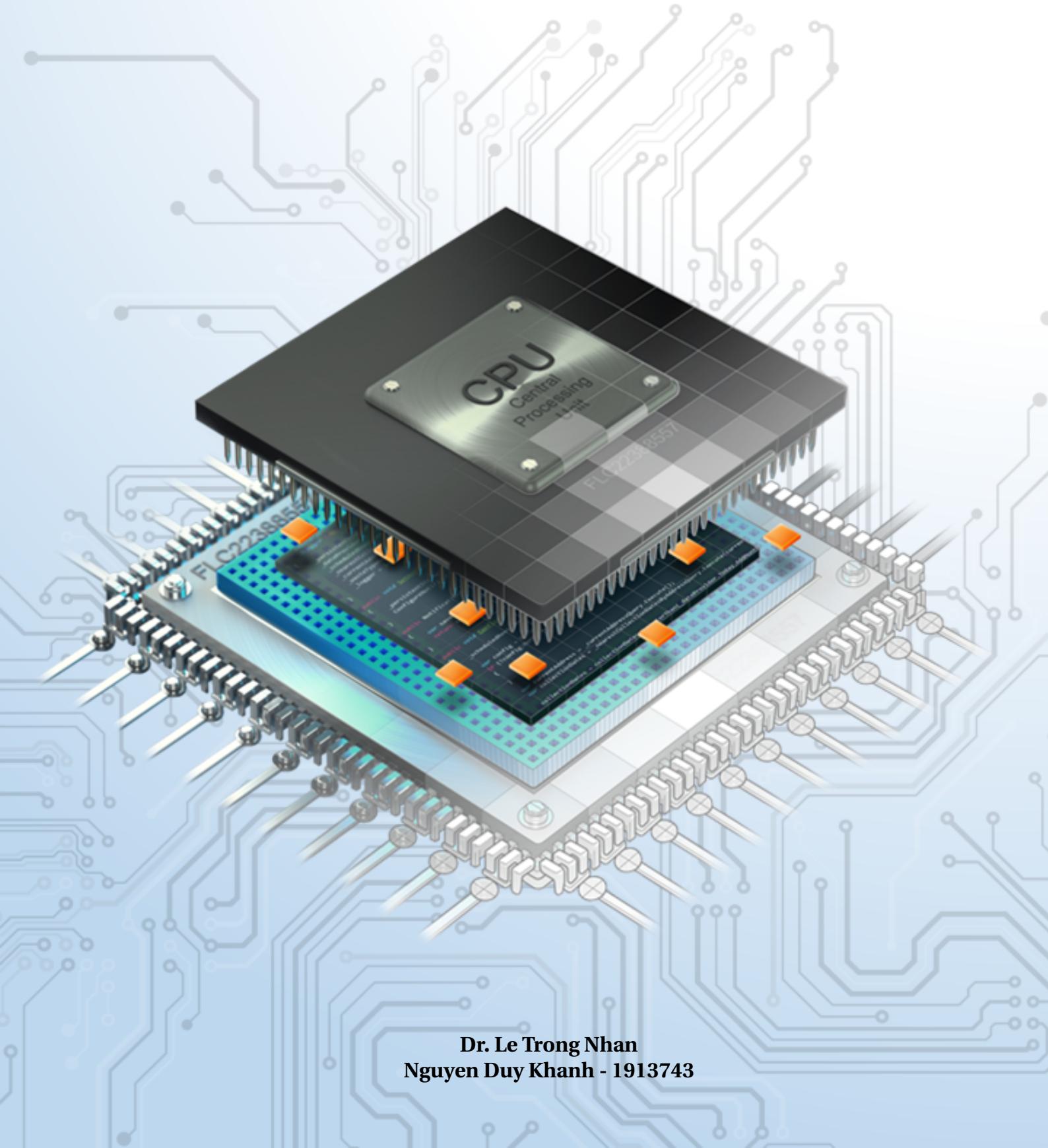




HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY
COMPUTER ENGINEERING

Microcontroller



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Mục lục

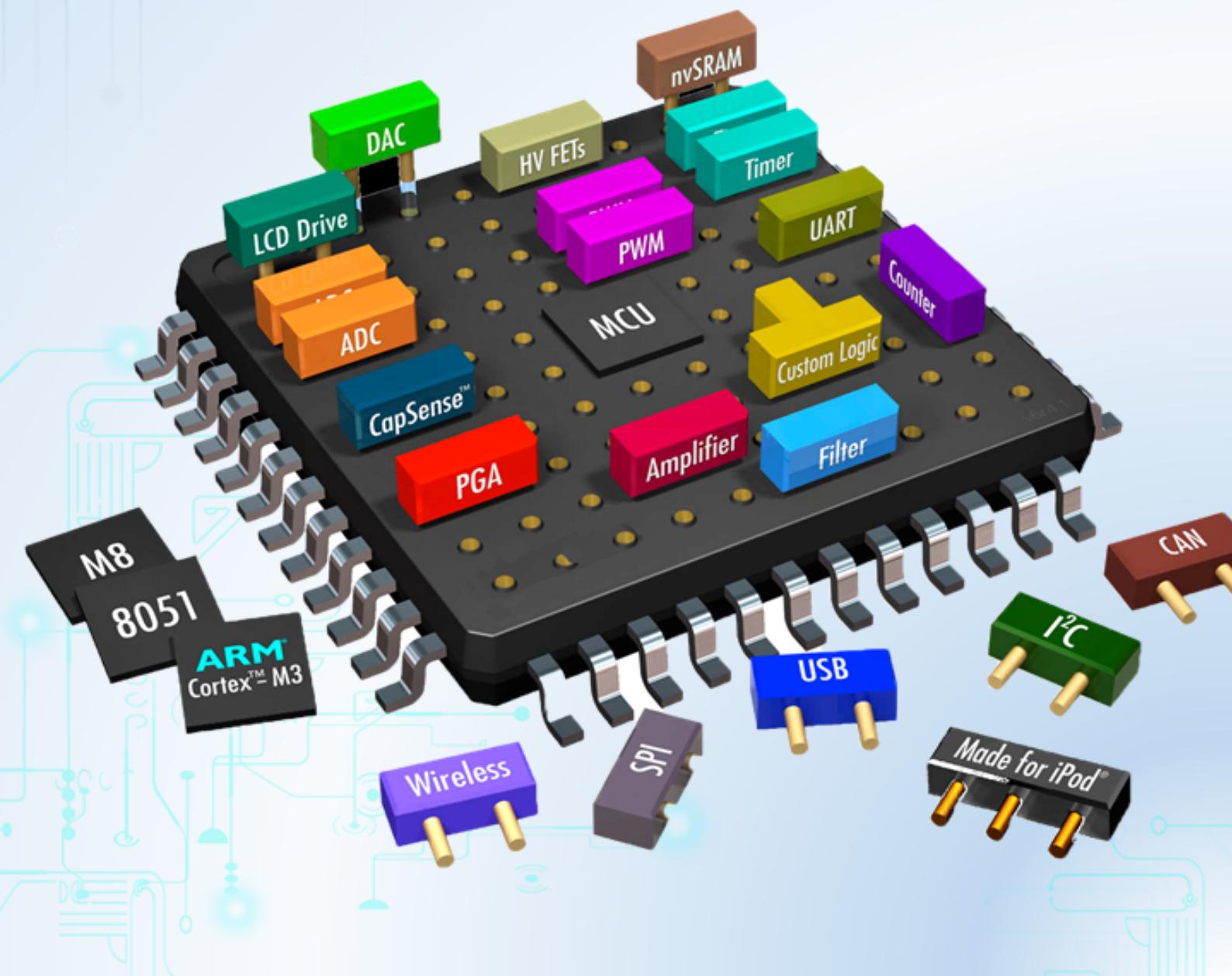
Chapter 1. LED Animations	7
1 Introduction	8
2 First project on STM32Cube	9
3 Simulation on Proteus	14
4 Exercise and Report	20
4.1 Exercise 1	20
4.2 Exercise 2	21
4.3 Exercise 3	23
4.4 Exercise 4	26
4.5 Exercise 5	28
4.6 Exercise 6	30
4.7 Exercise 7	33
4.8 Exercise 8	33
4.9 Exercise 9	34
4.10 Exercise 10	35
Chapter 2. Timer Interrupt and LED Scanning	37
1 Introduction	38
2 Timer Interrupt Setup	39
3 Exercise and Report	42
3.1 Exercise 1	42
3.2 Exercise 2	44
3.3 Exercise 3	46
3.4 Exercise 4	48
3.5 Exercise 5	48
3.6 Exercise 6	49
3.7 Exercise 7	51
3.8 Exercise 8	52
3.9 Exercise 9	53
3.10 Exercise 10	57
Chapter 3. Buttons/Switches	61
1 Objectives	62
2 Introduction	62
3 Basic techniques for reading from port pins	63
3.1 The need for pull-up resistors	63
3.2 Dealing with switch bounces	64
4 Reading switch input (basic code) using STM32	67

4.1	Input Output Processing Patterns	67
4.2	Setting up	68
4.2.1	Create a project	68
4.2.2	Create a file C source file and header file for input reading	68
4.3	Code For Read Port Pin and Debouncing	70
4.3.1	The code in the input_reading.c file	70
4.3.2	The code in the input_reading.h file	71
4.3.3	The code in the timer.c file	71
4.4	Button State Processing	72
4.4.1	Finite State Machine	72
4.4.2	The code for the FSM in the input_processing.c file	73
4.4.3	The code in the input_processing.h	73
4.4.4	The code in the main.c file	74
5	Exercises and Report	75
5.1	Specifications	75
5.2	Exercise 1: Sketch an FSM	76
5.3	Exercise 2: Proteus Schematic	77
5.4	Exercise 3: Create STM32 Project	78
5.5	Exercise 4: Modify Timer Parameters	78
5.6	Exercise 5: Adding code for button debouncing	79
5.7	Exercise 6: Adding code for displaying modes	81
5.8	Exercise 7: Adding code for increasing time duration value for the red LEDs	83
5.9	Exercise 8: Adding code for increasing time duration value for the amber LEDs	84
5.10	Exercise 9: Adding code for increasing time duration value for the green LEDs	84
5.11	Exercise 10: To finish the project	85
Chapter 4. A cooperative scheduler		87
1	Introduction	88
1.1	Super Loop Architecture	88
1.2	Timer-based interrupts and interrupt service routines	89
2	What is a scheduler?	90
2.1	The co-operative scheduler	90
2.2	Function pointers	91
2.3	Solution	92
2.3.1	Overview	92
2.3.2	The scheduler data structure and task array	94
2.3.3	The initialization function	94
2.3.4	The 'Update' function	95
2.3.5	The 'Add Task' function	96
2.3.6	The 'Dispatcher'	97
2.3.7	The 'Delete Task' function	98
2.3.8	Reducing power consumption	99
2.3.9	Reporting errors	99
2.3.10	Adding a watchdog	100
2.3.11	Reliability and safety implications	101

2.3.12	Portability	102
3	Objectives	102
4	Problem	102
5	Demonstration	102
6	Submission	103
7	References	103
8	Report	104
8.1	Proteus schematic	104
8.2	Idea	104
8.3	Flow Chart	105
8.4	STM32 Project	108
8.4.1	Project organization	108
8.4.2	Function <i>main</i>	108
8.4.3	Function Timer Interrupt	109
8.4.4	Module <i>display_LEDs</i>	109
8.4.5	Module <i>display_7_segment_LEDs</i>	110
8.4.6	Module <i>scheduler</i>	112
8.5	Gantt chart	115
8.6	Video demo	116

CHƯƠNG 1

LED Animations



1 Introduction

In this manual, the STM32CubeIDE is used as an editor to program the ARM microcontroller. STM32CubeIDE is an advanced C/C++ development platform with peripheral configuration, code generation, code compilation, and debug features for STM32 microcontrollers and microprocessors.



Hình 1.1: STM32Cube IDE for STM32 Programming

The most interest of STM32CubeIDE is that after the selection of an empty STM32 MCU or MPU, or preconfigured microcontroller or microprocessor from the selection of a board, the initialization code generated automatically. At any time during the development, the user can return to the initialization and configuration of the peripherals or middleware and regenerate the initialization code with no impact on the user code. This feature can simplify the initialization process and speedup the development application running on STM32 micro-controller. The software can be downloaded from the link bellow:

https://ubc.sgp1.digitaloceanspaces.com/BKU_Softwares/STM32/stm32cubeide_1.7.0.zip

Moreover, for a hangout class, the program is firstly simulated on Proteus. Students are also supposed to download and install this software as well:

https://ubc.sgp1.digitaloceanspaces.com/BKU_Softwares/STM32/Proteus_8.10_SP0_Pro.exe

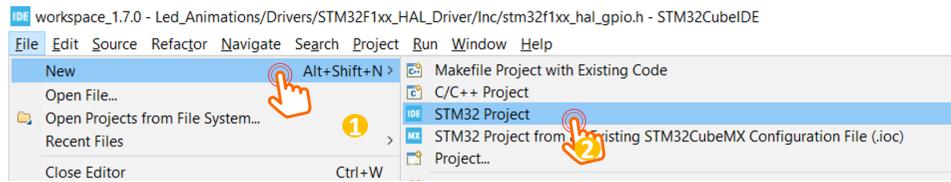
The rest of this manual consists of:

- Create a project on STM32Cube IDE
- Create a project on Proteus
- Simulate the project on Proteus

Finally, students are supposed to finish 10 different projects.

2 First project on STM32Cube

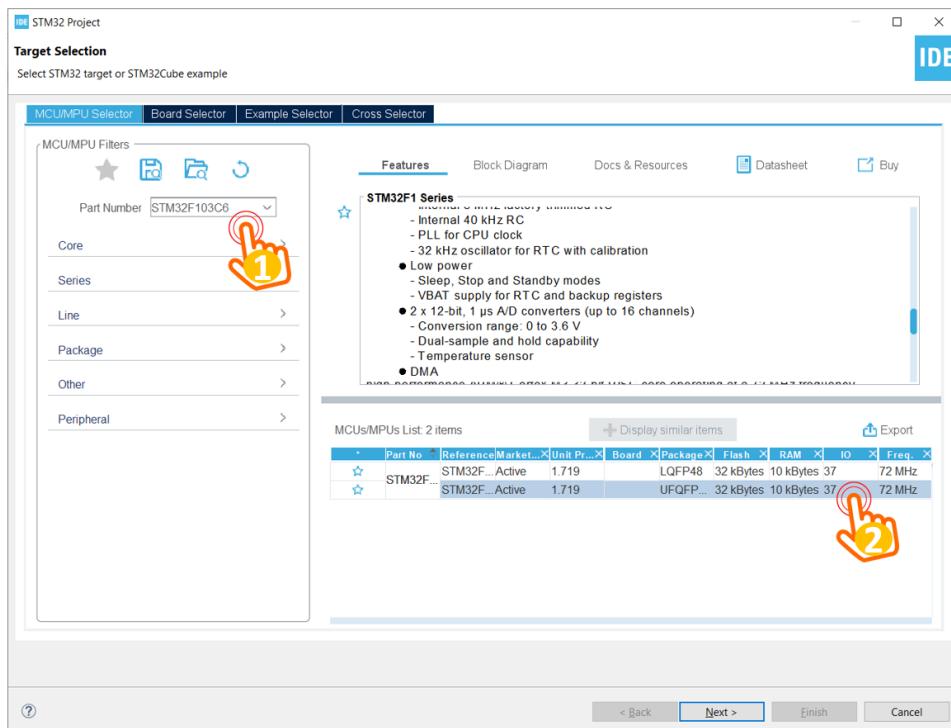
Step 1: Launch STM32CubeIDE, from the menu **File**, select **New**, then chose **STM32 Project**



Hình 1.2: Create a new project on STM32CubeIDE

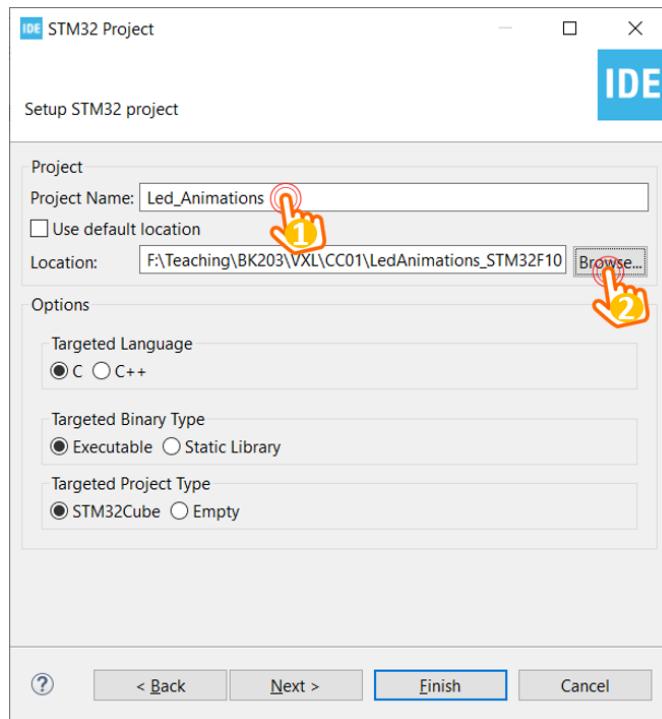
The IDE needs to download some packages, which normally takes time in this first time a project is created.

Step 2: Select the STM32F103C6 in the following dialog, then click on **Next**



Hình 1.3: Select the target device

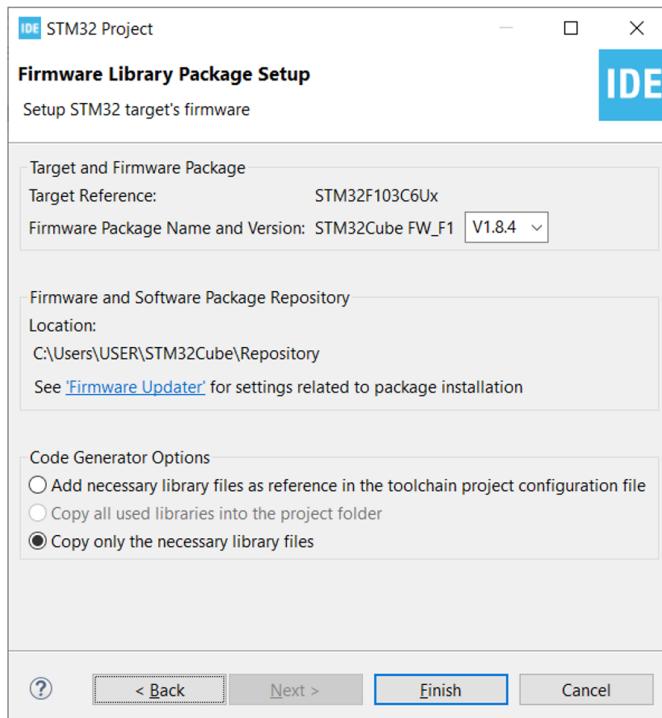
Step 3: Provide the **Name** and the **Location** for the project.



Hình 1.4: Select the target device

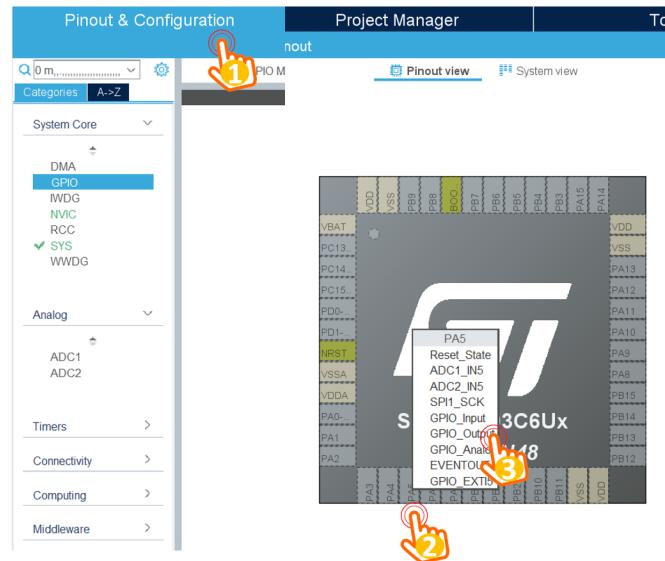
It is important to notice that the **Targeted Project Type** should be **STM32Cube**. In the case this option is disable, step 1 must be repeated. The location path should not contain special characters (e.g. the space). Finally, click on the **Next** button.

Step 4: On the last dialog, just keep the default firmware version and click on **Finish** button.



Hình 1.5: Keep default firmware version

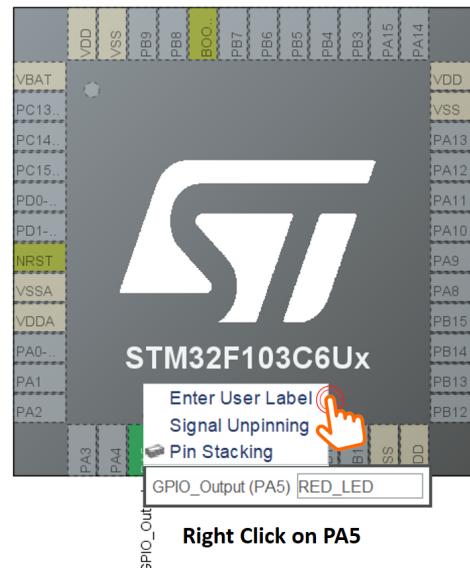
Step 5: The project is created and the wizard for configuration is display. This utility from CubeIDE can simplify the configuration process for an ARM micro-controller like the STM32.



Hình 1.6: Set PA5 to GPIO Output mode

From the configuration windows, select **Pin configuration**, select the pin **PA5** and set to **GPIO Output** mode, since this pin is connected to an LED in the STM32 development kit.

Step 6: Right click on PA5 and select **Enter user label**, and provide the name for this pin (e.g. **LED_RED**). This step helps programming afterward more memorable.



Hình 1.7: Provide a name for PA5

Finally, save the configuration process by pressing **Ctrl + S** and confirm this step by clicking on **OK** button. The code generation is started.

Step 7: Implement the first blinky project in the main function as follow:

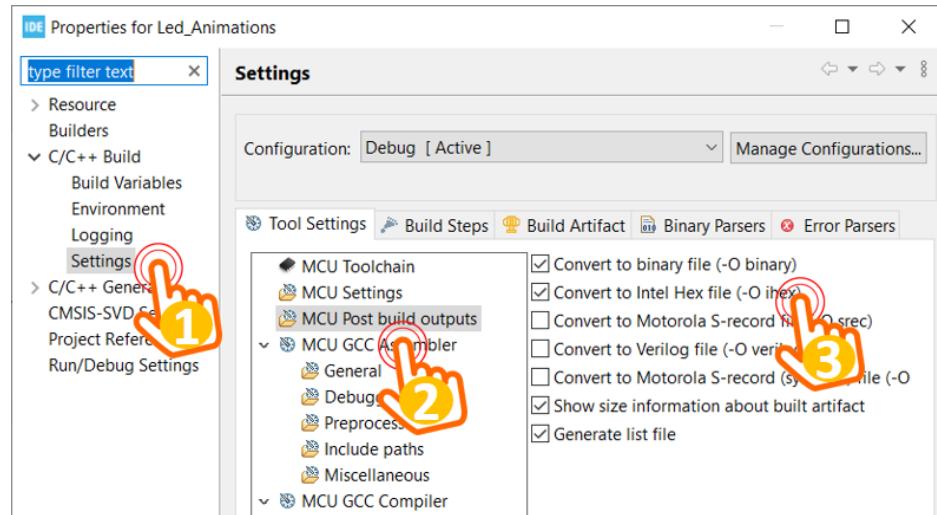
```
1 int main(void)
2 {
3     /* USER CODE BEGIN 1 */
4
5     /* USER CODE END 1 */
6
7     /* MCU Configuration
8      -----
9      */
10    /* Reset of all peripherals, Initializes the Flash
11       interface and the Systick. */
12    HAL_Init();
13
14    /* USER CODE BEGIN Init */
15
16    /* USER CODE END Init */
17
18    /* Configure the system clock */
19    SystemClock_Config();
20
21    /* USER CODE BEGIN SysInit */
22
23    /* Initialize all configured peripherals */
24    MX_GPIO_Init();
25    /* USER CODE BEGIN 2 */
26
27    /* USER CODE END 2 */
28
29    /* Infinite loop */
30    /* USER CODE BEGIN WHILE */
31
32    while (1)
33    {
34        HAL_GPIO_TogglePin(LED_RED_GPIO_Port, LED_RED_Pin);
35        HAL_Delay(1000);
36        /* USER CODE END WHILE */
37
38        /* USER CODE BEGIN 3 */
39    }
40    /* USER CODE END 3 */
41 }
```

Program 1.1: First blinky LED project

Actually, what is added to the main function is line number 34 and 35. Please put your code in a right place, otherwise it can be deleted when the code is gener-

ated (e.g. change the configuration of the project). When coding, frequently use the suggestions by pressing **Ctrl+Space**.

Step 7: Due to the simulation on Proteus, the hex file should be generated from STM32Cube IDE. From menu **Project**, select **Properties** to open the dialog bellow:



Hình 1.8: Config for hex file output

Navigate to **C/C++ Build**, select **Settings**, **MCU Post build outputs**, and check to the **Intel Hex file**.

Step 8: Build the project by clicking on menu **Project** and select **Build Project**. Please check on the output console of the IDE to be sure that the hex file is generated, as follow:

```
22:36:06 **** Incremental Build of configuration Debug for project Led_Animations ****
make -j8 all
arm-none-eabi-size  Led_Animations.elf
      text     data     bss   dec   hex filename
      4596       20    1572   6188   182c Led_Animations.elf
Finished building: default.size.stdout

22:36:06 Build Finished. 0 errors, 0 warnings. (took 272ms)
```

Hình 1.9: Compile the project and generate Hex file

The hex file is located under the **Debug** folder of your project, which is used for the simulation in Proteus afterward. In the case a development kit is connected to your PC, from menu **Run**, select **Run** to download the program to the hardware platform.

In the case there are multiple project in a work-space, double click on the project name to activate this project. Whenever a project is built, check the output files to make sure that you are working in a right project.

3 Simulation on Proteus

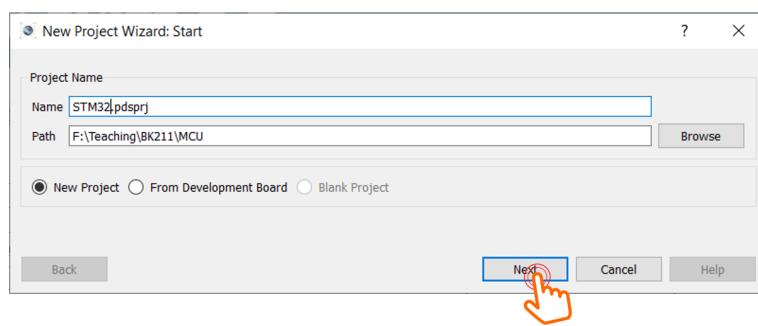
For an online training, a simulation on Proteus can be used. The details to create an STM32 project on Proteus are described below.

Step 1: Launch Proteus (with administration access) and from menu **File**, select **New Project**.



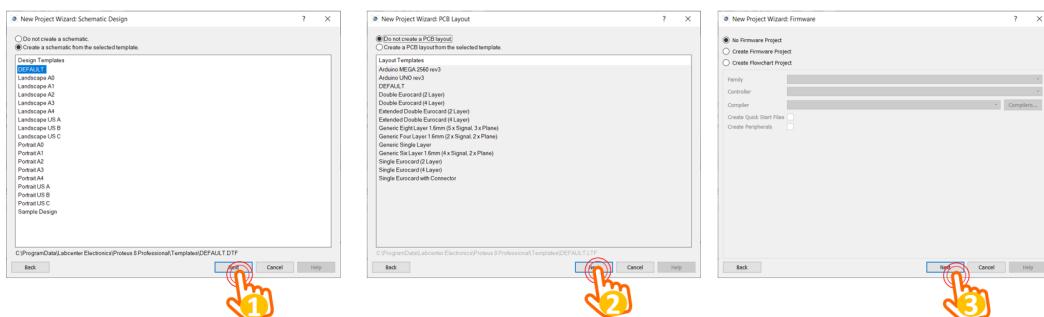
Hình 1.10: Create a new project on Proteus

Step 2: Provide the name and the location of the project, then click on **Next** button.



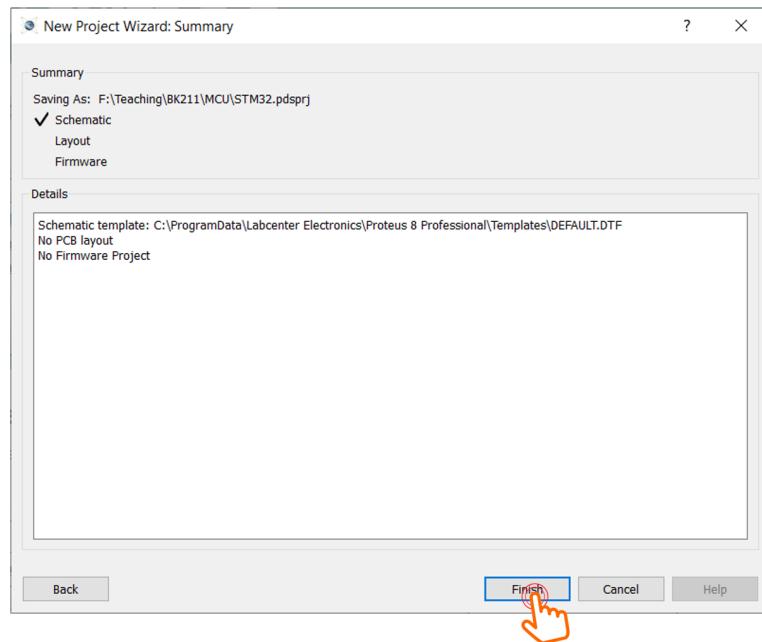
Hình 1.11: Provide project name and location

Step 3: For following dialog, just click on **Next** button as just a schematic is required for the lab.



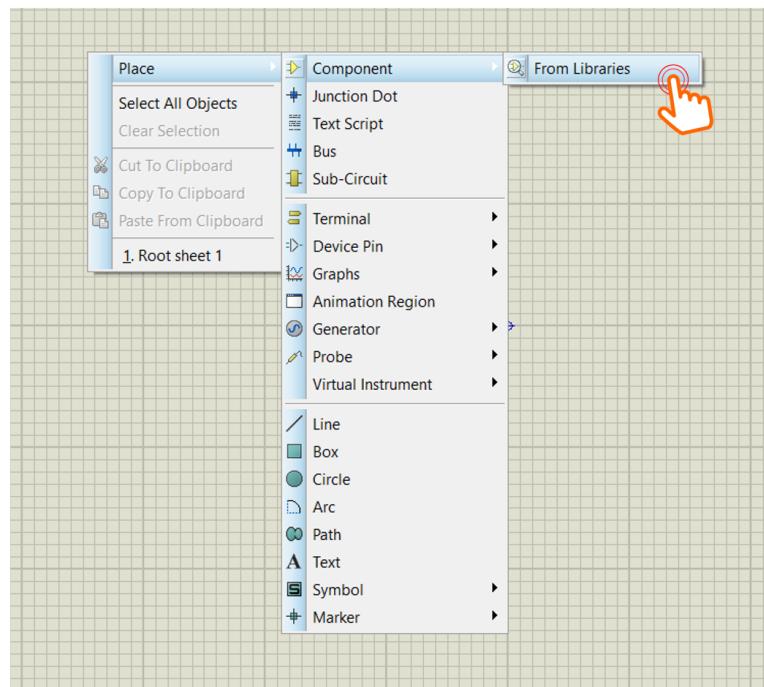
Hình 1.12: Keep the default options by clicking on Next

Step 4: Finally, click on **Finish** button to close the project wizard.



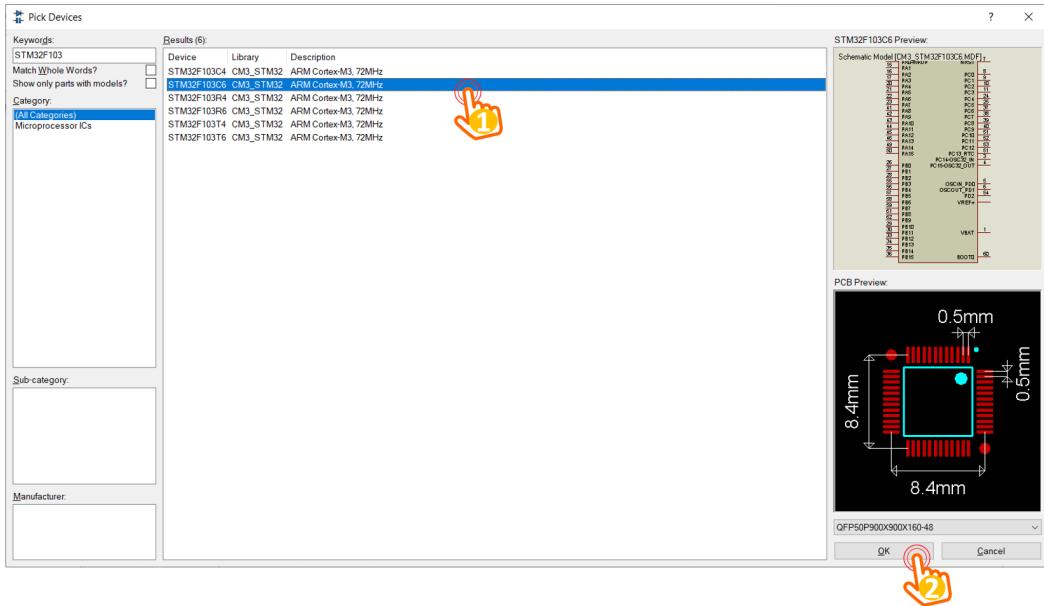
Hình 1.13: Finish the project wizard

Step 5: On the main page of the project, right click to select **Place, Components, From Libraries**, as follows:



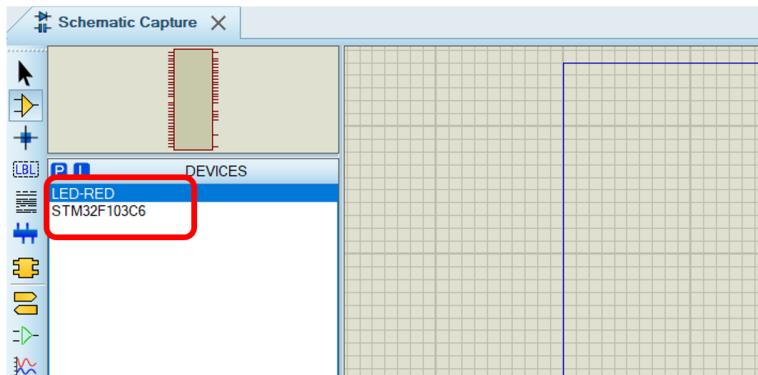
Hình 1.14: Select a component from the library

If there is an error with no library found, please restart the Proteus software with Run as administrator option.



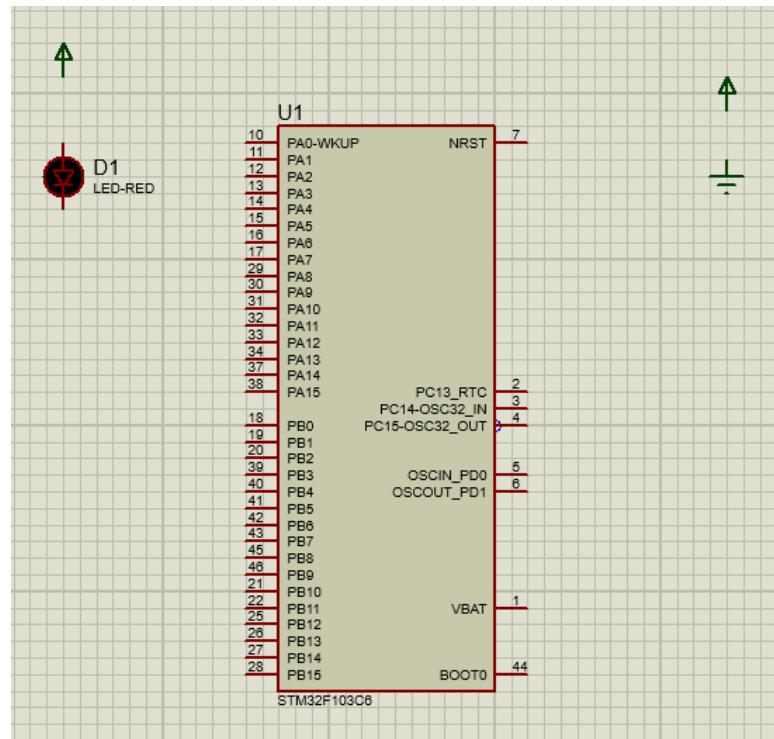
Hình 1.15: Select STM32F103C6

Step 6: From the list of components in the library, select STM32F103C6, as follows: Repeat step 5 and 6 to select an LED, named **LED-RED** in Proteus. Finally, these components are appeared on the DEVICES windows, which is on left hand side as follows:



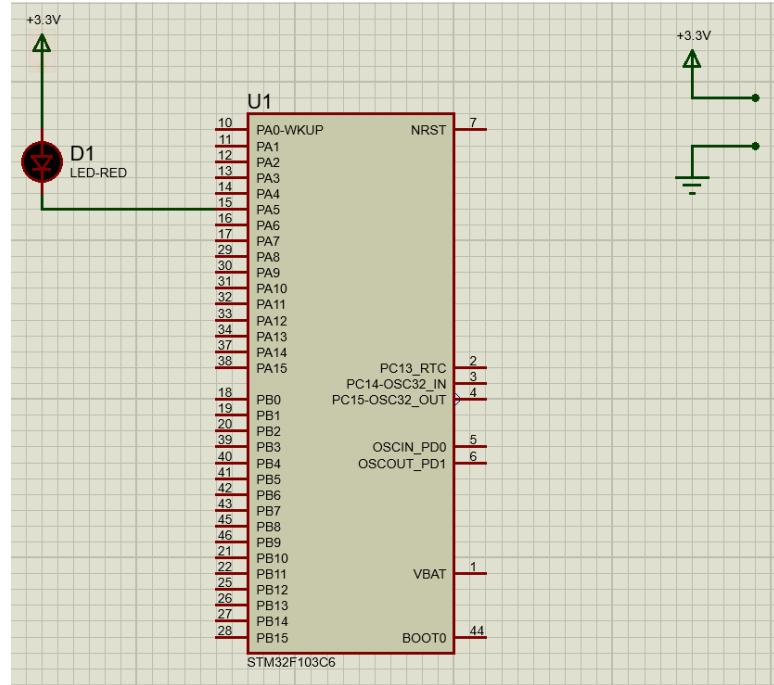
Hình 1.16: STM32 and an LED in the project

Step 7: Place the components to the project: right click on the main page, select on **Place, Component**, and select device added in Step 6. To add the Power and the Ground, right click on the main page, select on **Place, Terminal**. The result in this step is expected as follows:



Hình 1.17: Place components to the project

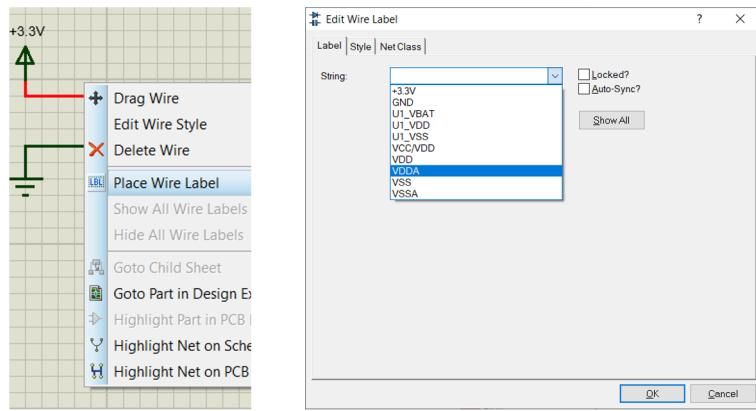
Step 8: Start wiring the circuit. The negative pin of the LED is connected to PA5 while its positive pin is connected to the power supply. For the power and the ground on the right, just make a short wire, which will be labeled in the next step.



Hình 1.18: Connect components and set the power to 3.3V

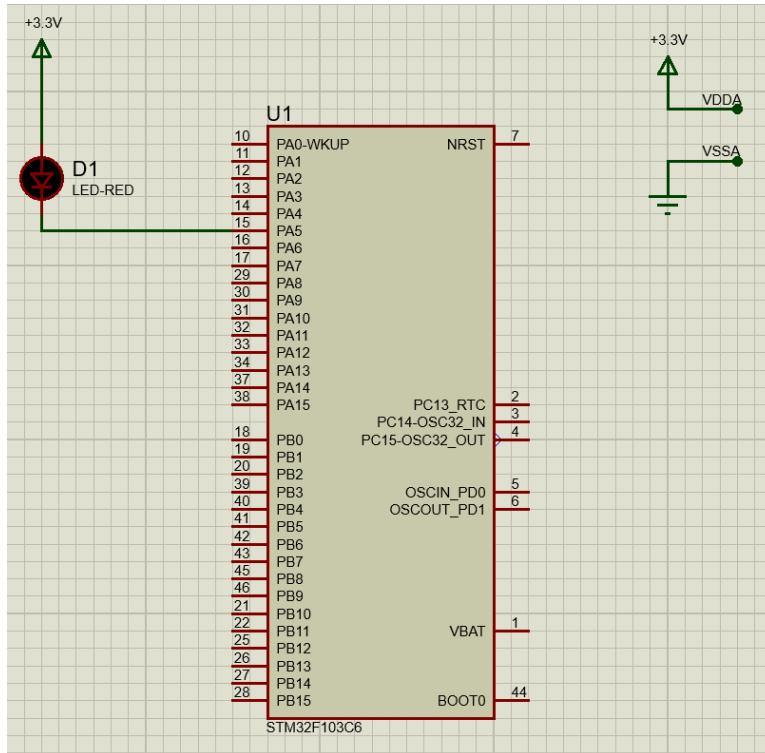
In this step, also double click on the power supply in order to provide the String property to **+3.3V**.

Step 8: Right click on the wire of the power supply and the ground, and select **Place wire Label**



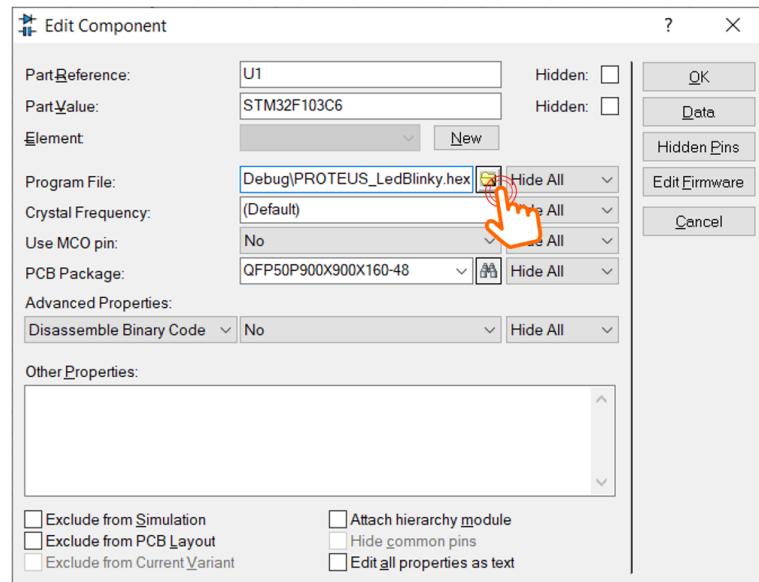
Hình 1.19: Place label for Power and Ground

This step is required as VDDA and VSSA of the STM32 must be connected to provide the reference voltage. Therefore, VDDA is connected to 3.3V, while the VSSA is connected to the Ground. Finally, the image of our schematic is shown bellow:



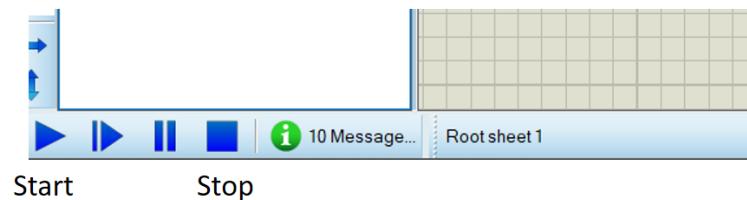
Hình 1.20: Finalize the schematic

Step 9: Double click on the STM32, and set the **Program File** to the Hex file, which is generated from Cube IDE, as following:



Hình 1.21: Set the program of the STM32 to the hex file from Cube IDE

From now, the simulation is ready to start by clicking on the menu **Debug**, and select on **Run simulation**. To stop the simulation, click on **Debug** and select **Stop VMS Debugging**. Moreover, there are some quick access bottom on the left corner of the Proteus to start or stop the simulation, as shown following:



Hình 1.22: Quick access buttons to start and stop the simulation

If everything is success, students can see the LED is blinking every second. Please stop the simulation before updating the project, either in Proteus or STM32Cube IDE. However, the step 9 (set the program file for STM32 in Proteus) is required to do once. Beside the toggle instruction, student can set or reset a pin as following:

```

1 while (1){
2     HAL_GPIO_WritePin(LED_RED_GPIO_Port , LED_RED_Pin ,
3         GPIO_PIN_SET);
4     HAL_Delay(1000);
5     HAL_GPIO_WritePin(LED_RED_GPIO_Port , LED_RED_Pin ,
6         GPIO_PIN_RESET);
7     HAL_Delay(1000);
8 }
```

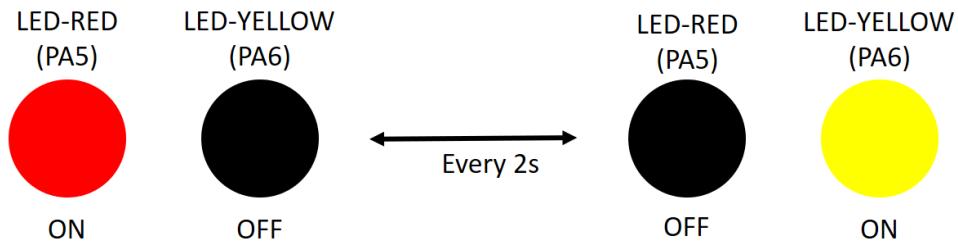
Program 1.2: An example for LED blinky

4 Exercise and Report

4.1 Exercise 1

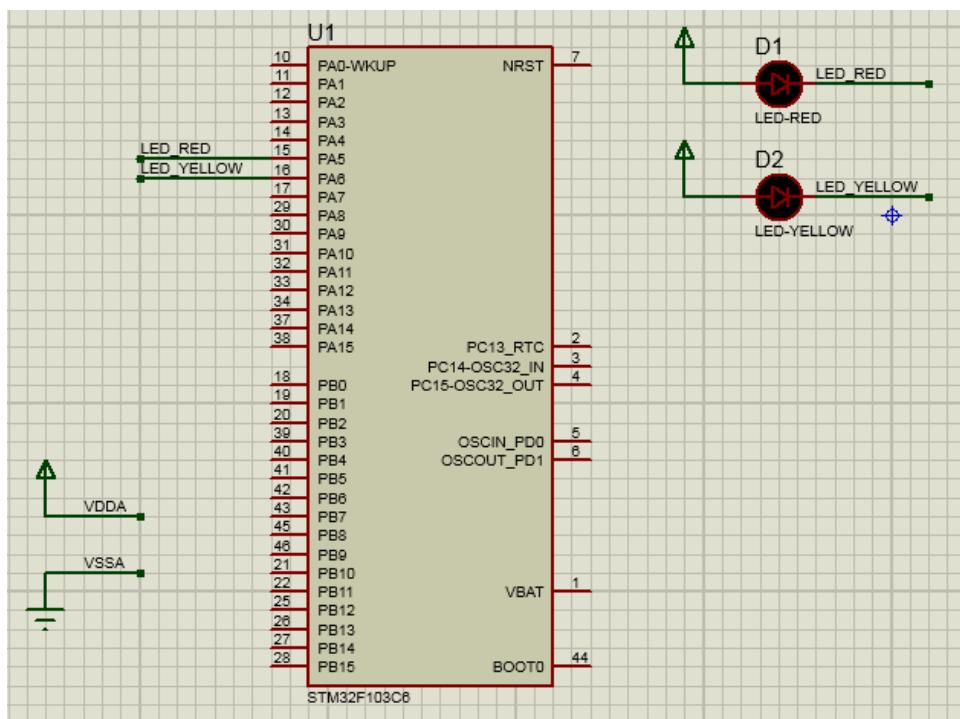
From the simulation on Proteus, one more LED is connected to pin **PA6** of the STM32 (negative pin of the LED is connected to PA6). The component suggested in this exercise is **LED-YELLOW**, which can be found from the device list.

In this exercise, the status of two LEDs are switched every 2 seconds, as demonstrated in the figure bellow.



Hình 1.23: State transitions for 2 LEDs

Report 1: Depict the schematic from Proteus simulation in this report. The caption of the figure is a downloadable link to the Proteus project file (e.g. a github link).



Hình 1.24: The schematic for exercise 1

Report 2: Present the source code in the infinite loop while of your project. If a user-defined functions is used, it is required to present in this part. A brief description can be added for this function (e.g. using comments). A template to present your source code is presented bellow.

```

1 while (1){
2     HAL_GPIO_TogglePin(GPIOA, GPIO_PIN_5);
3     HAL_Delay(1000);
4 }
```

Program 1.3: An example for your source code

```

1 while (1)
2 {
3     // I use delay 10ms, so 1s is need to count 100 times
4     // Declare uint16_t redYellow = 400;
5     // I use HAL_GPIO_TogglePin function in this exercise
6     // so I need a start state, redYellow == 400.
7     if(redYellow == 400){
8         HAL_GPIO_TogglePin(LED_YELLOW_GPIO_Port, LED_YELLOW_Pin
9     );
10    }
11    // The statements in this if's scope will loop every 2s
12    else if(redYellow == 200){
13        HAL_GPIO_TogglePin(LED_YELLOW_GPIO_Port, LED_YELLOW_Pin
14    );
15        HAL_GPIO_TogglePin(LED_RED_GPIO_Port, LED_RED_Pin);
16    }
17    // Reset redYellow to 201 because I have redYellow--
18    // after that.
19    else if(redYellow == 0){
20        redYellow = 201;
21    }
22    redYellow--;
23    HAL_Delay(10);
24 }
```

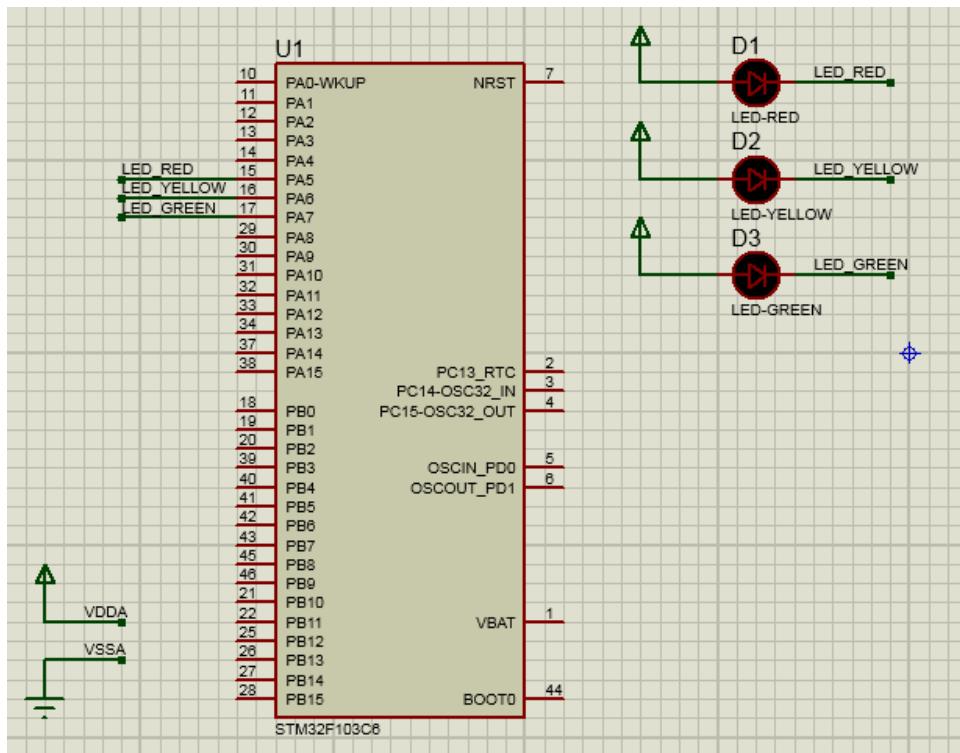
Program 1.4: Source code for exercise 1

4.2 Exercise 2

Extend the first exercise to simulate the behavior of a traffic light. A third LED, named **LED-GREEN** is added to the system, which is connected to **PA7**. A cycle in this traffic light is 5 seconds for the RED, 2 seconds for the YELLOW and 3 seconds for the GREEN. The LED-GREEN is also controlled by its negative pin.

Similarly, the report in this exercise includes the schematic of your circuit and a your source code in the while loop.

Report 1: Present the schematic.



```

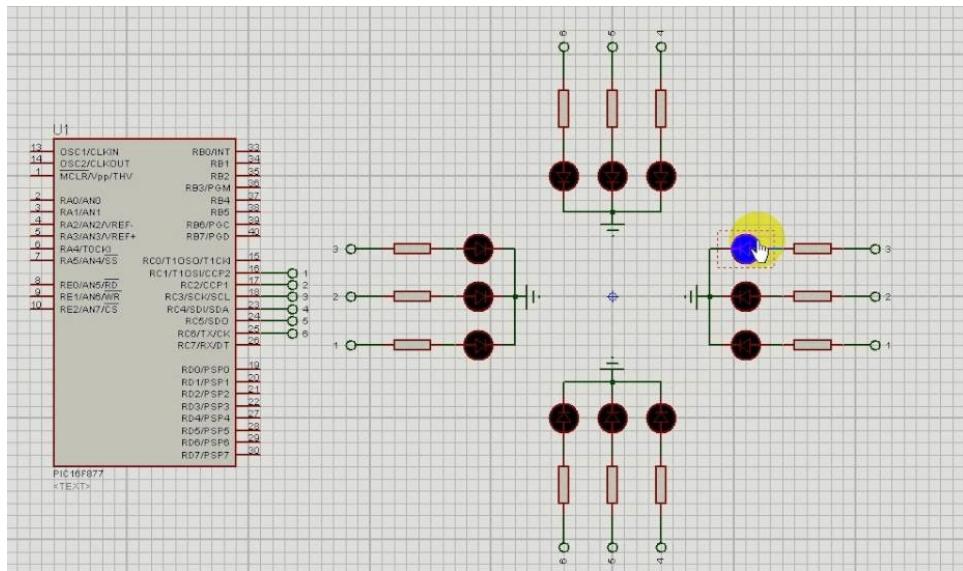
17         HAL_GPIO_TogglePin(LED_GREEN_GPIO_Port ,
18     LED_GREEN_Pin);
19         break;
20     case 1000: // red on, yellow off, green off
21         HAL_GPIO_TogglePin(LED_RED_GPIO_Port ,
22     LED_RED_Pin);
23         HAL_GPIO_TogglePin(LED_GREEN_GPIO_Port ,
24     LED_GREEN_Pin);
25         break;
26     case 500: // red off, yellow on, green off
27         HAL_GPIO_TogglePin(LED_RED_GPIO_Port ,
28     LED_RED_Pin);
29         HAL_GPIO_TogglePin(LED_YELLOW_GPIO_Port ,
30     LED_YELLOW_Pin);
31         break;
32     case 300: // red off, yellow off, green on
33         HAL_GPIO_TogglePin(LED_YELLOW_GPIO_Port ,
34     LED_YELLOW_Pin);
35         HAL_GPIO_TogglePin(LED_GREEN_GPIO_Port ,
36     LED_GREEN_Pin);
37         break;
38     case 0:
39         trafficLight = 1001; // Set to 1001 because I
have trafficLight-- after that.
        break;
    default:
        break;
}
trafficLight--;
HAL_Delay(10);
}

```

Program 1.5: Source code for exercise 2

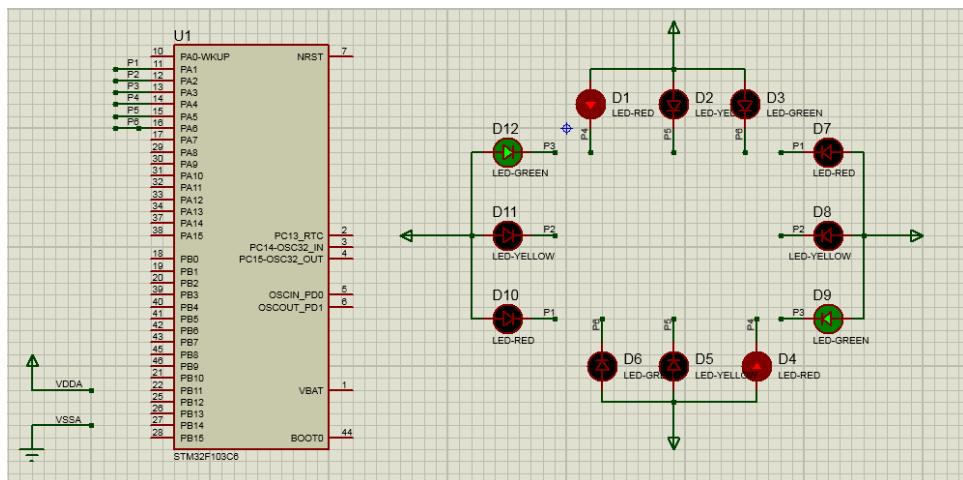
4.3 Exercise 3

Extend to the 4-way traffic light. Arrange 12 LEDs in a nice shape to simulate the behaviors of a traffic light. A reference design can be found in the figure bellow.



Hình 1.26: Reference design for a 4 way traffic light

Report 1: Present the schematic.



Hình 1.27: The schematic for exercise 3

Report 2: Present the source code in while.

```

1 while (1)
2 {
3     // I use delay 10ms, so 1s is need to count 100 times
4     // Declare uint16_t trafficLight = 2000;
5     // I use HAL_GPIO_TogglePin so I need a start state.
6     Case 2000, 1700, 1500, 1300 are executed only one time.
7     Case 1000, 700, 500, 300, 0 will be repeated.
8     switch(trafficLight){
9         case 2000: // red1, green2 on; the rest off
10            HAL_GPIO_TogglePin(P2_GPIO_Port, P2_Pin);
11            HAL_GPIO_TogglePin(P3_GPIO_Port, P3_Pin);
12            HAL_GPIO_TogglePin(P4_GPIO_Port, P4_Pin);

```

```

11     HAL_GPIO_TogglePin(P5_GPIO_Port, P5_Pin);
12     break;
13 case 1700: // red1, yellow2 on; the rest off
14     HAL_GPIO_TogglePin(P6_GPIO_Port, P6_Pin);
15     HAL_GPIO_TogglePin(P5_GPIO_Port, P5_Pin);
16     break;
17 case 1500: // green1, red2 on; the rest off
18     HAL_GPIO_TogglePin(P1_GPIO_Port, P1_Pin);
19     HAL_GPIO_TogglePin(P3_GPIO_Port, P3_Pin);
20     HAL_GPIO_TogglePin(P4_GPIO_Port, P4_Pin);
21     HAL_GPIO_TogglePin(P5_GPIO_Port, P5_Pin);
22     break;
23 case 1300: // yellow1, red2 on; the rest off
24     HAL_GPIO_TogglePin(P2_GPIO_Port, P2_Pin);
25     HAL_GPIO_TogglePin(P3_GPIO_Port, P3_Pin);
26     break;
27 case 1000: // red1, green2 on; the rest off
28     HAL_GPIO_TogglePin(P1_GPIO_Port, P1_Pin);
29     HAL_GPIO_TogglePin(P2_GPIO_Port, P2_Pin);
30     HAL_GPIO_TogglePin(P4_GPIO_Port, P4_Pin);
31     HAL_GPIO_TogglePin(P6_GPIO_Port, P6_Pin);
32     break;
33 case 700: // red1, yellow2 on; the rest off
34     HAL_GPIO_TogglePin(P6_GPIO_Port, P6_Pin);
35     HAL_GPIO_TogglePin(P5_GPIO_Port, P5_Pin);
36     break;
37 case 500: // green1, red2 on; the rest off
38     HAL_GPIO_TogglePin(P1_GPIO_Port, P1_Pin);
39     HAL_GPIO_TogglePin(P3_GPIO_Port, P3_Pin);
40     HAL_GPIO_TogglePin(P4_GPIO_Port, P4_Pin);
41     HAL_GPIO_TogglePin(P5_GPIO_Port, P5_Pin);
42     break;
43 case 200: // yellow1, red2 on; the rest off
44     HAL_GPIO_TogglePin(P2_GPIO_Port, P2_Pin);
45     HAL_GPIO_TogglePin(P3_GPIO_Port, P3_Pin);
46     break;
47 case 0:
48     trafficLight = 1001; // Set to 1001 because I have
49     trafficLight -- after that.
50     break;
51 default:
52     break;
53 }
54 trafficLight--;
55 HAL_Delay(10);
}

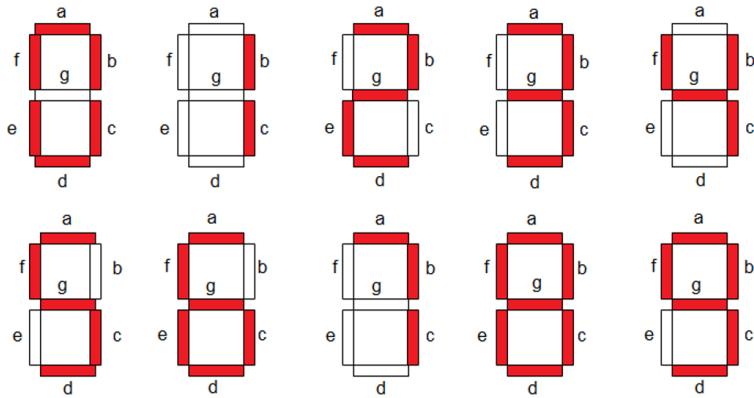
```

Program 1.6: Source code for exercise 3

4.4 Exercise 4

Add **only one 7 led segment** to the schematic in Exercise 3. This component can be found in Proteus by the keyword **7SEG-COM-ANODE**. For this device, the common pin should be connected to the power supply and other pins are supposed to be connected to PB0 to PB6. Therefore, to turn-on a segment in this 7SEG, the STM32 pin should be in logic 0 (0V).

Implement a function named **display7SEG(int num)**. The input for this function is from 0 to 9 and the outputs are listed as following:



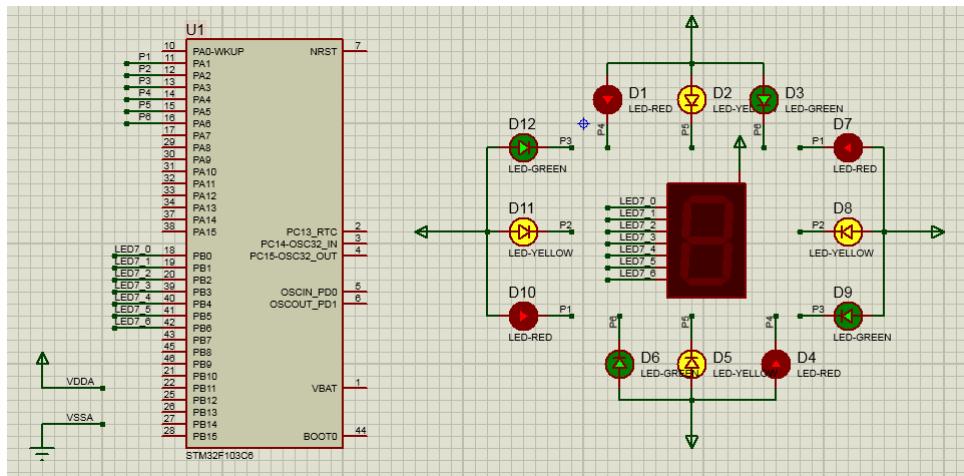
Hình 1.28: Display a number on 7 segment LED

This function is invoked in the while loop for testing as following:

```
1 int counter = 0;
2 while (1){
3     if(counter >= 10) counter = 0;
4     display7SEG(counter++);
5     HAL_Delay(1000);
6 }
7 }
```

Program 1.7: An example for your source code

Report 1: Present the schematic.



Hình 1.29: The schematic for exercise 4

Report 2: Present the source code for display7SEG function.

```

1 void display7SEG(int num){
2     // The 6 first segments 0-6 will arrange following
3     // clockwise and the rest is center. So turning on or off
4     // appreciate segments will display the require number.
5     switch(num){
6         case 0:
7             HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
8                 LED7_2_Pin|LED7_3_Pin|LED7_4_Pin|LED7_5_Pin, RESET);
9             HAL_GPIO_WritePin(GPIOB, LED7_6_Pin, SET);
10            break;
11        case 1:
12            HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_3_Pin|
13                LED7_4_Pin|LED7_5_Pin|LED7_6_Pin, SET);
14            HAL_GPIO_WritePin(GPIOB, LED7_1_Pin|LED7_2_Pin, RESET);
15            break;
16        case 2:
17            HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
18                LED7_3_Pin|LED7_4_Pin|LED7_6_Pin, RESET);
19            HAL_GPIO_WritePin(GPIOB, LED7_2_Pin|LED7_5_Pin, SET);
20            break;
21        case 3:
22            HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
23                LED7_2_Pin|LED7_3_Pin|LED7_6_Pin, RESET);
24            HAL_GPIO_WritePin(GPIOB, LED7_4_Pin|LED7_5_Pin, SET);
25            break;
26        case 4:
27            HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_3_Pin|
28                LED7_4_Pin, SET);
29            HAL_GPIO_WritePin(GPIOB, LED7_1_Pin|LED7_2_Pin|
30                LED7_5_Pin|LED7_6_Pin, RESET);

```

```

23     break;
24 case 5:
25     HAL_GPIO_WritePin(GPIOB ,LED7_0_Pin|LED7_2_Pin|
26         LED7_3_Pin|LED7_5_Pin|LED7_6_Pin , RESET);
27     HAL_GPIO_WritePin(GPIOB ,LED7_1_Pin|LED7_4_Pin , SET);
28     break;
29 case 6:
30     HAL_GPIO_WritePin(GPIOB ,LED7_0_Pin|LED7_2_Pin|
31         LED7_3_Pin|LED7_4_Pin|LED7_5_Pin|LED7_6_Pin , RESET);
32     HAL_GPIO_WritePin(GPIOB ,LED7_1_Pin , SET);
33     break;
34 case 7:
35     HAL_GPIO_WritePin(GPIOB ,LED7_0_Pin|LED7_1_Pin|
36         LED7_2_Pin , RESET);
37     HAL_GPIO_WritePin(GPIOB ,LED7_3_Pin|LED7_4_Pin|
38         LED7_5_Pin|LED7_6_Pin , SET);
39     break;
40 case 8:
41     HAL_GPIO_WritePin(GPIOB ,LED7_0_Pin|LED7_1_Pin|
42         LED7_2_Pin|LED7_3_Pin|LED7_4_Pin|LED7_5_Pin|LED7_6_Pin ,
43         RESET);
44     break;
45 case 9:
46     HAL_GPIO_WritePin(GPIOB ,LED7_0_Pin|LED7_1_Pin|
        LED7_2_Pin|LED7_3_Pin|LED7_5_Pin|LED7_6_Pin , RESET);
        HAL_GPIO_WritePin(GPIOB ,LED7_4_Pin , SET);
        break;
default:
    break;
}
}

```

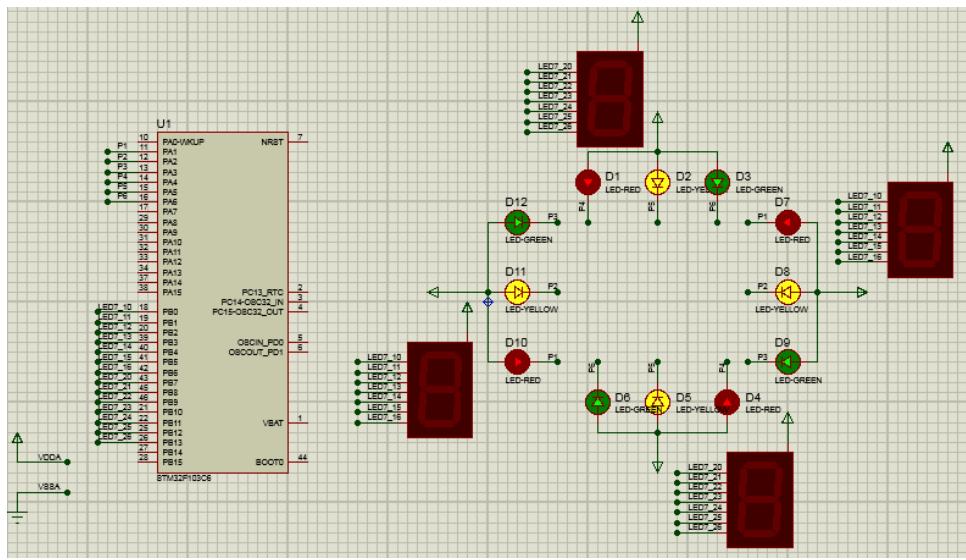
Program 1.8: Source code for exercise 4

4.5 Exercise 5

Integrate the 7SEG-LED to the 4 way traffic light. In this case, the 7SEG-LED is used to display countdown value.

In this exercise, only source code is required to present. The function `display7SEG` in previous exercise can be re-used.

Report 1: Present the schematic.



Hình 1.30: The schematic for exercise 5

Report 2: Present the source code in while.

```

1 while (1)
2 {
3     // I use delay 10ms, so 1s is need to count 100 times
4     // Declare int time = 1000;
5     // Function display7SEG_1, display7SEG_2 is similar to
6     // display7SEG present above.
7     switch(time){
8         case 1000:
9             HAL_GPIO_WritePin(GPIOA, P1_Pin|P6_Pin, RESET);
10            HAL_GPIO_WritePin(GPIOA, P2_Pin|P3_Pin|P4_Pin|P5_Pin,
11                SET);
12            display7SEG_1(5);
13            display7SEG_2(3);
14            break;
15         case 900:
16            display7SEG_1(4);
17            display7SEG_2(2);
18            break;
19         case 800:
20            display7SEG_1(3);
21            display7SEG_2(1);
22            break;
23         case 700:
24            HAL_GPIO_WritePin(GPIOA, P5_Pin, RESET);
25            HAL_GPIO_WritePin(GPIOA, P4_Pin|P6_Pin, SET);
26            display7SEG_1(2);
27            display7SEG_2(2);
28            break;
29     }
30 }
```

```

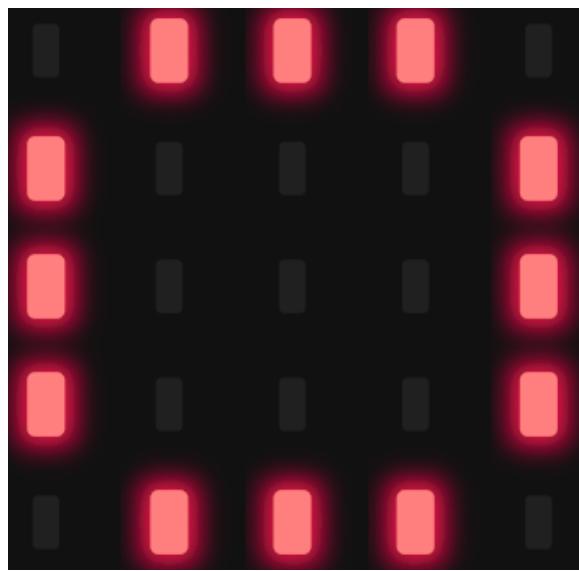
27   case 600:
28     display7SEG_1(1);
29     display7SEG_2(1);
30     break;
31   case 500:
32     HAL_GPIO_WritePin(GPIOA, P4_Pin|P3_Pin, RESET);
33     HAL_GPIO_WritePin(GPIOA, P1_Pin|P2_Pin|P5_Pin|P6_Pin,
34     SET);
35     display7SEG_1(3);
36     display7SEG_2(5);
37     break;
38   case 400:
39     display7SEG_1(2);
40     display7SEG_2(4);
41     break;
42   case 300:
43     display7SEG_1(1);
44     display7SEG_2(3);
45     break;
46   case 200:
47     HAL_GPIO_WritePin(GPIOA, P2_Pin, RESET);
48     HAL_GPIO_WritePin(GPIOA, P1_Pin|P3_Pin, SET);
49     display7SEG_1(2);
50     display7SEG_2(2);
51     break;
52   case 100:
53     display7SEG_1(1);
54     display7SEG_2(1);
55     break;
56   case 0:
57     time = 1001;
58     break;
59   default:
60     break;
61   }
62   time--;
63
64   HAL_Delay(10);
}

```

Program 1.9: Source code for exercise 5

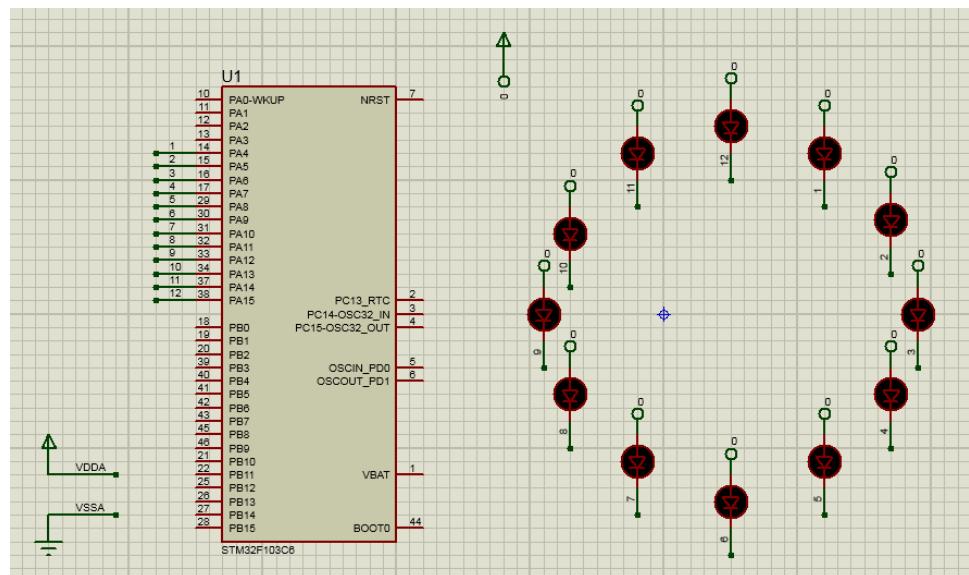
4.6 Exercise 6

In this exercise, a new Proteus schematic is designed to simulate an analog clock, with 12 different number. The connections for 12 LEDs are supposed from PA4 to PA15 of the STM32. The arrangement of 12 LEDs is depicted as follows.



Hình 1.31: 12 LEDs for an analog clock

Report 1: Present the schematic.



Hình 1.32: The schematic for exercise 6

Report 2: Implement a simple program to test the connection of every single LED. This testing program should turn every LED in a sequence.

```

1 while(1)
2 {
3     // I use delay 10ms, so 1s is need to count 100 times
4     // Declare int time = 1200;
5     switch(time){
6         case 1200:
7             HAL_GPIO_WritePin(GPIOA, P2_Pin|P3_Pin|P4_Pin|P5_Pin|
8                 P6_Pin|P7_Pin|P8_Pin|P9_Pin|P10_Pin|P11_Pin|P12_Pin, SET
9         );

```

```

8     HAL_GPIO_WritePin(GPIOA, P1_Pin, RESET);
9     break;
10    case 1100:
11        HAL_GPIO_TogglePin(GPIOA, P1_Pin|P2_Pin);
12        break;
13    case 1000:
14        HAL_GPIO_TogglePin(GPIOA, P2_Pin|P3_Pin);
15        break;
16    case 900:
17        HAL_GPIO_TogglePin(GPIOA, P3_Pin|P4_Pin);
18        break;
19    case 800:
20        HAL_GPIO_TogglePin(GPIOA, P4_Pin|P5_Pin);
21        break;
22    case 700:
23        HAL_GPIO_TogglePin(GPIOA, P5_Pin|P6_Pin);
24        break;
25    case 600:
26        HAL_GPIO_TogglePin(GPIOA, P6_Pin|P7_Pin);
27        break;
28    case 500:
29        HAL_GPIO_TogglePin(GPIOA, P7_Pin|P8_Pin);
30        break;
31    case 400:
32        HAL_GPIO_TogglePin(GPIOA, P8_Pin|P9_Pin);
33        break;
34    case 300:
35        HAL_GPIO_TogglePin(GPIOA, P9_Pin|P10_Pin);
36        break;
37    case 200:
38        HAL_GPIO_TogglePin(GPIOA, P10_Pin|P11_Pin);
39        break;
40    case 100:
41        HAL_GPIO_TogglePin(GPIOA, P11_Pin|P12_Pin);
42        break;
43    case 0:
44        time = 1201;
45        break;
46    default:
47        break;
48    }
49    time--;
50    HAL_Delay(10);
51 }
```

Program 1.10: Source code for exercise 6

4.7 Exercise 7

Implement a function named **clearAllClock()** to turn off all 12 LEDs. Present the source code of this function.

```
1 void clearAllClock(){  
2     //TODO  
3 }
```

Program 1.11: Function Implementation

```
1 void clearAllClock(){  
2     HAL_GPIO_WritePin(GPIOA, P1_Pin|P2_Pin|P3_Pin|P4_Pin|  
3         P5_Pin|P6_Pin|P7_Pin|P8_Pin|P9_Pin|P10_Pin|P11_Pin|  
4         P12_Pin, SET);  
5 }
```

Program 1.12: Function Implementation exercise 7

4.8 Exercise 8

Implement a function named **setNumberOnClock(int num)**. The input for this function is from **0 to 11** and an appropriate LED is turn on. Present the source code of this function.

```
1 void setNumberOnClock(int num){  
2     switch(num){  
3         case 0:  
4             HAL_GPIO_WritePin(GPIOA, P1_Pin, RESET);  
5             break;  
6         case 1:  
7             HAL_GPIO_WritePin(GPIOA, P2_Pin, RESET);  
8             break;  
9         case 2:  
10            HAL_GPIO_WritePin(GPIOA, P3_Pin, RESET);  
11            break;  
12        case 3:  
13            HAL_GPIO_WritePin(GPIOA, P4_Pin, RESET);  
14            break;  
15        case 4:  
16            HAL_GPIO_WritePin(GPIOA, P5_Pin, RESET);  
17            break;  
18        case 5:  
19            HAL_GPIO_WritePin(GPIOA, P6_Pin, RESET);  
20            break;  
21        case 6:  
22            HAL_GPIO_WritePin(GPIOA, P7_Pin, RESET);  
23            break;  
24        case 7:  
25            HAL_GPIO_WritePin(GPIOA, P8_Pin, RESET);  
26            break;  
27        case 8:
```

```

28     HAL_GPIO_WritePin(GPIOA , P9_Pin , RESET);
29     break;
30 case 9:
31     HAL_GPIO_WritePin(GPIOA , P10_Pin , RESET);
32     break;
33 case 10:
34     HAL_GPIO_WritePin(GPIOA , P11_Pin , RESET);
35     break;
36 case 11:
37     HAL_GPIO_WritePin(GPIOA , P12_Pin , RESET);
38     break;
39 default:
40     break;
41 }
42 }
```

Program 1.13: Function Implementation exercise 8

4.9 Exercise 9

Implement a function named **clearNumberOnClock(int num)**. The input for this function is from **0 to 11** and an appropriate LED is turn off.

```

1 void clearNumberOnClock(int num){
2     switch(num){
3         case 0:
4             HAL_GPIO_WritePin(GPIOA , P1_Pin , SET);
5             break;
6         case 1:
7             HAL_GPIO_WritePin(GPIOA , P2_Pin , SET);
8             break;
9         case 2:
10            HAL_GPIO_WritePin(GPIOA , P3_Pin , SET);
11            break;
12        case 3:
13            HAL_GPIO_WritePin(GPIOA , P4_Pin , SET);
14            break;
15        case 4:
16            HAL_GPIO_WritePin(GPIOA , P5_Pin , SET);
17            break;
18        case 5:
19            HAL_GPIO_WritePin(GPIOA , P6_Pin , SET);
20            break;
21        case 6:
22            HAL_GPIO_WritePin(GPIOA , P7_Pin , SET);
23            break;
24        case 7:
25            HAL_GPIO_WritePin(GPIOA , P8_Pin , SET);
26            break;
27    case 8:
```

```

28     HAL_GPIO_WritePin(GPIOA, P9_Pin, SET);
29     break;
30 case 9:
31     HAL_GPIO_WritePin(GPIOA, P10_Pin, SET);
32     break;
33 case 10:
34     HAL_GPIO_WritePin(GPIOA, P11_Pin, SET);
35     break;
36 case 11:
37     HAL_GPIO_WritePin(GPIOA, P12_Pin, SET);
38     break;
39 default:
40     break;
41 }
42 }
```

Program 1.14: Function Implementation exercise 9

4.10 Exercise 10

Integrate the whole system and use 12 LEDs to display a clock. At a given time, there are only 3 LEDs are turn on for hour, minute and second information.

```

1 while(1){
2     // Declare int h = 0, m = 0, s = 0, start = 0;
3     // h: hour, m: minute, s: second
4     // start: if start == 0 then state of system 12 LEDs is
5     // start state else if start != 0 it isn't start state
6     // Function clearAllClock(), setNumberOnClock() present
7     // above
8     // Schematic of system is schematic in exercise 6.
9     // Explain: Every second divisibility for 5 or at start
10    // state, it will turn off all LEDs then turn on some LEDs
11    // . You can set value for h, m and s. The time will
12    // continue running.
13    if(s % 5 == 0 || start == 0) {
14        start = 1;
15        clearAllClock();
16    }
17    if(s == 0) // second equal to 0, LED 12 on
18        setNumberOnClock(11);
19    else{
20        if((s/5-1) < 0) setNumberOnClock(11);
21        else setNumberOnClock(s/5 - 1);
22    }
23    if(m == 0) // minute equal to 0, LED 12 on
24        setNumberOnClock(11);
25    else{
26        if((m/5-1) < 0) setNumberOnClock(11);
27        else setNumberOnClock(m/5 - 1);
```

```

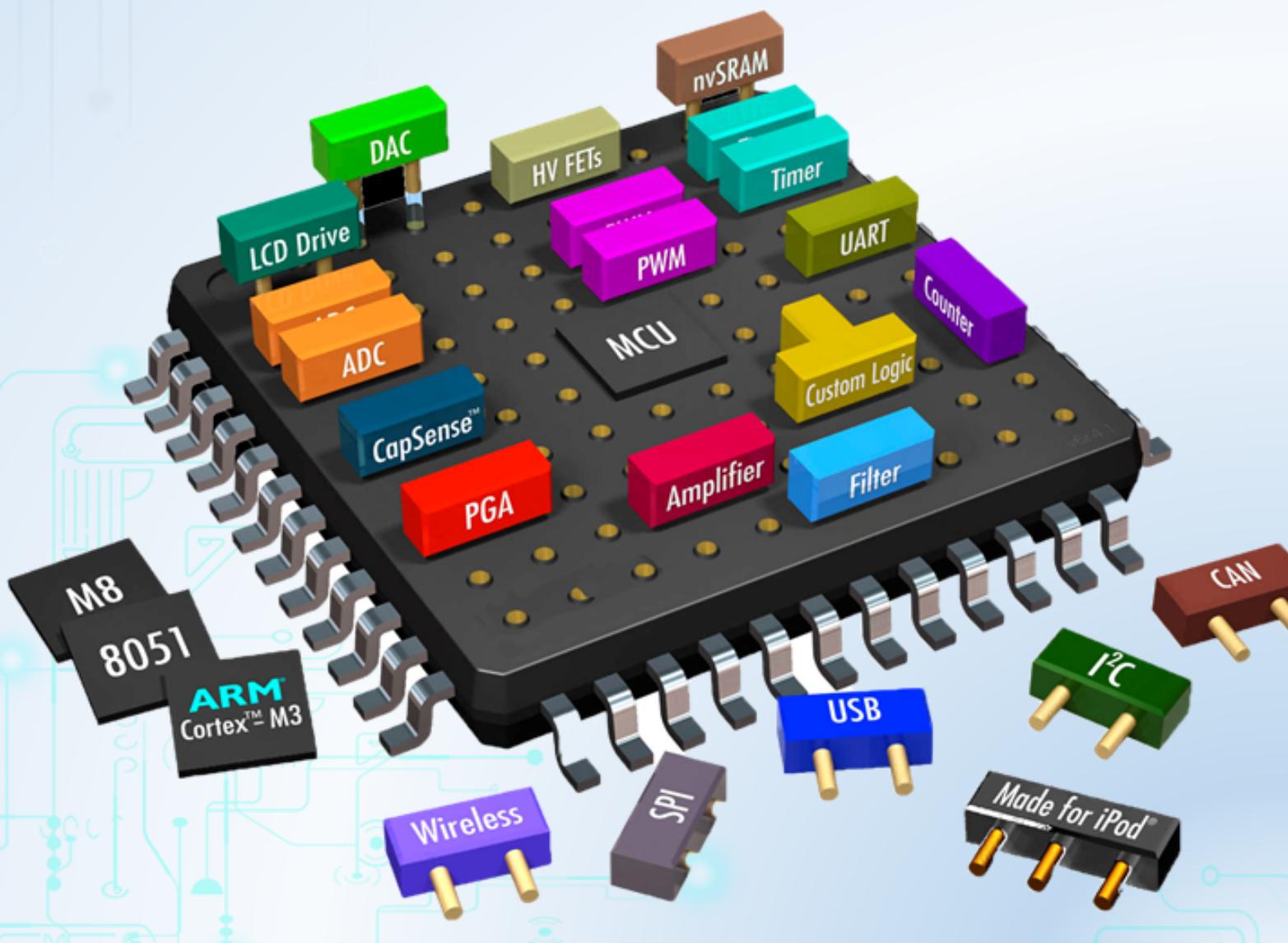
23 }
24 if((h%12) == 0) // hour equal to 0 or 12, LED 12 on
25     setNumberOnClock(11);
26 else {
27     setNumberOnClock(h%12 - 1);
28 }
29 s++;
30 if(s == 60){
31     s = 0;
32     m++;
33 }
34 if(m == 60){
35     m = 0;
36     h++;
37 }
38 if(h == 24){
39     h = 0;
40 }
41 HAL_Delay(1000);
42 }

```

Program 1.15: Source code for exercise 10

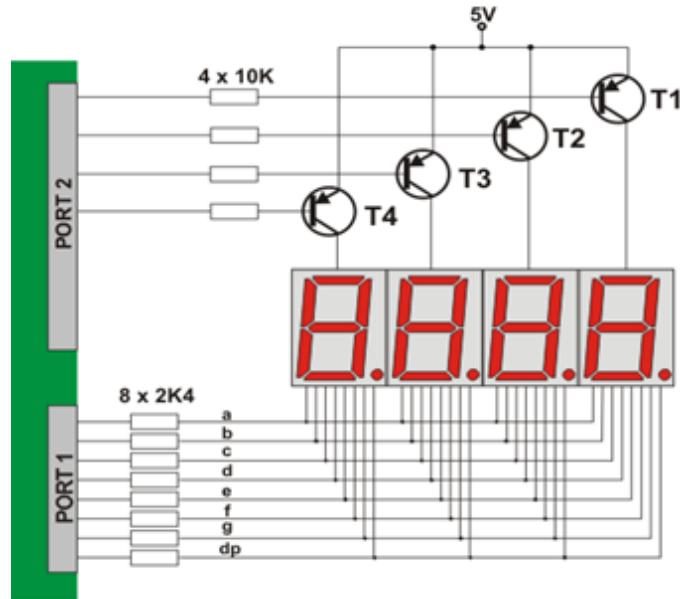
CHƯƠNG 2

Timer Interrupt and LED Scanning



1 Introduction

Timers are one of the most important features in modern micro-controllers. They allow us to measure how long something takes to execute, create non-blocking code, precisely control pin timing, and even run operating systems. In this manual, how to configure a timer using STM32CubeIDE is presented how to use them to flash an LED. Finally, students are proposed to finalize 10 exercises using timer interrupt for applications based LED Scanning.



Hình 2.1: Four seven segment LED interface for a micro-controller

Design an interface for with multiple LED (seven segment or matrix) displays which is to be controlled is depends on the number of input and output pins needed for controlling all the LEDs in the given matrix display, the amount of current that each pin can source and sink and the speed at which the micro-controller can send out control signals. With all these specifications, interfacing can be done for 4 seven segment LEDs with a micro-controller is proposed in the figure above.

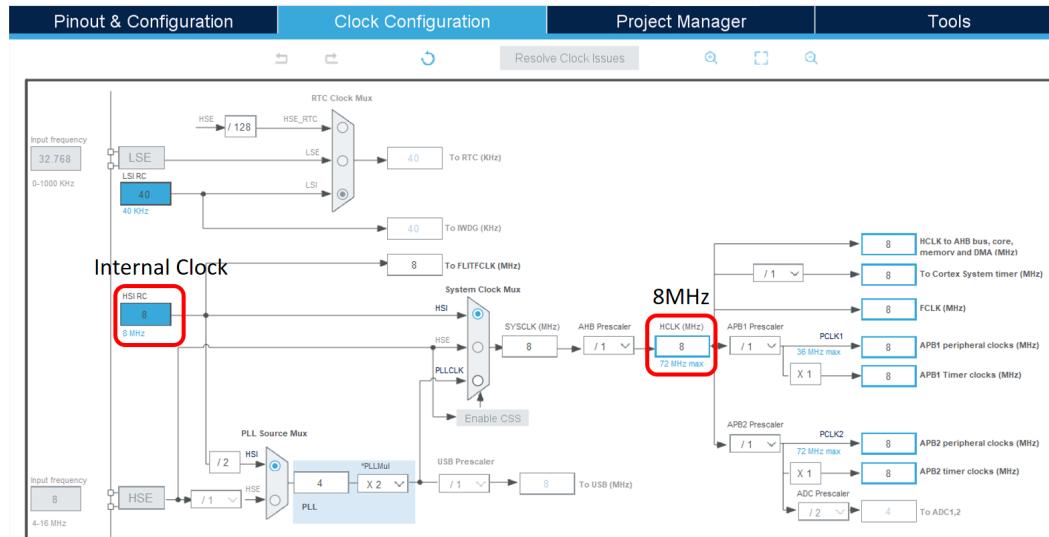
In the above diagram each seven segment display is having 8 internal LEDs, leading to the total number of LEDs is 32. However, not all the LEDs are required to turn ON, but one of them is needed. Therefore, only 12 lines are needed to control the whole 4 seven segment LEDs. By controlling with the micro-controller, we can turn ON an LED during a same interval T_S . Therfore, the period for controlling all 4 seven segment LEDs is $4T_S$. In other words, these LEDs are scanned at frequency $f = 1/4T_S$. Finally, it is obviously that if the frequency is greater than 30Hz (e.g. $f = 50Hz$), it seems that all LEDs are turn ON at the same time.

In this manual, the timer interrupt is used to design the interval T_S for LED scanning. Unfortunately, the simulation on Proteus can not execute at high frequency, the frequency f is set to a low value (e.g. 1Hz). In a real implementation, this frequency should be 50Hz.

2 Timer Interrupt Setup

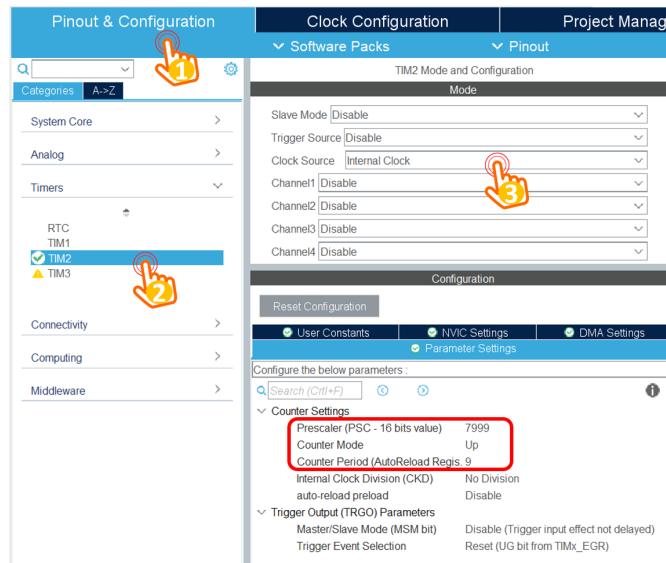
Step 1: Create a simple project, which LED connected to PA5. The manual can be found in the first lab.

Step 2: Check the clock source of the system on the tab **Clock Configuration** (from *.ioc file). In the default configuration, the internal clock source is used with 8MHz, as shown in the figure bellow.



Hình 2.2: Default clock source for the system

Step 3: Configure the timer on the **Parameter Settings**, as follows:



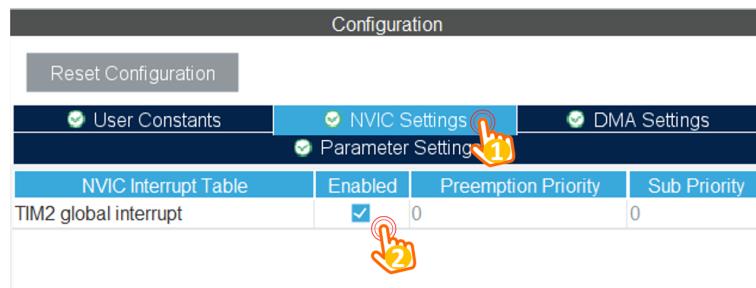
Hình 2.3: Configure for Timer 2

Select the clock source for timer 2 to the **Internal Clock**. Finally, set the prescaller and the counter to 7999 and 9, respectively. These values are explained as follows:

- The target is to set an interrupt timer to 10ms

- The clock source is 8MHz, by setting the prescaler to 7999, the input clock source to the timer is **8MHz/(7999+1) = 1000Hz**.
- The interrupt is raised when the timer counter is counted from 0 to 9, meaning that the frequency is divided by 10, which is 100Hz.
- The frequency of the timer interrupt is 100Hz, meaning that the period is **1/100Hz = 10ms**.

Step 4: Enable the timer interrupt by switching to **NVIC Settings** tab, as follows:



Hình 2.4: Enable timer interrupt

Finally, save the configuration file to generate the source code.

Step 5: On the **main()** function, call the timer init function, as follows:

```

1 int main(void)
2 {
3     HAL_Init();
4     SystemClock_Config();
5
6     MX_GPIO_Init();
7     MX_TIM2_Init();
8
9     /* USER CODE BEGIN 2 */
10    HAL_TIM_Base_Start_IT(&htim2);
11    /* USER CODE END 2 */
12
13    while (1){
14
15    }
16 }
```

Program 2.1: Init the timer interrupt in main

Please put the init function in a right place to avoid conflicts when code generation is executed (e.g. ioc file is updated).

Step 6: Add the interrupt service routine function, this function is invoked every 10ms, as follows:

```
1 /* USER CODE BEGIN 4 */
2 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
3 {
4 }
5 /* USER CODE END 4 */
```

Program 2.2: Add an interrupt service routine

Step 7: To run a LED Blinky demo using interrupt, a short manual is presented as follows:

```
1 /* USER CODE BEGIN 4 */
2 int counter = 100;
3 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
4 {
5     counter--;
6     if(counter <= 0){
7         counter = 100;
8         HAL_GPIO_TogglePin(LED_RED_GPIO_Port, LED_RED_Pin);
9     }
10 /* USER CODE END 4 */
```

Program 2.3: LED Blinky using timer interrupt

The **HAL_TIM_PeriodElapsedCallback** function is an infinite loop, which is invoked every cycle of the timer 2, in this case, is 10ms.

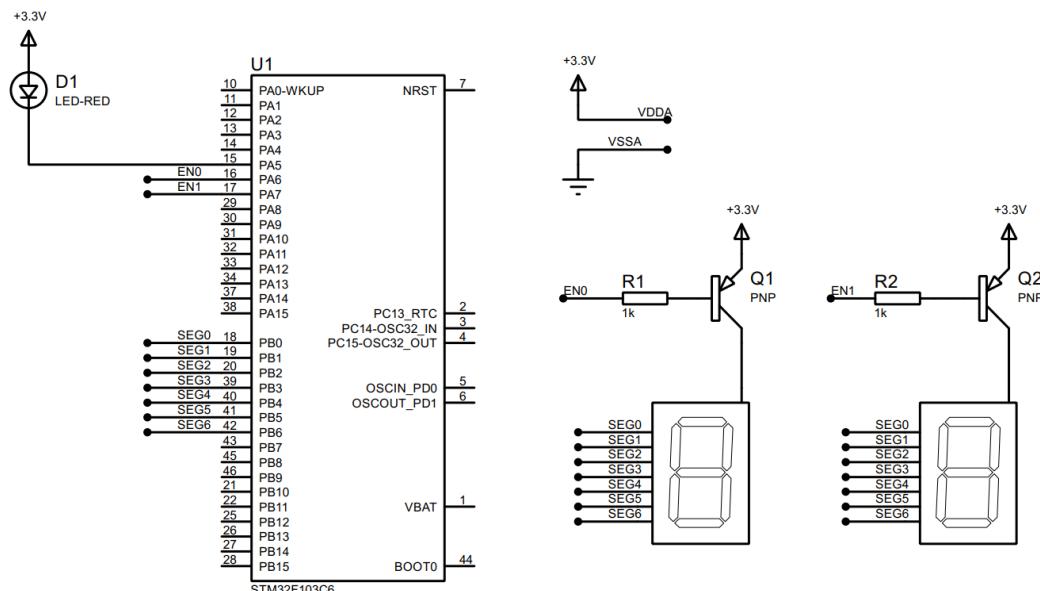
3 Exercise and Report

3.1 Exercise 1

The first exercise show how to interface for multiple seven segment LEDs to STM32F103C6 micro-controller (MCU). Seven segment displays are common anode type, meaning that the anode of all LEDs are tied together as a single terminal and cathodes are left alone as individual pins.

In order to save the resource of the MCU, individual cathode pins from all the seven segment LEDs are connected together, and connect to 7 pins of the MCU. These pins are popular known as the **signal pins**. Meanwhile, the anode pin of each seven segment LEDs are controlled under a power enabling circuit, for instance, an PNP transistor. At a given time, only one seven segment LED is turned on. However, if the delay is small enough, it seems that all LEDs are enabling.

Implement the circuit simulation in Proteus with two 7-SEGMENT LEDs as following:



Hình 2.5: Simulation schematic in Proteus

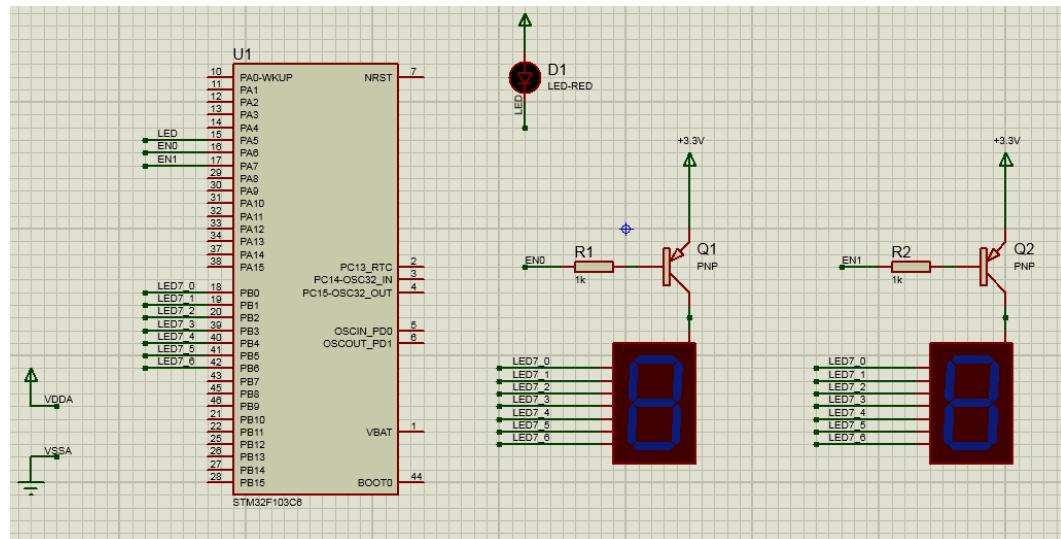
Components used in the schematic are listed bellow:

- 7SEG-COM-ANODE (connected from PB0 to PB6)
- LED-RED
- PNP
- RES
- STM32F103C6

Students are proposed to use the function **display7SEG(int num)** in the Lab 1 in this exercise. Implement the source code in the interrupt callback function to display number "1" on the first seven segment and number "2" for second one. The

switching time between 2 LEDs is half of second.

Report 1: Capture your schematic from Proteus and show in the report.



Hình 2.6: Schematic for exercise 1

Report 2: Present your source code in the **HAL_TIM_PeriodElapsedCallback** function.

```

1 // Declare int count=50; int state=1;
2 // count is counter variable, state is value will display
   by LED 7 segment
3 // Every 500ms, count==50, the system will change state by
   change value of enable pin and value to display
4 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
{
5   if(count == 50 && state == 1){
6     display7SEG(1);
7     HAL_GPIO_WritePin(GPIOA , EN0_Pin , RESET);
8     HAL_GPIO_WritePin(GPIOA , EN1_Pin , SET);
9     HAL_GPIO_TogglePin(GPIOA , LED_RED_Pin);
10    state = 2;
11  }
12  else if(count == 50 && state == 2){
13    display7SEG(2);
14    HAL_GPIO_WritePin(GPIOA , EN0_Pin , SET);
15    HAL_GPIO_WritePin(GPIOA , EN1_Pin , RESET);
16    HAL_GPIO_TogglePin(GPIOA , LED_RED_Pin);
17    state = 1;
18  }
19  count--;
20  if(count <= 0) count = 50;

```

Program 2.4: Source code in exercise 1

Short question: What is the frequency of the scanning process?

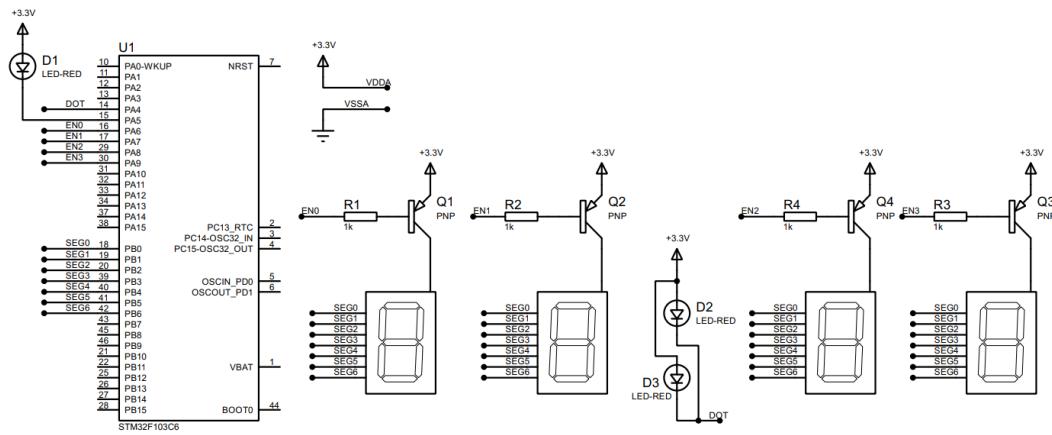
\Rightarrow **Answer:**

The switching time between 2 LEDs is half of second $\Rightarrow T_s = 0.5(s)$

The period for controlling all 2 seven segment LEDs is $2T_s \Rightarrow f = 1/2T_s = 1/(2 \times 0.5) = 1(\text{Hz})$

3.2 Exercise 2

Extend to 4 seven segment LEDs and two LEDs (connected to PA4, labeled as **DOT**) in the middle as following:



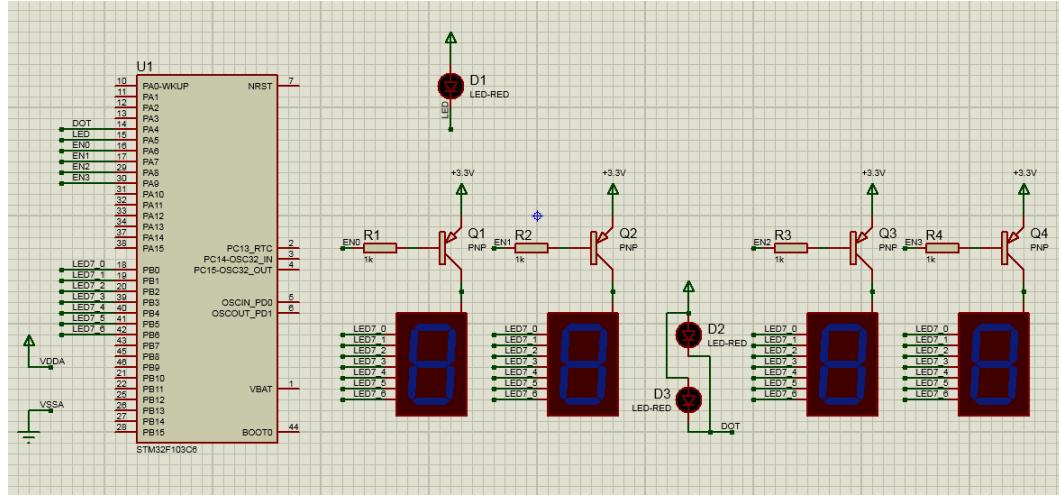
Hình 2.7: Simulation schematic in Proteus

Blink the two LEDs every second. Meanwhile, number 3 is displayed on the third seven segment and number 0 is displayed on the last one (to present 12 hour and a half). The switching time for each seven segment LED is also a half of second (500ms). **Implement your code in the timer interrupt function.**

Report 1: Capture your schematic from Proteus and show in the report.

Report 2: Present your source code in the `HAL_TIM_PeriodElapsedCallback` function.

```
1 // Declare int countSEG=50, counDOT = 100; int state=1;
2 // countSEG is counter variable for LED 7 Segment, countLED
3 // is counter variable for LED, state is value will
4 // display by LED 7 segment
5 // Every 1s, counterDOT == 100, LEDs will change state.
6 // Every 500ms, count==50, 7 segment LEDs will change state
7 // by change value of enable pin and value to display
8 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
9 {
10     if(countDOT == 100){
11         HAL_GPIO_TogglePin(GPIOA , LED_RED_Pin);
```



Hình 2.8: Schematic for exercise 2

```

8     HAL_GPIO_TogglePin(GPIOA , DOT_Pin);
9 }
10    if(countSEG == 50){
11        display7SEG(state);
12        if(state == 1) {
13            HAL_GPIO_WritePin(GPIOA , EN0_Pin , RESET);
14            HAL_GPIO_WritePin(GPIOA , EN1_Pin|EN2_Pin|EN3_Pin , SET
15        );
16        state = 2;
17    }
18    else if(state == 2) {
19        HAL_GPIO_WritePin(GPIOA , EN0_Pin|EN2_Pin|EN3_Pin , SET
20    );
21        HAL_GPIO_WritePin(GPIOA , EN1_Pin , RESET);
22        state = 3;
23    }
24    else if(state == 3) {
25        HAL_GPIO_WritePin(GPIOA , EN0_Pin|EN1_Pin|EN3_Pin , SET
26    );
27        HAL_GPIO_WritePin(GPIOA , EN2_Pin , RESET);
28        state = 0;
29    }
30    else if(state == 0) {
31        HAL_GPIO_WritePin(GPIOA , EN0_Pin|EN1_Pin|EN2_Pin , SET
32    );
33        HAL_GPIO_WritePin(GPIOA , EN3_Pin , RESET);
34        state = 1;
35    }
36    countSEG--;
37    countDOT--;
38    if(countSEG <= 0) countSEG = 50;
39    if(countDOT <= 0) countDOT = 100;

```

Program 2.5: Source code in exercise 2

Short question: What is the frequency of the scanning process?

⇒ **Answer:**

The switching time between for each seven LED is half of second $\Rightarrow T_s = 0.5(s)$

The period for controlling all 4 seven segment LEDs is $4T_s \Rightarrow f = 1/4T_s = 1/(4 \times 0.5) = 0.5(Hz)$

3.3 Exercise 3

Implement a function named **update7SEG(int index)**. An array of 4 integer numbers are declared in this case. The code skeleton in this exercise is presented as following:

```

1 const int MAX_LED = 4;
2 int index_led = 0;
3 int led_buffer[4] = {1, 2, 3, 4};
4 void update7SEG(int index){
5     switch (index){
6         case 0:
7             //Display the first 7SEG with led_buffer[0]
8             break;
9         case 1:
10            //Display the second 7SEG with led_buffer[1]
11            break;
12        case 2:
13            //Display the third 7SEG with led_buffer[2]
14            break;
15        case 3:
16            //Display the forth 7SEG with led_buffer[3]
17            break;
18        default:
19            break;
20    }
21 }
```

Program 2.6: An example for your source code

This function should be invoked in the timer interrupt, e.g `update7SEG(index_led++)`. The variable **index_led** is updated to stay in a valid range, which is from 0 to 3.

Report 1: Present the source code of the `update7SEG` function.

```

1 void update7SEG(int index){
2     switch(index){
3         case 0:
4             HAL_GPIO_WritePin(GPIOA, EN0_Pin, RESET);
5             HAL_GPIO_WritePin(GPIOA, EN1_Pin|EN2_Pin|EN3_Pin, SET);
6             display7SEG(led_buffer[0]);
```

```

7     break;
8 case 1:
9     HAL_GPIO_WritePin(GPIOA, EN1_Pin, RESET);
10    HAL_GPIO_WritePin(GPIOA, EN0_Pin|EN2_Pin|EN3_Pin, SET);
11    display7SEG(led_buffer[1]);
12    break;
13 case 2:
14    HAL_GPIO_WritePin(GPIOA, EN2_Pin, RESET);
15    HAL_GPIO_WritePin(GPIOA, EN0_Pin|EN1_Pin|EN3_Pin, SET);
16    display7SEG(led_buffer[2]);
17    break;
18 case 3:
19    HAL_GPIO_WritePin(GPIOA, EN3_Pin, RESET);
20    HAL_GPIO_WritePin(GPIOA, EN0_Pin|EN1_Pin|EN2_Pin, SET);
21    display7SEG(led_buffer[3]);
22    break;
23 default:
24     break;
25 }
26 }
```

Program 2.7: Source code of the update7SEG function

Report 2: Present the source code in the HAL_TIM_PeriodElapsedCallback.

```

1 // Declare int countSEG=50, counDOT = 100;
2 // countSEG is counter variable for LED 7 Segment, countDOT
3 // is counter variable for LED
4 // Every 1s, counterDOT == 100, LEDs will change state.
5 // Every 500ms, count==50, 7 segment LEDs will change state
6 // by call update7SEG function
7 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
8 {
9     if(countDOT == 100){
10         HAL_GPIO_TogglePin(GPIOA, DOT_Pin);
11         HAL_GPIO_TogglePin(GPIOA, LED_RED_Pin);
12     }
13     if(countSEG == 50){
14         update7SEG(index_led++);
15         if(index_led >= MAX_LED) index_led = 0;
16     }
17     countSEG--;
18     countDOT--;
19     if(countSEG <= 0) countSEG = 50;
20     if(countDOT <= 0) countDOT = 100;
21 }
```

Program 2.8: Source code in exercise 3

Students are proposed to change the values in the **led_buffer** array for unit test this function, which is used afterward.

3.4 Exercise 4

Change the period of invoking update7SEG function in order to set the frequency of 4 seven segment LEDs to 1Hz. The DOT is still blinking every second.

Report 1: Present the source code in the **HAL_TIM_PeriodElapsedCallback**.

⇒ **Answer:**

The frequency of 4 seven segment LEDs is 1Hz $\Rightarrow f = 1(\text{Hz})$

The period for controlling all 4 seven segment LEDs is $4T_s \Rightarrow f = 1/(4T_s) \Rightarrow T_s = 1/(4f) = 0.25(\text{s})$

```
1 // Declare int countSEG=25, counDOT = 100; int state=1;
2 // countSEG is counter variable for LED 7 Segment, countLED
3 // is counter variable for LED, state is value will
4 // display by LED 7 segment
5 // Every 1s, counterDOT == 100, LEDs will change state.
6 // Every 250ms, count==25, 7 segment LEDs will change state
7 // by call update7SEG function.
8 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
9 {
10    if(countDOT == 100){
11        HAL_GPIO_TogglePin(GPIOA, DOT_Pin);
12        HAL_GPIO_TogglePin(GPIOA, LED_RED_Pin);
13    }
14    if(countSEG == 25){
15        update7SEG(index_led++);
16        if(index_led >= MAX_LED) index_led = 0;
17    }
18 }
```

Program 2.9: Source code for exercise 4

3.5 Exercise 5

Implement a digital clock with **hour** and **minute** information displayed by 2 seven segment LEDs. The code skeleton in the **main** function is presented as follows:

```
1 int hour = 15, minute = 8, second = 50;
2
3 while(1){
4     second++;
5     if (second >= 60){
6         second = 0;
7         minute++;
8     }
9     if(minute >= 60){
```

```

10         minute = 0;
11         hour++;
12     }
13     if(hour >=24){
14         hour = 0;
15     }
16     updateClockBuffer();
17     HAL_Delay(1000);
18 }
```

Program 2.10: An example for your source code

The function **updateClockBuffer** will generate values for the array **led_buffer** according to the values of hour and minute. In the case these values are 1 digit number, digit 0 is added.

Report 1: Present the source code in the **updateClockBuffer** function.

```

1 void updateClockBuffer(){
2     led_buffer[0] = hour/10;
3     led_buffer[1] = hour%10;
4     led_buffer[2] = minute/10;
5     led_buffer[3] = minute%10;
6 }
```

Program 2.11: The source code in the updateClockBuffer() function

3.6 Exercise 6

The main target from this exercise to reduce the complexity (or reduce code processing) in the timer interrupt. The time consumed in the interrupt can lead to the nested interrupt issue, which can crash the whole system. A simple solution can disable the timer whenever the interrupt occurs, the enable it again. However, the real-time processing is not guaranteed anymore.

In this exercise, a software timer is created and its counter is count down every timer interrupt is raised (every 10ms). By using this timer, the **Hal_Delay(1000)** in the main function is removed. In a MCU system, non-blocking delay is better than blocking delay. The details to create a software timer are presented bellow. The source code is added to your current program, **do not delete the source code you have on Exercise 5.**

Step 1: Declare variables and functions for a software timer, as following:

```

1 /* USER CODE BEGIN 0 */
2 int timer0_counter = 0;
3 int timer0_flag = 0;
4 int TIMER_CYCLE = 10;
5 void set
6 Timer0(int duration){
7     timer0_counter = duration /TIMER_CYCLE;
8     timer0_flag = 0;
```

```

9 }
10 void timer_run(){
11     if(timer0_counter > 0){
12         timer0_counter--;
13         if(timer0_counter == 0) timer0_flag = 1;
14     }
15 }
16 /* USER CODE END 0 */

```

Program 2.12: Software timer based timer interrupt

Please change the **TIMER_CYCLE** to your timer interrupt period. In the manual code above, it is **10ms**.

Step 2: The **timer_run()** is invoked in the timer interrupt as following:

```

1 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
{
2
3     timer_run();
4
5     //YOUR OTHER CODE
6 }

```

Program 2.13: Software timer based timer interrupt

Step 3: Use the timer in the main function by invoked **setTimer0** function, then check for its flag (**timer0_flag**). An example to blink an LED connected to PA5 using software timer is shown as follows:

```

1 setTimer0(1000);
2 while (1){
3     if(timer0_flag == 1){
4         HAL_GPIO_TogglePin(LED_RED_GPIO_Port, LED_RED_Pin);
5         setTimer0(2000);
6     }
7 }

```

Program 2.14: Software timer is used in main fuction to blink the LED

Report 1: if in line 1 of the code above is miss, what happens after that and why?

⇒ **Answer:** if in line 1 of the code above is miss the LED red will always on and not change state. Explain:

- The LED red is on: because the **LED_RED_Pin** is initiated by default to RESET this make the LED red on.
- The LED red dose not change state: because at declaring the **timer0_counter** variable it is initiated to 0, so if's expression in function **timer_run** is false and the statements in that if not be executed. Therefore, **timer0_flag** will not be set to 1 and the state of LED not change.

Report 2: if in line 1 of the code above is changed to **setTimer0(1)**, what happens after that and why?

⇒ **Answer:** if in line 1 of the code above is change to setTimer0(1), the LED red will always on and not change state. Explain:

- The LED red is on: because the LED_RED_Pin is initiated by default to RESET this make the LED red on.
- The LED red dose not change state: because in setTimer0() function the timer0_counter variable is assigned to 0, because $1/10 = 0$, so if's expression in function timer_run is false and the statements in that if not be executed. Therefore, timer0_flat will not be set to 1 and the state of LED not change.

Report 3: if in line 1 of the code above is changed to setTimer0(10), what is changed compared to 2 first questions and why?

⇒ **Answer:** if in line 1 of the code above is changed to setTimer0(10) then the LED will off in 2 seconds, on in 2 seconds and repeat. Because in the first call function setTimer0, setTimer0(10), timer0_counter is assigned to 1, so after timer_run is called timer0_flat is assigned to 1, so all statements in if in while(1) will be executed. When statement setTimer0(2000) is executed, it mean waiting for 2 second to change timer0_flat to 1 and change state of LED because function timer_run is executed 200 times, each time take 10ms, to able to change timer0_flat to 1.

3.7 Exercise 7

Upgrade the source code in Exercise 5 (update values for hour, minute and second) by using the software timer and remove the HAL_Delay function at the end. Moreover, the DOT (connected to PA4) of the digital clock is also moved to main function.

Report 1: Present your source code in the while loop on main function.

```
1 while (1)
2 {
3     if(timer0_flat == 1){
4         second++;
5         if(second >= 60){
6             second = 0;
7             minute++;
8         }
9         if(minute >= 60){
10            minute = 0;
11            hour++;
12        }
13        if(hour >= 24){
14            hour = 0;
15        }
16        updateClockBuffer();
17        HAL_GPIO_TogglePin(GPIOA, DOT_Pin);
18        setTimer0(1000);
19    }
20 }
```

Program 2.15: Source code in exercise

3.8 Exercise 8

Move also the update7SEG() function from the interrupt timer to the main. Finally, the timer interrupt only used to handle software timers. All processing (or complex computations) is move to an infinite loop on the main function, optimizing the complexity of the interrupt handler function.

Report 1: Present your source code in the the main function. In the case more extra functions are used (e.g. the second software timer), present them in the report as well.

```
1 // In this exercise I add new function is setTimer1
2 /*
3 void setTimer1(int duration){
4     timer1_counter = duration / TIMER_CYCLE;
5     timer1_flat = 0;
6 }
7 /*
8 and in function timer_run I add:
9 /*
10 if(timer1_counter > 0){
11     timer1_counter--;
12     if(timer1_counter == 0) timer1_flat = 1;
13 }
14 */
15
16 int main(void)
17 {
18     HAL_Init();
19     SystemClock_Config();
20     MX_GPIO_Init();
21     MX_TIM2_Init();
22     HAL_TIM_Base_Start_IT(&htim2);
23     setTimer0(10);
24     setTimer1(10);
25     while (1)
26     {
27         if(timer1_flat == 1){
28             update7SEG(index_seg);
29             index_seg++;
30             if(index_seg >= 4) index_seg = 0;
31             setTimer1(250);
32         }
33
34         if(timer0_flat == 1){
35             second++;
36             if(second >= 60){
37                 second = 0;
38                 minute++;
39             }
40     }
41 }
```

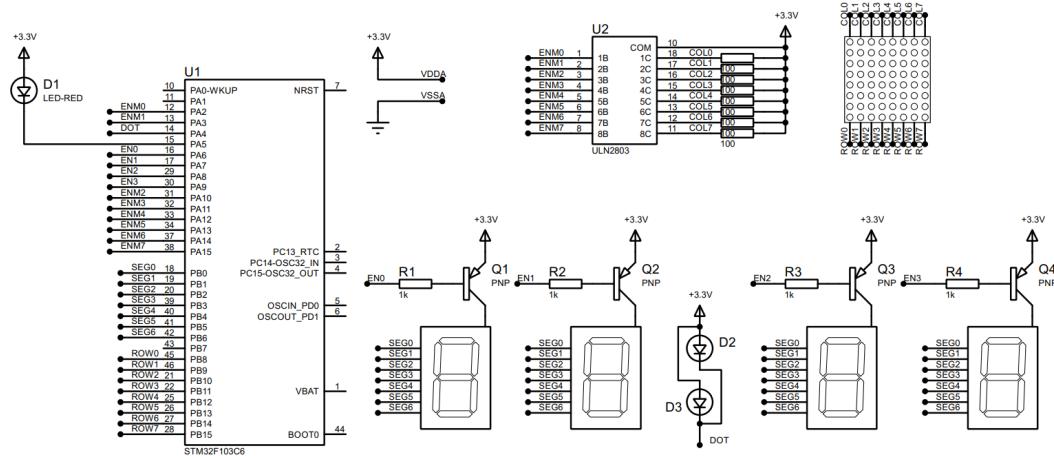
```

40         if(minute >= 60){
41             minute = 0;
42             hour++;
43         }
44         if(hour >= 24){
45             hour = 0;
46         }
47         updateClockBuffer();
48         HAL_GPIO_TogglePin(GPIOA , DOT_Pin);
49         setTimer0(1000);
50     }
51 }
52 }
```

Program 2.16: Source code for exercise 8

3.9 Exercise 9

This is an extra works for this lab. A LED Matrix is added to the system. A reference design is shown in figure bellow:



Hình 2.9: LED matrix is added to the simulation

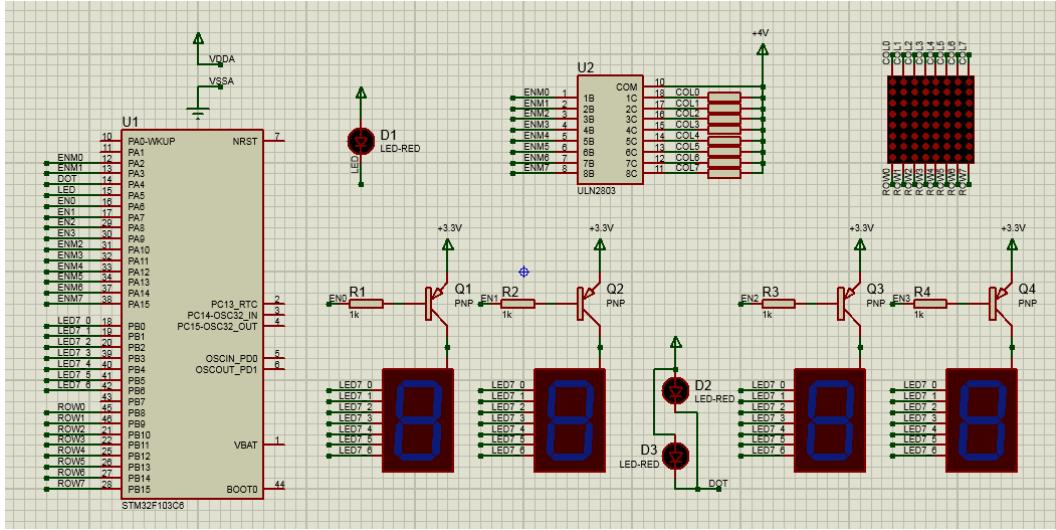
In this schematic, two new components are added, including the **MATRIX-8X8-RED** and **ULN2803**, which is an NPN transistor array to enable the power supply for a column of the LED matrix. Students can change the enable signal (from ENM0 to ENM7) if needed. Finally, the data signal (from ROW0 to ROW7) is connected to PB8 to PB15.

Report 1: Present the schematic of your system by capturing the screen in Proteus.

Report 2: Implement the function, updateLEDMatrix(int index), which is similarly to 4 seven led segments.

```

1 const int MAX_LED_MATRIX = 8;
2 int index_led_matrix = 0;
3 uint8_t matrix_buffer[8] = {0x01, 0x02, 0x03, 0x04, 0x05, 0
    x06, 0x07, 0x08};
```



Hình 2.10: Schematic for exercise 9

```

4 void updateLEDMatrix(int index){
5     switch (index){
6         case 0:
7             break;
8         case 1:
9             break;
10        case 2:
11            break;
12        case 3:
13            break;
14        case 4:
15            break;
16        case 5:
17            break;
18        case 6:
19            break;
20        case 7:
21            break;
22        default:
23            break;
24    }
25 }
```

Program 2.17: Function to display data on LED Matrix

Student are free to choose the invoking frequency of this function. However, this function is supposed to invoked in main function. Finally, please update the **matrix_buffer** to display character "A".

```

1 void updateLEDMatrix(int index){
2     switch(index){
3         case 0:
4             HAL_GPIO_WritePin(GPIOA , ENM0_Pin , RESET);
5             HAL_GPIO_WritePin(GPIOA , ENM1_Pin|ENM2_Pin|ENM3_Pin |
```

```

ENM4_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
    displayRowLEDMatrix(matrix_buffer[0]);
    break;
case 1:
    HAL_GPIO_WritePin(GPIOA, ENM1_Pin, RESET);
    HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM2_Pin|ENM3_Pin|
ENM4_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
    displayRowLEDMatrix(matrix_buffer[1]);
    break;
case 2:
    HAL_GPIO_WritePin(GPIOA, ENM2_Pin, RESET);
    HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM3_Pin|
ENM4_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
    displayRowLEDMatrix(matrix_buffer[2]);
    break;
case 3:
    HAL_GPIO_WritePin(GPIOA, ENM3_Pin, RESET);
    HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
ENM4_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
    displayRowLEDMatrix(matrix_buffer[3]);
    break;
case 4:
    HAL_GPIO_WritePin(GPIOA, ENM4_Pin, RESET);
    HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
ENM3_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
    displayRowLEDMatrix(matrix_buffer[4]);
    break;
case 5:
    HAL_GPIO_WritePin(GPIOA, ENM5_Pin, RESET);
    HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
ENM3_Pin|ENM4_Pin|ENM6_Pin|ENM7_Pin, SET);
    displayRowLEDMatrix(matrix_buffer[5]);
    break;
case 6:
    HAL_GPIO_WritePin(GPIOA, ENM6_Pin, RESET);
    HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
ENM3_Pin|ENM4_Pin|ENM5_Pin|ENM7_Pin, SET);
    displayRowLEDMatrix(matrix_buffer[6]);
    break;
case 7:
    HAL_GPIO_WritePin(GPIOA, ENM7_Pin, RESET);
    HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
ENM3_Pin|ENM4_Pin|ENM5_Pin|ENM6_Pin, SET);
    displayRowLEDMatrix(matrix_buffer[7]);
    break;
default:
    break;
}

```

Program 2.18: Source code for function updateLEDMatrix()

```

1 // This function will turn on or off row following value of
2 // value variable
3 // By convert value to binary, if the last bit is 1 the
4 // first row will on and reverse, if the next the last bit
5 // is 1 the secand row will on and reverse, ...
6 void displayRowLEDMatrix(uint8_t value){
7     HAL_GPIO_WritePin(GPIOB, ROW0_Pin, !(value&1));
8     HAL_GPIO_WritePin(GPIOB, ROW1_Pin, !((value>>1)&1));
9     HAL_GPIO_WritePin(GPIOB, ROW2_Pin, !((value>>2)&1));
10    HAL_GPIO_WritePin(GPIOB, ROW3_Pin, !((value>>3)&1));
11    HAL_GPIO_WritePin(GPIOB, ROW4_Pin, !((value>>4)&1));
12    HAL_GPIO_WritePin(GPIOB, ROW5_Pin, !((value>>5)&1));
13    HAL_GPIO_WritePin(GPIOB, ROW6_Pin, !((value>>6)&1));
14    HAL_GPIO_WritePin(GPIOB, ROW7_Pin, !((value>>7)&1));
15 }
```

Program 2.19: Source code for function displayRowLEDMatrix

```

1 int main(void)
2 {
3     HAL_Init();
4     SystemClock_Config();
5     MX_GPIO_Init();
6     MX_TIM2_Init();
7     HAL_TIM_Base_Start_IT(&htim2);
8     setTimer0(10);
9     setTimer1(10);
10    setTimer2(10);
11    while (1)
12    {
13        /*-----BEGIN LED SCOPE-----*/
14        if(timer0_flat == 1){
15            second++;
16            if(second >= 60){
17                second = 0;
18                minute++;
19            }
20            if(minute >= 60){
21                minute = 0;
22                hour++;
23            }
24            if(hour >= 24){
25                hour = 0;
26            }
27            updateClockBuffer();
28            HAL_GPIO_TogglePin(GPIOA, LED_RED_Pin);
29            HAL_GPIO_TogglePin(GPIOA, DOT_Pin);
```

```

30     setTimer0(1000);
31 }
32 /*-----END LED SCOPE-----*/
33
34 /*-----BEGIN LED7SEG SCOPE-----*/
35 if(timer1_flat == 1){
36     update7SEG(index_seg);
37     index_seg++;
38     if(index_seg >= MAX_LED7SEG) index_seg = 0;
39     setTimer1(250);
40 }
41 /*-----END LED7SEG SCOPE-----*/
42
43 /*-----BEGIN LED MATRIX SCOPE-----*/
44 if(timer2_flat == 1){
45     updateLEDMatrix(index_led_matrix);
46     index_led_matrix++;
47     if(index_led_matrix >= MAX_LED_MATRIX) index_led_matrix
48     = 0;
49     setTimer2(10);
50 }
51 /*-----END LED MATRIX SCOPE-----*/
52 }

```

Program 2.20: Source code in main function

3.10 Exercise 10

Create an animation on LED matrix, for example, the character is shifted to the left.

Report 1: Briefly describe your solution and present your source code in the report.

⇒ **Solution:** I use variable to record the number of times shift, in function updateLEDMatrix I add the second parameter is shift. If shift equal to 0, it means is not shifted, if shift not equal to 0 then turn circle matrix_buffer shift times by add index by shift, if that result greater than 7, we will replace it by it's remainder when divide for 8.

```

1 void updateLEDMatrix(int index, int shift){
2     switch(index){
3         case 0:
4             HAL_GPIO_WritePin(GPIOA, ENM0_Pin, RESET);
5             HAL_GPIO_WritePin(GPIOA, ENM1_Pin|ENM2_Pin|ENM3_Pin|
6             ENM4_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
7             displayRowLEDMatrix(matrix_buffer[(0+shift)%8]);
8             break;
9         case 1:
10            HAL_GPIO_WritePin(GPIOA, ENM1_Pin, RESET);

```

```

10     HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM2_Pin|ENM3_Pin|
11     ENM4_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
12     displayRowLEDMatrix(matrix_buffer[(1+shift)%8]);
13     break;
14 case 2:
15     HAL_GPIO_WritePin(GPIOA, ENM2_Pin, RESET);
16     HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM3_Pin|
17     ENM4_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
18     displayRowLEDMatrix(matrix_buffer[(2+shift)%8]);
19     break;
20 case 3:
21     HAL_GPIO_WritePin(GPIOA, ENM3_Pin, RESET);
22     HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
23     ENM4_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
24     displayRowLEDMatrix(matrix_buffer[(3+shift)%8]);
25     break;
26 case 4:
27     HAL_GPIO_WritePin(GPIOA, ENM4_Pin, RESET);
28     HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
29     ENM3_Pin|ENM5_Pin|ENM6_Pin|ENM7_Pin, SET);
30     displayRowLEDMatrix(matrix_buffer[(4+shift)%8]);
31     break;
32 case 5:
33     HAL_GPIO_WritePin(GPIOA, ENM5_Pin, RESET);
34     HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
35     ENM3_Pin|ENM4_Pin|ENM6_Pin|ENM7_Pin, SET);
36     displayRowLEDMatrix(matrix_buffer[(5+shift)%8]);
37     break;
38 case 6:
39     HAL_GPIO_WritePin(GPIOA, ENM6_Pin, RESET);
40     HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
41     ENM3_Pin|ENM4_Pin|ENM5_Pin|ENM7_Pin, SET);
42     displayRowLEDMatrix(matrix_buffer[(6+shift)%8]);
43     break;
44 case 7:
45     HAL_GPIO_WritePin(GPIOA, ENM7_Pin, RESET);
46     HAL_GPIO_WritePin(GPIOA, ENM0_Pin|ENM1_Pin|ENM2_Pin|
47     ENM3_Pin|ENM4_Pin|ENM5_Pin|ENM6_Pin, SET);
48     displayRowLEDMatrix(matrix_buffer[(7+shift)%8]);
49     break;
50 default:
51     break;
52 }
53 }
```

Program 2.21: Source code for new function updateLEDMatrix

```

1 // Declare int index_seg = 0, index_led_matrix = 0, shift =
2 // 0;
2 // index_seg is order of 7 segment LED will on
```

```

3 // index_led_matrix is column of led matrix will on
4 // shift is number of times shift
5 int main(void)
{
    HAL_Init();
    SystemClock_Config();
    MX_GPIO_Init();
    MX_TIM2_Init();
    HAL_TIM_Base_Start_IT(&htim2);
    setTimer0(10);
    setTimer1(10);
    setTimer2(10);
    while (1)
    {
        /*-----BEGIN LED SCOPE-----*/
        if(timer0_flat == 1){
            second++;
            if(second >= 60){
                second = 0;
                minute++;
            }
            if(minute >= 60){
                minute = 0;
                hour++;
            }
            if(hour >= 24){
                hour = 0;
            }
            updateClockBuffer();
            HAL_GPIO_TogglePin(GPIOA, LED_RED_Pin);
            HAL_GPIO_TogglePin(GPIOA, DOT_Pin);
            setTimer0(1000);
        }
        /*-----END LED SCOPE-----*/
        /*-----BEGIN LED7SEG SCOPE-----*/
        if(timer1_flat == 1){
            update7SEG(index_seg);
            index_seg++;
            if(index_seg >= MAX_LED7SEG) index_seg = 0;
            setTimer1(250);
        }
        /*-----END LED7SEG SCOPE-----*/
        /*-----BEGIN LED MATRIX SCOPE-----*/
        if(timer2_flat == 1){
            updateLEDMatrix(index_led_matrix, shift);
            index_led_matrix++;
            if(index_led_matrix >= MAX_LED_MATRIX) {

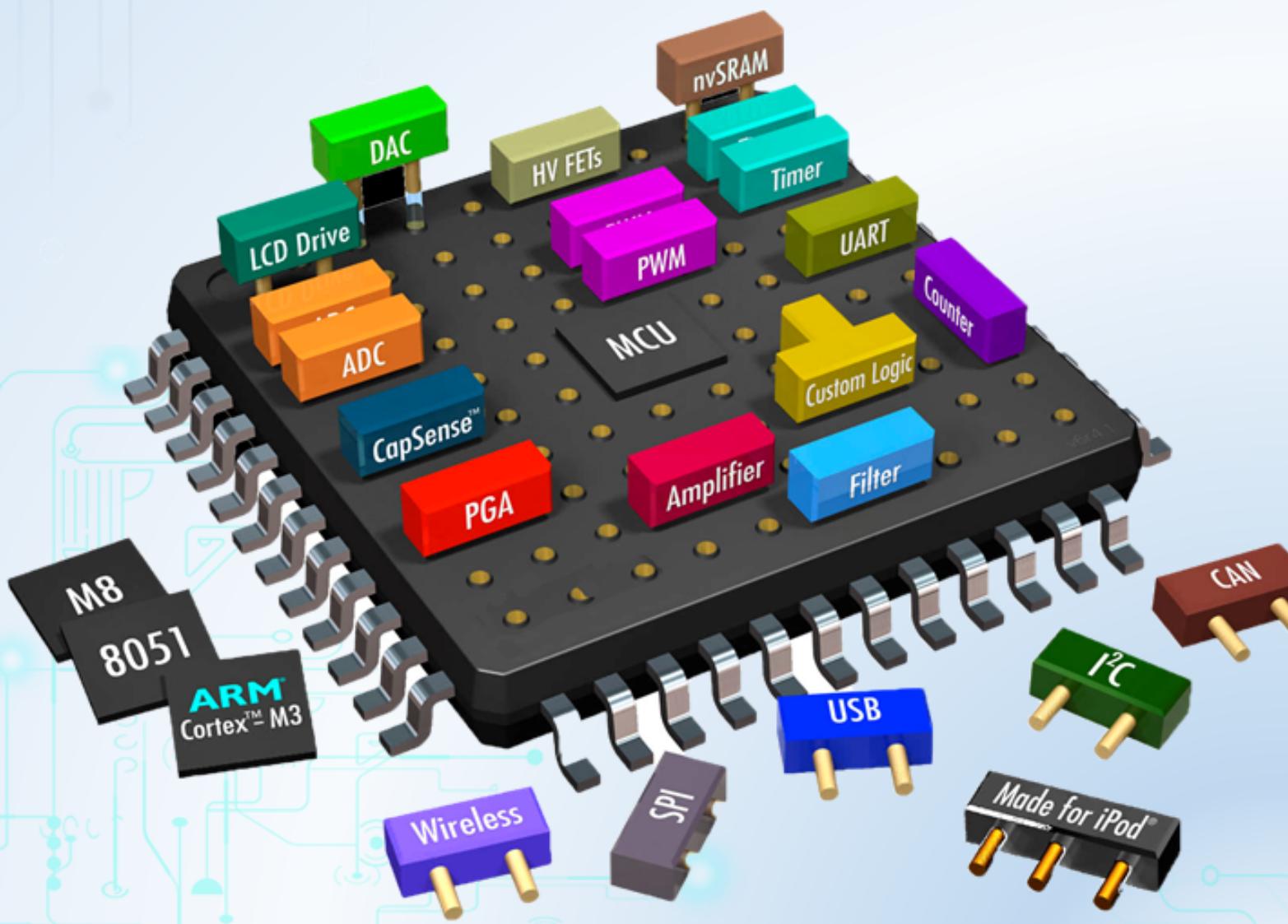
```

```
52     index_led_matrix = 0;
53     shift++;
54     if(shift == 8) shift = 0;
55 }
56 setTimer2(50);
57 }
58 /*-----END LED MATRIX SCOPE-----*/
59 }
60 }
```

Program 2.22: Source code in main function

CHƯƠNG 3

Buttons/Switches



1 Objectives

In this lab, you will

- Learn how to add new C source files and C header files in an STM32 project,
- Learn how to read digital inputs and display values to LEDs using a timer interrupt of a microcontroller (MCU).
- Learn how to debounce when reading a button.
- Learn how to create an FSM and implement an FSM in an MCU.

2 Introduction

Embedded systems usually use buttons (or keys, or switches, or any form of mechanical contacts) as part of their user interface. This general rule applies from the most basic remote-control system for opening a garage door, right up to the most sophisticated aircraft autopilot system. Whatever the system you create, you need to be able to create a reliable button interface.

A button is generally hooked up to an MCU so as to generate a certain logic level when pushed or closed or "active" and the opposite logic level when unpushed or open or "inactive." The active logic level can be either '0' or '1', but for reasons both historical and electrical, an active level of '0' is more common.

We can use a button if we want to perform operations such as:

- Drive a motor while a switch is pressed.
- Switch on a light while a switch is pressed.
- Activate a pump while a switch is pressed.

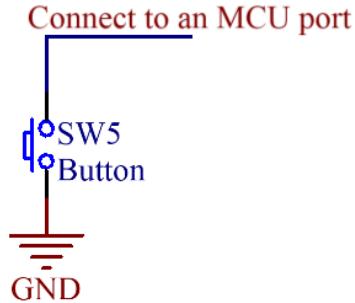
These operations could be implemented using an electrical button without using an MCU; however, use of an MCU may well be appropriate if we require more complex behaviours. For example:

- Drive a motor while a switch is pressed.
Condition: If the safety guard is not in place, don't turn the motor. Instead sound a buzzer for 2 seconds.
- Switch on a light while a switch is pressed.
Condition: To save power, ignore requests to turn on the light during daylight hours.
- Activate a pump while a switch is pressed
Condition: If the main water reservoir is below 300 litres, do not start the main pump: instead, start the reserve pump and draw the water from the emergency tank.

In this lab, we consider how you read inputs from mechanical buttons in your embedded application using an MCU.

3 Basic techniques for reading from port pins

3.1 The need for pull-up resistors



Hình 3.1: Connecting a button to an MCU

Figure 3.1 shows a way to connect a button to an MCU. This hardware operates as follows:

- When the switch is open, it has no impact on the port pin. An internal resistor on the port "pulls up" the pin to the supply voltage of the MCU (typically 3.3V for STM32F103). If we read the pin, we will see the value '1'.
- When the switch is closed (pressed), the pin voltage will be 0V. If we read the pin, we will see the value '0'.

However, if the MCU does not have a pull-up resistor inside, when the button is pressed, the read value will be '0', but even we release the button, the read value is still '0' as shown in Figure 3.2.

With pull-ups:

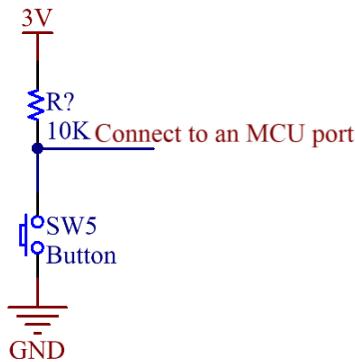


Without pull-ups:



Hình 3.2: The need of pull up resistors

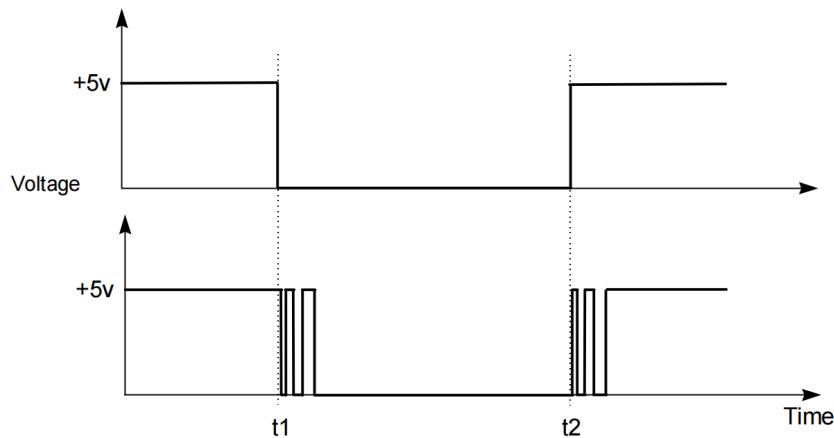
So a reliable way to connect a button/switch to an MCU is that we explicitly use an external pull-up resistor as shown in Figure 3.3.



Hình 3.3: A reliable way to connect a button to an MCU

3.2 Dealing with switch bounces

In practice, all mechanical switch contacts bounce (that is, turn on and off, repeatedly, for short period of time) after the switch is closed or opened as shown in Figure 3.4.



Hình 3.4: Switch bounces

Every system that uses any kind of mechanical switch must deal with the issue of debouncing. The key task is to make sure that one mechanical switch or button action is only read as one action by the MCU, even though the MCU will typically be fast enough to detect the unwanted switch bounces and treat them as separate events. Bouncing can be eliminated by special ICs or by RC circuitry, but in most cases debouncing is done in software because software is "free".

As far as the MCU concerns, each "bounce" is equivalent to one press and release of an "ideal" switch. Without appropriate software design, this can give several problems:

- Rather than reading 'A' from a keypad, we may read 'AAAAA'

- Counting the number of times that a switch is pressed becomes extremely difficult
- If a switch is depressed once, and then released some time later, the ‘bounce’ may make it appear as if the switch has been pressed again (at the time of release).

The key to debouncing is to establish a minimum criterion for a valid button push, one that can be implemented in software. This criterion must involve differences in time - two button presses in 20ms must be treated as one button event, while two button presses in 2 seconds must be treated as two button events. So what are the relevant times we need to consider? They are these:

- Bounce time: most buttons seem to stop bouncing within 10ms
- Button press time: the shortest time a user can press and release a button seems to be between 50 and 100ms
- Response time: a user notices if the system response is 100ms after the button press, but not if it is 50ms after

Combining all of these times, we can set a few goals

- Ignore all bouncing within 10ms
- Provide a response within 50ms of detecting a button push (or release)
- Be able to detect a 50ms push and a 50ms release

The simplest debouncing method is to examine the keys (or buttons or switches) every N milliseconds, where $N > 10\text{ms}$ (our specified button bounce upper limit) and $N \leq 50\text{ms}$ (our specified response time). We then have three possible outcomes every time we read a button:

- We read the button in the solid ‘0’ state
- We read the button in the solid ‘1’ state
- We read the button while it is bouncing (so we will get either a ‘0’ or a ‘1’)

Outcomes 1 and 2 pose no problems, as they are what we would always like to happen. Outcome 3 also poses no problem because during a bounce either state is acceptable. If we have just pressed an active-low button and we read a ‘1’ as it bounces, the next time through we are guaranteed to read a ‘0’ (remember, the next time through all bouncing will have ceased), so we will just detect the button push a bit later. Otherwise, if we read a ‘0’ as the button bounces, it will still be ‘0’ the next time after all bouncing has stopped, so we are just detecting the button push a bit earlier. The same applies to releasing a button. Reading a single bounce (with all bouncing over by the time of the next read) will never give us an invalid button state. It’s only reading multiple bounces (multiple reads while bouncing is occurring) that can give invalid button states such as repeated push signals from one physical push.

So if we guarantee that all bouncing is done by the time we next read the button, we’re good. Well, almost good, if we’re lucky...

MCUs often live among high-energy beasts, and often control the beasts. High energy devices make electrical noise, sometimes great amounts of electrical noise. This noise can, at the worst possible moment, get into your delicate button-and-high-value-pullup circuit and act like a real button push. Oops, missile launched, sorry!

If the noise is too intense we cannot filter it out using only software, but will need hardware of some sort (or even a redesign). But if the noise is only occasional, we can filter it out in software without too much bother. The trick is that instead of regarding a single button ‘make’ or ‘break’ as valid, we insist on N contiguous makes or breaks to mark a valid button event. N will be a factor of your button scanning rate and the amount of filtering you want to add. Bigger N gives more filtering. The simplest filter (but still a big improvement over no filtering) is just an N of 2, which means compare the current button state with the last button state, and only if both are the same is the output valid.

Note that now we have not two but three button states: active (or pressed), inactive (or released), and indeterminate or invalid (in the middle of filtering, not yet filtered). In most cases we can treat the invalid state the same as the inactive state, since we care in most cases only about when we go active (from whatever state) and when we cease being active (to inactive or invalid). With that simplification we can look at simple N = 2 filtering reading a button wired to STM32 MCU:

```
1 void button_reading(void){  
2     static unsigned char last_button;  
3     unsigned char raw_button;  
4     unsigned char filtered_button;  
5     last_button = raw_button;  
6     raw_button = HAL_GPIO_ReadPin(BUTTON_1_GPIO_Port ,  
7                                     BUTTON_1_Pin);  
8     if(last_button == raw_button){  
9         filtered_button = raw_button;  
10    }  
11 }
```

Program 3.1: Read port pin and debouncing

The function `button_reading()` must be called no more often than our debounce time (10ms).

To expand to greater filtering (larger N), keep in mind that the filtering technique essentially involves reading the current button state and then either counting or resetting the counter. We count if the current button state is the same as the last button state, and if our count reaches N we then report a valid new button state. We reset the counter if the current button state is different than the last button state, and we then save the current button state as the new button state to compare against the next time. Also note that the larger our value of N the more often our filtering routine must be called, so that we get a filtered response within our specified 50ms deadline. So for example with an N of 8 we should be calling our filtering routine every 2 - 5ms, giving a response time of 16 - 40ms (>10ms and <50ms).

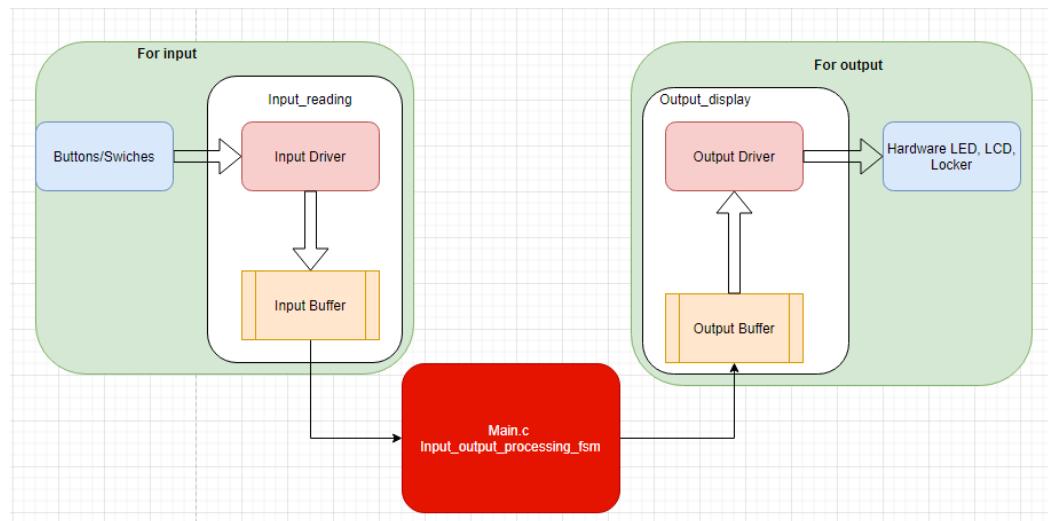
4 Reading switch input (basic code) using STM32

To demonstrate the use of buttons/switches in STM32, we use an example which requires to write a program that

- Has a timer which has an interrupt in every 10 milliseconds.
- Reads values of button PB0 every 10 milliseconds.
- Increases the value of LEDs connected to PORTA by one unit when the button PB0 is pressed.
- Increases the value of PORTA automatically in every 0.5 second, if the button PB0 is pressed in more than 1 second.

4.1 Input Output Processing Patterns

For both input and output processing, we have a similar pattern to work with. Normally, we have a module named driver which works directly to the hardware. We also have a buffer to store temporarily values. In the case of input processing, the driver will store the value of the hardware status to the buffer for further processing. In the case of output processing, the driver uses the buffer data to output to the hardware.



Hình 3.5: Input Output Processing Patterns

Figure 3.5 shows that we should have an *input_reading* module to process the buttons, then store the processed data to the buffer. Then a module of *input_output_processing_fsm* will process the input data, and update the output buffer. The output driver gets the value from the output buffer to transfer to the hardware.

4.2 Setting up

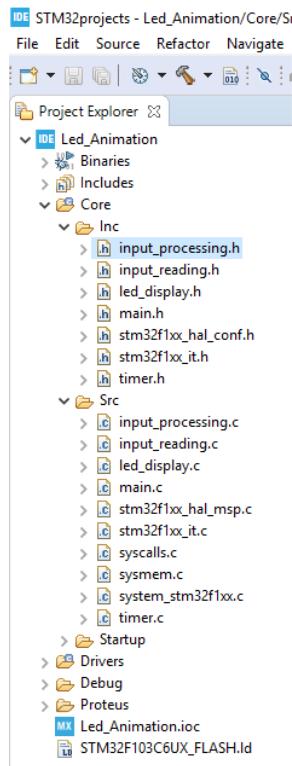
4.2.1 Create a project

Please follow the instruction in Labs 1 and 2 to create a project that includes:

- PB0 as an input port pin,
- PA0-PA7 as output port pins, and
- Timer 2 10ms interrupt

4.2.2 Create a file C source file and header file for input reading

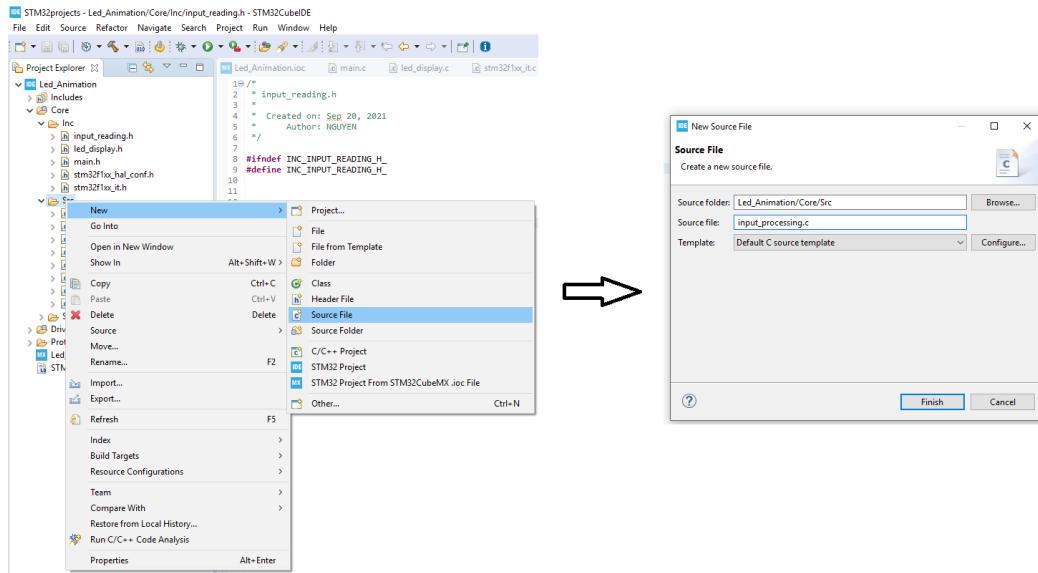
We are expected to have files for button processing and led display as shown in Figure 3.6.



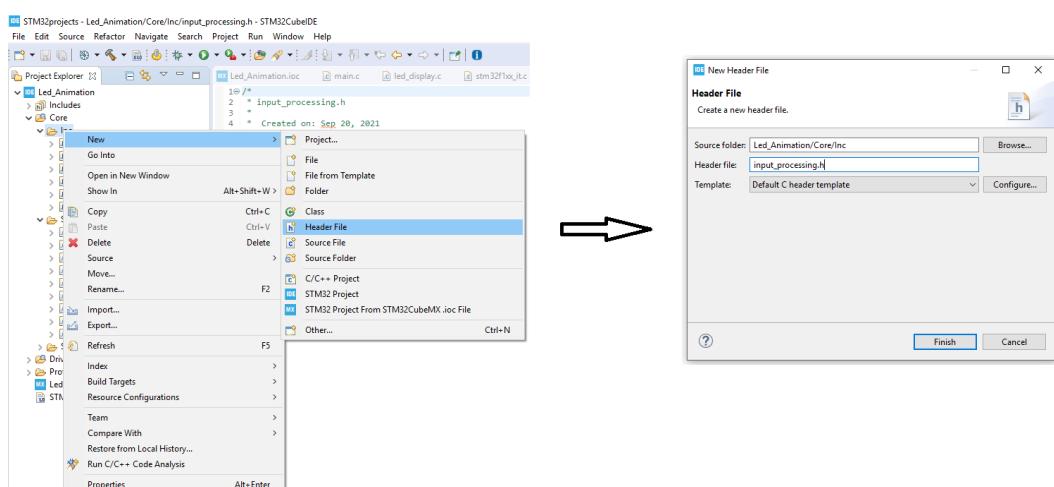
Hình 3.6: File Organization

Steps 1 (Figure 3.7): Right click to the folder **Src**, select **New**, then select **Source File**. There will be a pop-up. Please type the file name, then click **Finish**.

Step 2 (Figure 3.8): Do the same for the C header file in the folder **Inc**.



Hình 3.7: Step 1: Create a C source file for input reading



Hình 3.8: Step 2: Create a C header file for input processing

4.3 Code For Read Port Pin and Debouncing

4.3.1 The code in the input_reading.c file

```
1 #include "main.h"
2 //we aim to work with more than one buttons
3 #define NO_OF_BUTTONS 1
4 //timer interrupt duration is 10ms, so to pass 1 second,
5 //we need to jump to the interrupt service routine 100 time
6 #define DURATION_FOR_AUTO_INCREASING 100
7 #define BUTTON_IS_PRESSED GPIO_PIN_RESET
8 #define BUTTON_IS_RELEASED GPIO_PIN_SET
9 //the buffer that the final result is stored after
10 //debouncing
11 static GPIO_PinState buttonBuffer[NO_OF_BUTTONS];
12 //we define two buffers for debouncing
13 static GPIO_PinState debounceButtonBuffer1[NO_OF_BUTTONS];
14 static GPIO_PinState debounceButtonBuffer2[NO_OF_BUTTONS];
15 //we define a flag for a button pressed more than 1 second.
16 static uint8_t flagForButtonPress1s[NO_OF_BUTTONS];
17 //we define counter for automatically increasing the value
18 //after the button is pressed more than 1 second.
19 static uint16_t counterForButtonPress1s[NO_OF_BUTTONS];
20 void button_reading(void){
21     for(char i = 0; i < NO_OF_BUTTONS; i ++){
22         debounceButtonBuffer2[i] = debounceButtonBuffer1[i];
23         debounceButtonBuffer1[i] = HAL_GPIO_ReadPin(
24             BUTTON_1_GPIO_Port, BUTTON_1_Pin);
25         if(debounceButtonBuffer1[i] == debounceButtonBuffer2[i])
26             buttonBuffer[i] = debounceButtonBuffer1[i];
27         if(buttonBuffer[i] == BUTTON_IS_PRESSED){
28             //if a button is pressed, we start counting
29             if(counterForButtonPress1s[i] <
30                 DURATION_FOR_AUTO_INCREASING){
31                 counterForButtonPress1s[i]++;
32             } else {
33                 //the flag is turned on when 1 second has passed
34                 //since the button is pressed.
35                 flagForButtonPress1s[i] = 1;
36                 //todo
37             }
38         } else {
39             counterForButtonPress1s[i] = 0;
40             flagForButtonPress1s[i] = 0;
41         }
42     }
43 }
```

Program 3.2: Define constants buffers and button_reading function

```

1 unsigned char is_button_pressed(uint8_t index){
2     if(index >= NO_OF_BUTTONS) return 0;
3     return (buttonBuffer[index] == BUTTON_IS_PRESSED);
4 }
```

Program 3.3: Checking a button is pressed or not

```

1 unsigned char is_button_pressed_1s(unsigned char index){
2     if(index >= NO_OF_BUTTONS) return 0xff;
3     return (flagForButtonPress1s[index] == 1);
4 }
```

Program 3.4: Checking a button is pressed more than a second or not

4.3.2 The code in the input_reading.h file

```

1 #ifndef INC_INPUT_READING_H_
2 #define INC_INPUT_READING_H_
3 void button_reading(void);
4 unsigned char is_button_pressed(unsigned char index);
5 unsigned char is_button_pressed_1s(unsigned char index);
6 #endif /* INC_INPUT_READING_H_ */
```

Program 3.5: Prototype in input_reading.h file

4.3.3 The code in the timer.c file

```

1 #include "main.h"
2 #include "input_reading.h"
3
4 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
5 {
6     if(htim->Instance == TIM2){
7         button_reading();
8     }
9 }
```

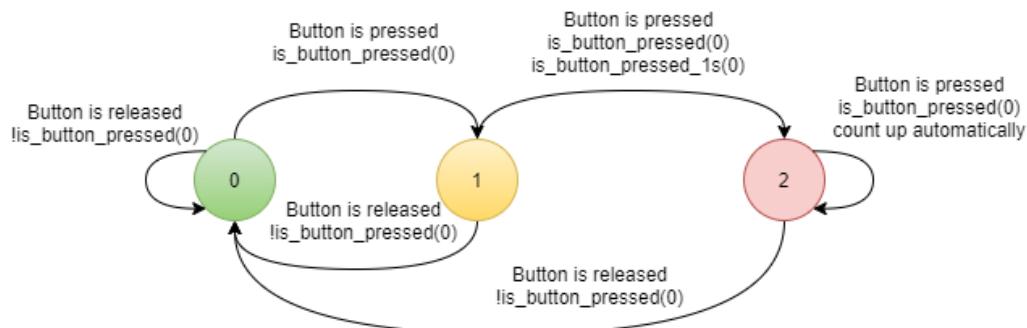
Program 3.6: Timer interrupt callback function

4.4 Button State Processing

4.4.1 Finite State Machine

To solve the example problem, we define 3 states as follows:

- State 0: The button is released or the button is in the initial state.
- State 1: When the button is pressed, the FSM will change to State 1 that is increasing the values of PORTA by one value. If the button is released, the FSM goes back to State 0.
- State 2: while the FSM is in State 1, the button is kept pressing more than 1 second, the state of FSM will change from 1 to 2. In this state, if the button is kept pressing, the value of PORTA will be increased automatically in every 500ms. If the button is released, the FSM goes back to State 0.



Hình 3.9: An FSM for processing a button

4.4.2 The code for the FSM in the input_processing.c file

Please note that *fsm_for_input_processing* function should be called inside the super loop of the main functin.

```
1 #include "main.h"
2 #include "input_reading.h"
3
4 enum ButtonState{BUTTON_RELEASED , BUTTON_PRESSED ,
5     BUTTON_PRESSED_MORE_THAN_1_SECOND} ;
6 enum ButtonState buttonState = BUTTON_RELEASED;
7 void fsm_for_input_processing(void){
8     switch(buttonState){
9         case BUTTON_RELEASED:
10             if(is_button_pressed(0)){
11                 buttonState = BUTTON_PRESSED;
12                 //INCREASE VALUE OF PORT A BY ONE UNIT
13             }
14             break;
15         case BUTTON_PRESSED:
16             if(!is_button_pressed(0)){
17                 buttonState = BUTTON_RELEASED;
18             } else {
19                 if(is_button_pressed_1s(0)){
20                     buttonState = BUTTON_PRESSED_MORE_THAN_1_SECOND;
21                 }
22             }
23             break;
24         case BUTTON_PRESSED_MORE_THAN_1_SECOND:
25             if(!is_button_pressed(0)){
26                 buttonState = BUTTON_RELEASED;
27             }
28             //todo
29             break;
30     }
31 }
```

Program 3.7: The code in the input_processing.c file

4.4.3 The code in the input_processing.h

```
1 #ifndef INC_INPUT_PROCESSING_H_
2 #define INC_INPUT_PROCESSING_H_
3
4 void fsm_for_input_processing(void);
5
6 #endif /* INC_INPUT_PROCESSING_H_ */
```

Program 3.8: Code in the input_processing.h file

4.4.4 The code in the main.c file

```
1 #include "main.h"
2 #include "input_processing.h"
3 //don't modify this part
4 int main(void){
5     HAL_Init();
6     /* Configure the system clock */
7     SystemClock_Config();
8     /* Initialize all configured peripherals */
9     MX_GPIO_Init();
10    MX_TIM2_Init();
11    while (1)
12    {
13        //you only need to add the fsm function here
14        fsm_for_input_processing();
15    }
16 }
```

Program 3.9: The code in the main.c file

5 Exercises and Report

5.1 Specifications

You are required to build an application of a traffic light in a cross road which includes some features as described below:

- The application has 12 LEDs including 4 red LEDs, 4 amber LEDs, 4 green LEDs.
- The application has 4 seven segment LEDs to display time with 2 for each road. The 2 seven segment LEDs will show time for each color LED corresponding to each road.
- The application has three buttons which are used
 - to select modes,
 - to modify the time for each color led on the fly, and
 - to set the chosen value.
- The application has at least 4 modes which is controlled by the first button. Mode 1 is a normal mode, while modes 2 3 4 are modification modes. You can press the first button to change the mode. Modes will change from 1 to 4 and back to 1 again.

Mode 1 - Normal mode:

- The traffic light application is running normally.

Mode 2 - Modify time duration for the red LEDs: This mode allows you to change the time duration of the red LED in the main road. The expected behaviours of this mode include:

- All single red LEDs are blinking in 2 Hz.
- Use two seven-segment LEDs to display the value.
- Use the other two seven-segment LEDs to display the mode.
- The second button is used to increase the time duration value for the red LEDs.
- The value of time duration is in a range of 1 - 99.
- The third button is used to set the value.

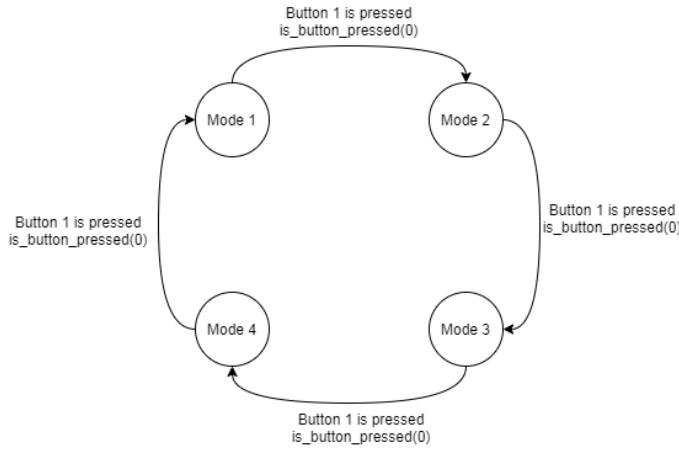
Mode 3 - Modify time duration for the amber LEDs: Similar for the red LEDs described above with the amber LEDs.

Mode 4 - Modify time duration for the green LEDs: Similar for the red LEDs described above with the green LEDs.

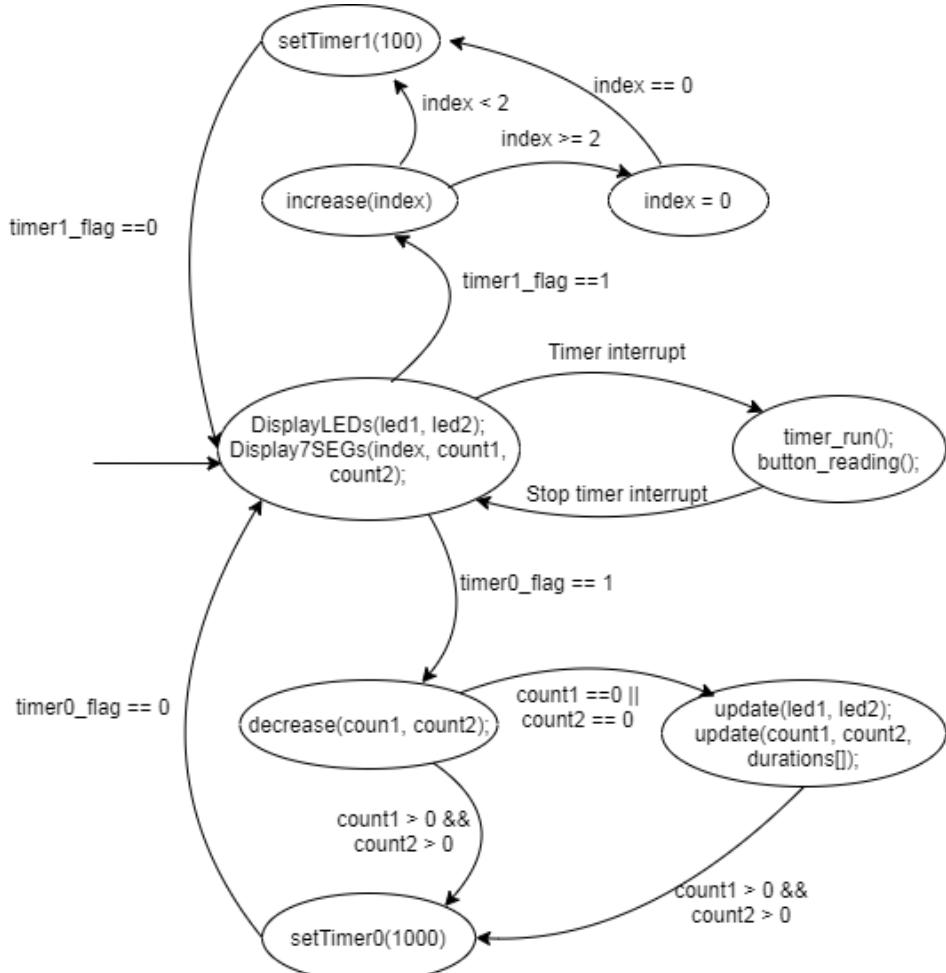
5.2 Exercise 1: Sketch an FSM

Your task in this exercise is to sketch an FSM that describes your idea of how to solve the problem.

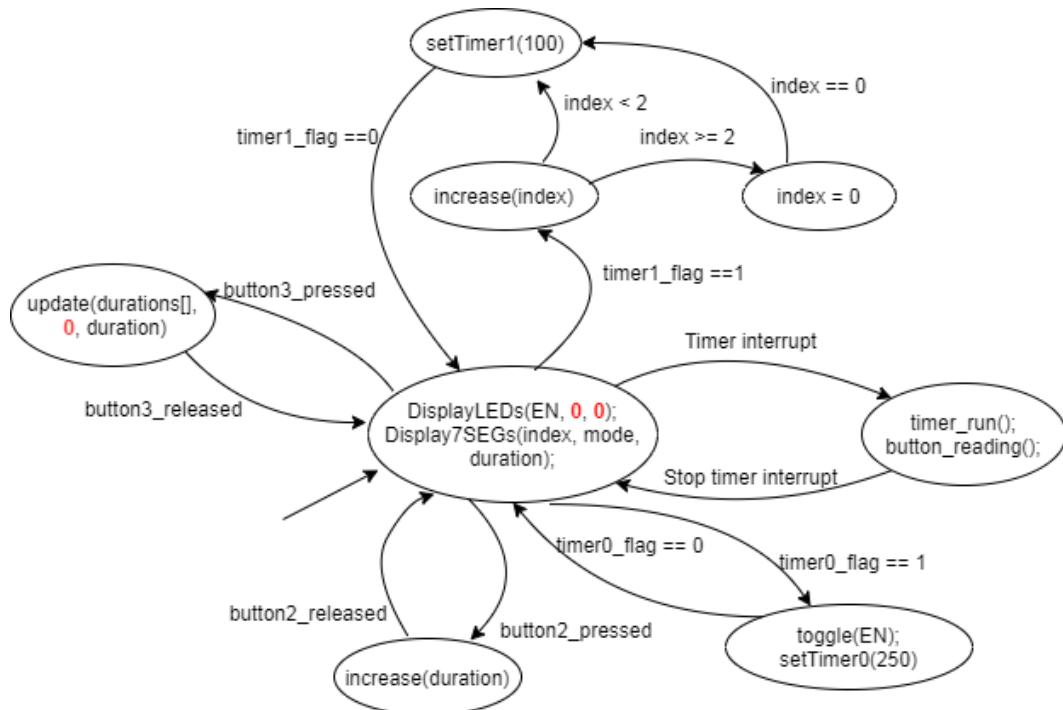
Please add your report here.



Hình 3.10: An FSM for system



Hình 3.11: An FSM for mode 1

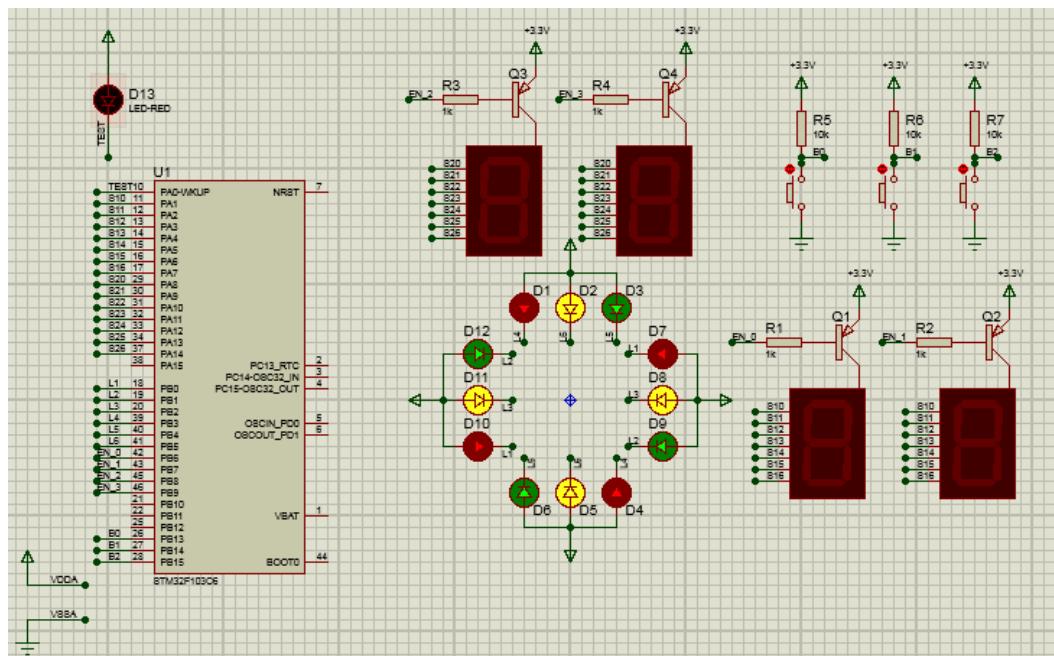


Hình 3.12: An FSM for mode 2

⇒ Mode 2, 3, 4 are similar to mode 1, we only replace 0 (red color) with 1 or 2 or 3

5.3 Exercise 2: Proteus Schematic

Your task in this exercise is to draw a Proteus schematic for the problem above. Please add your report here.

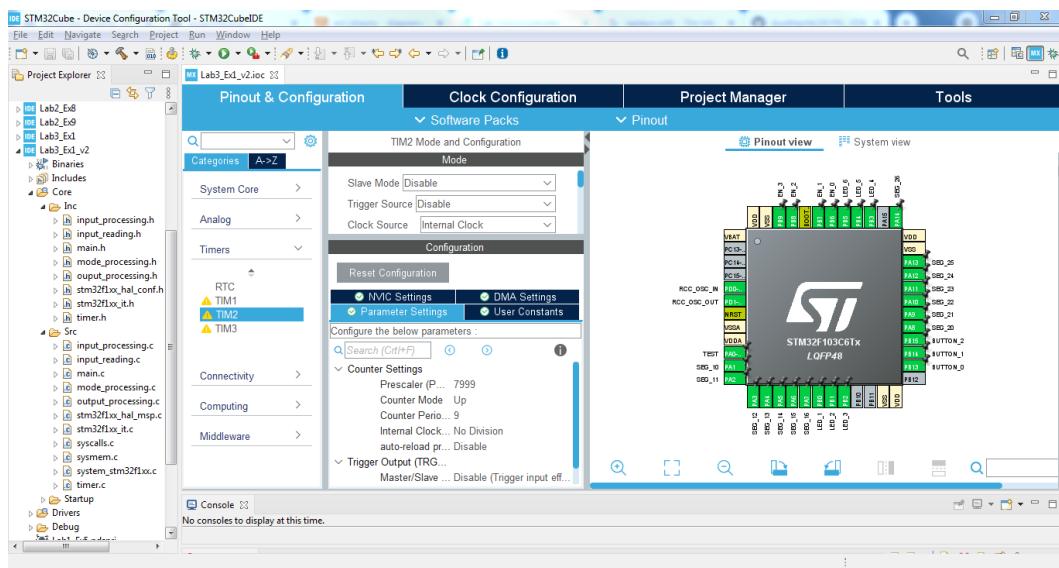


Hình 3.13: A Proteus schematic for system

5.4 Exercise 3: Create STM32 Project

Your task in this exercise is to create a project that has pin corresponding to the Proteus schematic that you draw in previous section. You need to set up your timer interrupt is about 10ms.

Please add your report here.



Hình 3.14: My project in STM32CubeIDE

5.5 Exercise 4: Modify Timer Parameters

Your task in this exercise is to modify the timer settings so that when we want to change the time duration of the timer interrupt, we change it the least and it will not affect the overall system. For example, the current system we have implemented is that it can blink an LED in 2 Hz, with the timer interrupt duration is 10ms. However, when we want to change the timer interrupt duration to 1ms or 100ms, it will not affect the 2Hz blinking LED.

Please add your report here.

⇒ Answer:

- I define: TIMER_CYCLE to save timer interrupt duration; FREQUENCY_LED_BLINKING to save frequency for LEDs blinking.
 - Cycle of blinking is $1000 / FREQUENCY_LED_BLINKING$ (ms)
 - In one cycle LEDs turn on in half of cycle, turn off in half of cycle. So duration for toggle state is $1000 / (2 * FREQUENCY_LED_BLINKING)$ (ms)
 - Therefore, I use software timer with `setTimer(1000 / (2 * FREQUENCY_LED_BLINKING))` to set duration to toggle state of LEDs

5.6 Exercise 5: Adding code for button debouncing

Following the example of button reading and debouncing in the previous section, your tasks in this exercise are:

- To add new files for input reading and output display,
- To add code for button debouncing,
- To add code for increasing mode when the first button is pressed.

Please add your report here.

```
1 // Function button_reading will read from button Pins with
2 // debouncing
3 void button_reading(void){
4     // Repeat for 3 buttons
5     for(unsigned char i = 0; i < NO_OF_BUTTONS; i++){
6         // Begin debouncing
7         debounceButtonBuffer2[i] = debounceButtonBuffer1[i];
8         // According to i, I will read from appropriated pin.
9         switch(i){
10             case 0:
11                 debounceButtonBuffer1[i] = HAL_GPIO_ReadPin(
12                     BUTTON_0_GPIO_Port, BUTTON_0_Pin);
13                 break;
14             case 1:
15                 debounceButtonBuffer1[i] = HAL_GPIO_ReadPin(
16                     BUTTON_1_GPIO_Port, BUTTON_1_Pin);
17                 break;
18             case 2:
19                 debounceButtonBuffer1[i] = HAL_GPIO_ReadPin(
20                     BUTTON_2_GPIO_Port, BUTTON_2_Pin);
21                 break;
22             default:
23                 break;
24         }
25         if(debounceButtonBuffer1[i] == debounceButtonBuffer2[i]){
26             buttonBuffer[i] = debounceButtonBuffer1[i];
27             // This section using for pressed more than 1s, but
28             // in this exercise it is ignored
29             if(buttonBuffer[i] == BUTTON_IS_PRESSED){
30                 if(counterForButtonPress1s[i] <
31                     DURATION_FOR_AUTOINCREASING){
32                     counterForButtonPress1s[i]++;
33                 }
34                 else{
35                     flagForButtonPress1s[i] = 1;
36                 }
37             }
38         }
39     }
40 }
```

```

33         counterForButtonPress1s[i] = 0;
34         flagForButtonPress1s[i] = 0;
35     }
36 }
37 }
38 }
```

Program 3.10: Code for button debouncing

```

1 // Function fsm_for_input_processing will get states of
2 // buttons and process.
3 void fsm_for_input_processing(void){
4     for(unsigned char i = 0; i < NO_OF_BUTTONS; i++){
5         switch(buttonState[i]){
6             case BUTTON_RELEASED:
7                 if(is_button_pressed(i)){
8                     buttonState[i] = BUTTON_PRESSED;
9                     switch(i){
10                         // If button 1 is pressed, it will call
11                         increaseMode() function to go to next mode
12                         case 0:
13                             increaseMode();
14                             break;
15                         // If button 2 is pressed, it will call
16                         increaseTimeDuration() to increase timeDuration variable
17                         case 1:
18                             increaseTimeDuration();
19                             break;
20                         // If button 3 is pressed, it will call
21                         setTimeDuration() function to set time duration
22                         case 2:
23                             setTimeDuration();
24                             break;
25                         default:
26                             break;
27                     }
28                 }
29                 break;
30             case BUTTON_PRESSED:
31                 if(!is_button_pressed(i)){
32                     buttonState[i] = BUTTON_RELEASED;
33                 }
34                 else{
35                     if(is_button_pressed_1s(i)){
36                         buttonState[i] = BUTTON_PRESSED_MORE_THAN_1S;
37                     }
38                 }
39                 break;
40             // This case in this exercise is not used
41             case BUTTON_PRESSED_MORE_THAN_1S:
```

```

38     if(!is_button_pressed(i)){
39         buttonState[i] = BUTTON_RELEASED;
40     }
41     break;
42     default:
43     break;
44 }
45 }
46 }
```

Program 3.11: Code for processing when buttons are pressed

5.7 Exercise 6: Adding code for displaying modes

Your tasks in this exercise are:

- To add code for display mode on seven-segment LEDs, and
- To add code for blinking LEDs depending on the mode that is selected.

Please add your report here.

```

1 // I using scanning LED for two 7-segment LEDs to display
   mode with frequency is 5Hz.
2 // Function update7SEG(indexSEG, count_1, count_2) will
   turn on 7-segment LED at indexSEG of two road, and
   display with value count_1/10 for first road, count_2/10
   for second road if indexSEG == 0 and display with value
   count_1%10 for first road, count_2%10 for second road
   if indexSEG == 1.
3 // So if we want to display mode in second road then we
   will assign count_2 = mode.
4 if(getTimer1Flag() == 1){
5     update7SEG(indexSEG, count_1, count_2);
6     indexSEG++;
7     if(indexSEG >= 2) indexSEG = 0;
8     setTimer1(100);
9 }
```

Program 3.12: Code for display mode on seven-segment LEDs

```

1 // status_LED_1, status_LED_2 is used to determine status
   of single LEDs, if status_LED_1 == 0 then turn on red
   LED in first road, status_LED_1 == 1 for green LED,
   status_LED_1 == 2 for yellow LED and similar for
   status_LED_2 in second road.
2 // count_1 is value which will display in 2 7-segment LEDs
   on first road, count_2 for second road.
3 // Function updateLED(status_LED_1, status_LED_2) use to
   turn on appropriate led in each road
4 // Function toggleLED() use to turn on or off all the same
   color LEDs in each road.
```

```

5 switch(mode){
6 case 1:
7     if(initState == 0){
8         status_LED_1 = 0;
9         status_LED_2 = 1;
10        count_1 = timeDurations[status_LED_1];
11        count_2 = timeDurations[status_LED_2];
12        initState = 1;
13        updateLED(status_LED_1, status_LED_2);
14        setTimer0(1000);
15    }
16 else{
17     // After 1 second it will update count_1, count_2,
18     status_LED_1, status_LED_2 and call updateLED() function
19     .
20     if(getTimer0Flag() == 1){
21         count_1--;
22         count_2--;
23         if(count_1 <= 0){
24             status_LED_1++;
25             if(status_LED_1 >= 3) status_LED_1 = 0;
26             count_1 = timeDurations[status_LED_1];
27         }
28         if(count_2 <= 0){
29             status_LED_2++;
30             if(status_LED_2 >= 3) status_LED_2 = 0;
31             count_2 = timeDurations[status_LED_2];
32         }
33         updateLED(status_LED_1, status_LED_2);
34         setTimer0(1000);
35     }
36 }
37 break;
38 case 2:
39     if(initState == 0){
40         timeDuration = timeDurations[0];
41         status_LED_1 = 0;
42         status_LED_2 = 0;
43         updateLED(status_LED_1, status_LED_2);
44         setTimer0(durationLEDBlinky);
45         initState = 1;
46     }
47     else{
48         if(getTimer0Flag() == 1){
49             toggleLED(status_LED_1, status_LED_2);
50             setTimer0(durationLEDBlinky);
51         }
52     }
53     count_1 = timeDuration;

```

```

52     count_2 = mode;
53     break;
54 case 3:
55     if(initState == 0){
56         timeDuration = timeDurations[1];
57         status_LED_1 = 1;
58         status_LED_2 = 1;
59         updateLED(status_LED_1, status_LED_2);
60         setTimer0(durationLEDBlinky);
61         initState = 1;
62     }
63     else{
64         if(getTimer0Flag() == 1){
65             toggleLED(status_LED_1, status_LED_2);
66             setTimer0(durationLEDBlinky);
67         }
68     }
69     count_1 = timeDuration;
70     count_2 = mode;
71     break;
72 case 4:
73     if(initState == 0){
74         timeDuration = timeDurations[2];
75         status_LED_1 = 2;
76         status_LED_2 = 2;
77         updateLED(status_LED_1, status_LED_2);
78         setTimer0(durationLEDBlinky);
79         initState = 1;
80     }
81     else{
82         if(getTimer0Flag() == 1){
83             toggleLED(status_LED_1, status_LED_2);
84             setTimer0(durationLEDBlinky);
85         }
86     }
87     count_1 = timeDuration;
88     count_2 = mode;
89     break;
90 default:
91     break;
92 }
```

Program 3.13: Code for blinking LEDs depending on the mode that is selected

5.8 Exercise 7: Adding code for increasing time duration value for the red LEDs

Your tasks in this exercise are:

- to use the second button to increase the time duration value of the red LEDs

- to use the third button to set the value for the red LEDs.

Please add your report here.

⇒ **Answer:**

- When button 2 is pressed, I will call increaseTimeDuration(), to increase static variable timeDuration.
- When button 3 is pressed, I will assign first element in timeDurations array.
- the code is showed in exercise 5 and 6

5.9 Exercise 8: Adding code for increasing time duration value for the amber LEDs

Your tasks in this exercise are:

- to use the second button to increase the time duration value of the amber LEDs
- to use the third button to set the value for the amber LEDs.

Please add your report here.

⇒ **Answer:**

- When button 2 is pressed, I will call increaseTimeDuration(), to increase static variable timeDuration.
- When button 3 is pressed, I will assign third element in timeDurations array.
- the code is showed in exercise 5 and 6

5.10 Exercise 9: Adding code for increasing time duration value for the green LEDs

Your tasks in this exercise are:

- to use the second button to increase the time duration value of the green LEDs
- to use the third button to set the value for the green LEDs.

Please add your report here.

⇒ **Answer:**

- When button 2 is pressed, I will call increaseTimeDuration(), to increase static variable timeDuration.
- When button 3 is pressed, I will assign second element in timeDurations array.
- the code is showed in exercise 5 and 6

5.11 Exercise 10: To finish the project

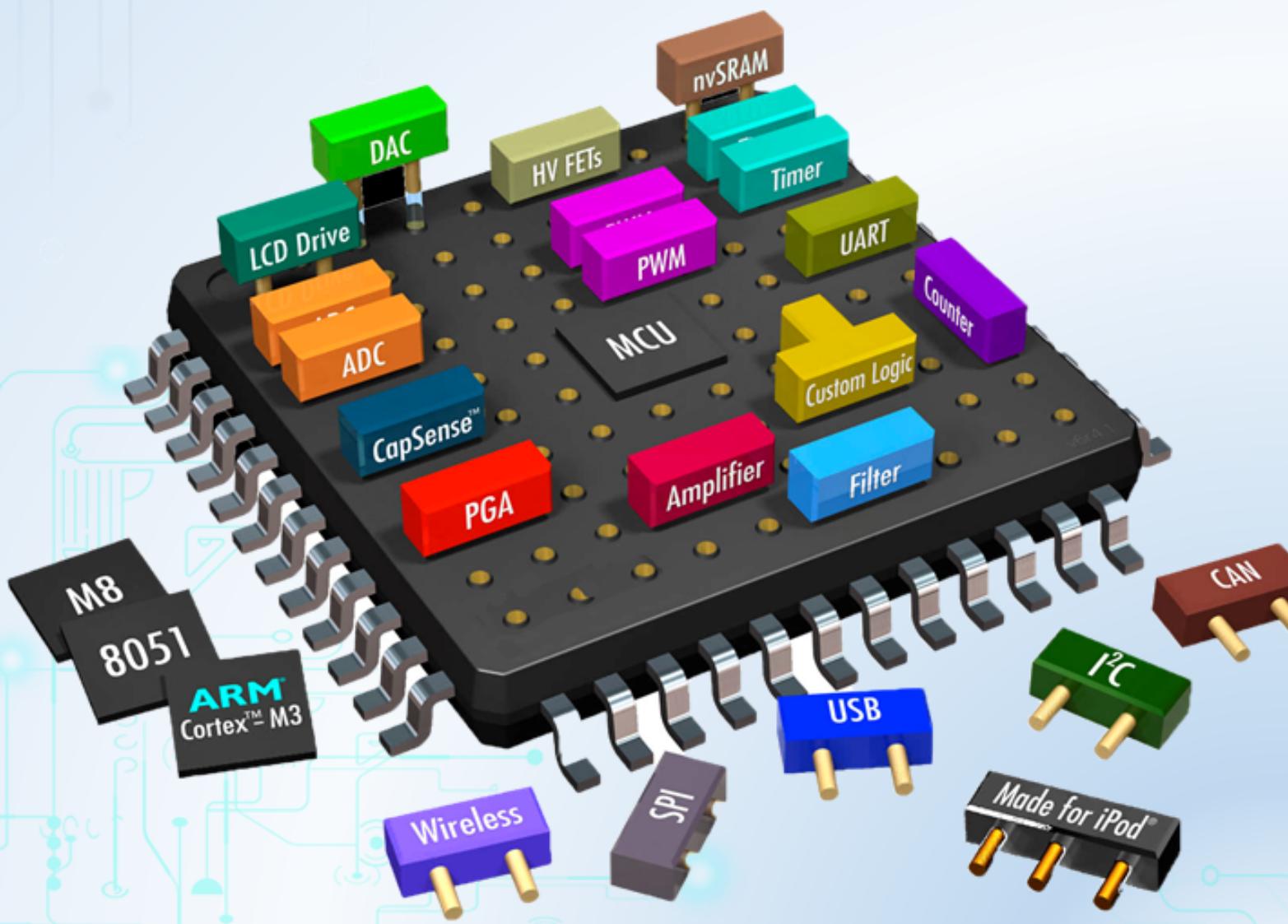
Your tasks in this exercise are:

- To integrate all the previous tasks to one final project
- To create a video to show all features in the specification
- To add a report to describe your solution for each exercise.
- To submit your report and code on the BKeL

⇒ **Answer:** [Link for video about system](#)

CHƯƠNG 4

A cooperative scheduler



1 Introduction

1.1 Super Loop Architecture

```
1 }
2 void main(void) {
3     // Prepare for Task X
4     X_Init();
5     while(1) { // 'for ever' (Super Loop)
6         X(); // Perform the task
7     }
8 }
```

Program 4.1: Super loop program

The main advantages of the Super Loop architecture illustrated above are:

- (1) that it is simple, and therefore easy to understand, and
- (2) that it consumes virtually no system memory or CPU resources.

However, we get ‘nothing for nothing’: Super Loops consume little memory or processor resources because they provide few facilities to the developer. A particular limitation with this architecture is that it is very difficult to execute Task X at precise intervals of time: as we will see, this is a very significant drawback.

For example, consider a collection of requirements assembled from a range of different embedded projects (in no particular order):

- The current speed of the vehicle must be measured at 0.5 second intervals.
- The display must be refreshed 40 times every second.
- The calculated new throttle setting must be applied every 0.5 seconds.
- A time-frequency transform must be performed 20 times every second.
- If the alarm sounds, it must be switched off (for legal reasons) after 20 minutes.
- If the front door is opened, the alarm must sound in 30 seconds if the correct password is not entered in this time.
- The engine vibration data must be sampled 1,000 times per second.
- The frequency-domain data must be classified 20 times every second.
- The keypad must be scanned every 200 ms.
- The master (control) node must communicate with all other nodes (sensor nodes and sounder nodes) once per second.
- The new throttle setting must be calculated every 0.5 seconds.
- The sensors must be sampled once per second.

We can summarize this list by saying that many embedded systems must carry out tasks at particular instants of time. More specifically, we have two kinds of activity to perform:

- Periodic tasks, to be performed (say) once every 100 ms
- One-shot tasks, to be performed once after a delay of (say) 50 ms

This is very difficult to achieve with the primitive architecture shown in Program above. Suppose, for example, that we need to start Task X every 200 ms, and that the task takes 10 ms to complete. Program below illustrates one way in which we might adapt the code in order to try to achieve this.

```
1 }
2 void main(void) {
3     // Prepare for Task X
4     X_Init();
5     while(1) {           // 'for ever' (Super Loop)
6         X();             // Perform the task (10 ms duration)
7         Delay_190ms();   // Delay for 190 ms
8     }
9 }
```

Program 4.2: Trying to use the Super Loop architecture to execute tasks at regular intervals

The approach is not generally adequate, because it will only work if the following conditions are satisfied:

- We know the precise duration of Task X
- This duration never varies

In practical applications, determining the precise task duration is rarely straightforward. Suppose we have a very simple task that does not interact with the outside world but, instead, performs some internal calculations. Even under these rather restricted circumstances, changes to compiler optimization settings – even changes to an apparently unrelated part of the program – can alter the speed at which the task executes. This can make fine-tuning the timing very tedious and error prone.

The second condition is even more problematic. Often in an embedded system the task will be required to interact with the outside world in a complex way. In these circumstances the task duration will vary according to outside activities in a manner over which the programmer has very little control.

1.2 Timer-based interrupts and interrupt service routines

A better solution to the problems outlined is to use timer-based interrupts as a means of invoking functions at particular times.

An interrupt is a hardware mechanism used to notify a processor that an ‘event’ has taken place: such events may be internal events or external events.

When an interrupt is generated, the processor ‘jumps’ to an address at the bottom of the CODE memory area. These locations must contain suitable code with which the microcontroller can respond to the interrupt or, more commonly, the locations

will include another ‘jump’ instruction, giving the address of suitable ‘interrupt service routine’ located elsewhere in (CODE) memory.
Please see lab 3 for the more information of this approach.

2 What is a scheduler?

There are two ways of viewing a scheduler:

- At one level, a scheduler can be viewed as a simple operating system that allows tasks to be called periodically or (less commonly) on a one-shot basis.
- At a lower level, a scheduler can be viewed as a single timer interrupt service routine that is shared between many different tasks. As a result, only one timer needs to be initialized, and any changes to the timing generally requires only one function to be altered. Furthermore, we can generally use the same scheduler whether we need to execute one, ten or 100 different tasks.

```
1 void main(void) {
2     // Set up the scheduler
3     SCH_Init();
4     // Add the tasks (1ms tick interval)
5     // Function_A will run every 2 ms
6     SCH_Add_Task(Function_A, 0, 2);
7     // Function_B will run every 10 ms
8     SCH_Add_Task(Function_B, 1, 10);
9     // Function_C will run every 15 ms
10    SCH_Add_Task(Function_C, 3, 15);
11    while(1) {
12        SCH_Dispatch_Tasks();
13    }
14 }
```

Program 4.3: Example of how a scheduler uses

2.1 The co-operative scheduler

A co-operative scheduler provides a single-tasking system architecture
Operation:

- Tasks are scheduled to run at specific times (either on a periodic or one-shot basis)
- When a task is scheduled to run it is added to the waiting list
- When the CPU is free, the next waiting task (if any) is executed
- The task runs to completion, then returns control to the scheduler

Implementation:

- The scheduler is simple and can be implemented in a small amount of code

- The scheduler must allocate memory for only a single task at a time
- The scheduler will generally be written entirely in a high-level language (such as ‘C’)
- The scheduler is not a separate application; it becomes part of the developer’s code

Performance:

- Obtaining rapid responses to external events requires care at the design stage
- Reliability and safety:

Co-operate scheduling is simple, predictable, reliable and safe

A co-operative scheduler provides a simple, highly predictable environment. The scheduler is written entirely in ‘C’ and becomes part of the application: this tends to make the operation of the whole system more transparent and eases development, maintenance and porting to different environments. Memory overheads are 17 bytes per task and CPU requirements (which vary with tick interval) are low.

2.2 Function pointers

One area of the language with which many ‘C’ programmers are unfamiliar is the function pointer. While comparatively rarely used in desktop programs, this language feature is crucial in the creation of schedulers: we therefore provide a brief introductory example here.

The key point to note is that – just as we can, for example, determine the starting address of an array of data in memory – we can also find the address in memory at which the executable code for a particular function begins. This address can be used as a ‘pointer’ to the function; most importantly, it can be used to call the function. Used with care, function pointers can make it easier to design and implement complex programs. For example, suppose we are developing a large, safety-critical, application, controlling an industrial plant. If we detect a critical situation, we may wish to shut down the system as rapidly as possible. However, the appropriate way to shut down the system will vary, depending on the system state. What we can do is create a number of different recovery functions and a function pointer. Every time the system state changes, we can alter the function pointer so that it is always pointing to the most appropriate recovery function. In this way, we know that – if there is ever an emergency situation – we can rapidly call the most appropriate function, by means of the function pointer.

```

1 // ----- Private function prototypes -----
2 void Square_Number(int , int *) ;
3
4 int main(void)
5 {
6     int a = 2, b = 3;
7     /* Declares pFn to be a pointer to fn with
8      int and int pointer parameters (returning void) */
9     void (* pFn)(int , int *) ;
10
11     int Result_a , Result_b ;

```

```

12     pFn = Square_Number; // pFn holds address of Square_Number
13     printf("Function code starts at address: %u\n", (tWord) pFn);
14     printf("Data item a starts at address: %u\n\n", (tWord) &a);
15     // Call 'Square_Number' in the conventional way
16     Square_Number(a, &Result_a);
17     // Call 'Square_Number' using function pointer
18     (*pFn)(b,&Result_b);
19     printf("%d squared is %d (using normal fn call)\n", a, Result_a
) ;
20     printf("%d squared is %d (using fn pointer)\n", b, Result_b);
21     while(1);
22     return 0;
23 }
24
25 void Square_Number(int a, int* b)
26 { // Demo - calculate square of a
27     *b = a * a;
28 }
```

Program 4.4: Example of how to use function pointers

2.3 Solution

A scheduler has the following key components:

- The scheduler data structure.
- An initialization function.
- A single interrupt service routine (ISR), used to update the scheduler at regular time intervals.
- A function for adding tasks to the scheduler.
- A dispatcher function that causes tasks to be executed when they are due to run.
- A function for removing tasks from the scheduler (not required in all applications).

We consider each of the required components in this section

2.3.1 Overview

Before discussing the scheduler components, we consider how the scheduler will typically appear to the user. To do this we will use a simple example: a scheduler used to flash a single LED on and off repeatedly: on for one second off for one second etc.

```

1 int main(void) {
2     //Init all the requirements for the system to run
3     System_Initialization();
4     //Init a schedule
5     SCH_Init();
```

```

6 //Add a task to repeatedly call in every 1 second.
7 SCH_Add_Task(Led_Display, 0, 1000);
8 while (1) {
9     SCH_Dispatch_Tasks();
10 }
11 return 0;
12 }
```

Program 4.5: Example of how to use a scheduler

- We assume that the LED will be switched on and off by means of a ‘task’ Led_Display(). Thus, if the LED is initially off and we call Led_Display() twice, we assume that the LED will be switched on and then switched off again.

To obtain the required flash rate, we therefore require that the scheduler calls Led_Display() every second ad infinitum.

- We prepare the scheduler using the function SCH_Init().
- After preparing the scheduler, we add the function Led_Display() to the scheduler task list using the SCH_Add_Task() function. At the same time we specify that the LED will be turned on and off at the required rate as follows:

SCH_Add_Task(Led_Display, 0, 1000);

We will shortly consider all the parameters of SCH_Add_Task(), and examine its internal structure.

- The timing of the Led_Display() function will be controlled by the function SCH_Update(), an interrupt service routine triggered by the overflow of Timer 2:

```

1 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim) {
2     SCH\Update();
3 }
```

Program 4.6: Example of how to call SCH_Update function

- The ‘Update’ function does not execute the task: it calculates when a task is due to run and sets a flag. The job of executing LED_Display() falls to the dispatcher function (SCH_Dispatch_Tasks()), which runs in the main (‘super’) loop:

```

1 while(1) {
2     SCH_Dispatch_Tasks();
3 }
```

Before considering these components in detail, we should acknowledge that this is, undoubtedly, a complicated way of flashing an LED: if our intention were to develop an LED flasher application that requires minimal memory and minimal code size, this would not be a good solution. However, the key point is that we will be able to use the same scheduler architecture in all our subsequent examples, including a number of substantial and complex applications and the effort required to understand the operation of this environment will be rapidly repaid.

It should also be emphasized that the scheduler is a ‘low-cost’ option: it consumes a small percentage of the CPU resources (we will consider precise percentages shortly). In addition, the scheduler itself requires no more than 17 bytes of memory for each task. Since a typical application will require no more than four to six tasks, the task – memory budget (around 60 bytes) is not excessive, even on an 8-bit microcontroller.

2.3.2 The scheduler data structure and task array

At the heart of the scheduler is the scheduler data structure: this is a user-defined data type which collects together the information required about each task.

```

1  typedef struct {
2      // Pointer to the task (must be a 'void (void)' function)
3      void ( * pTask)(void);
4      // Delay (ticks) until the function will (next) be run
5      uint32_t Delay;
6      // Interval (ticks) between subsequent runs.
7      uint32_t Period;
8      // Incremented (by scheduler) when task is due to execute
9      uint8_t RunMe;
10     // This is a hint to solve the question below.
11     uint32_t TaskID;
12 } sTask;
13
14
15 // MUST BE ADJUSTED FOR EACH NEW PROJECT
16 #define SCH_MAX_TASKS      40
17 #define NO_TASK_ID         0
18 sTask SCH_tasks_G[SCH_MAX_TASKS];

```

Program 4.7: A struct of a task

The size of the task array

You must ensure that the task array is sufficiently large to store the tasks required in your application, by adjusting the value of SCH_MAX_TASKS. For example, if you schedule three tasks as follows:

- SCH_Add_Task(Function_A, 0, 2);
- SCH_Add_Task(Function_B, 1, 10);
- SCH_Add_Task(Function_C, 3, 15);

then SCH_MAX_TASKS must have a value of three (or more) for correct operation of the scheduler.

Note also that, if this condition is not satisfied, the scheduler should generate an error code.

2.3.3 The initialization function

Like most of the tasks we wish to schedule, the scheduler itself requires an initialization function. While this performs various important operations – such as

preparing the scheduler array (discussed earlier) and the error code variable (discussed later) – the main purpose of this function is to set up a timer that will be used to generate the regular ‘ticks’ that will drive the scheduler.

```

1 void SCH_Init(void) {
2     unsigned char i;
3     for (i = 0; i < SCH_MAX_TASKS; i++) {
4         SCH_Delete_Task(i);
5     }
6     // Reset the global error variable
7     // - SCH_Delete_Task() will generate an error code,
8     // (because the task array is empty)
9     Error_code_G = 0;
10    Timer_init();
11    Watchdog_init();
12 }
```

Program 4.8: Example of how

2.3.4 The ‘Update’ function

The ‘Update’ function is involved in the ISR. It is invoked when the timer is overflow.

When it determines that a task is due to run, the update function increments the RunMe field for this task: the task will then be executed by the dispatcher, as we discuss later.

```

1 void SCH_Update(void) {
2     unsigned char Index;
3     // NOTE: calculations are in *TICKS* (not milliseconds)
4     for (Index = 0; Index < SCH_MAX_TASKS; Index++) {
5         // Check if there is a task at this location
6         if (SCH_tasks_G[Index].pTask) {
7             if (SCH_tasks_G[Index].Delay == 0) {
8                 // The task is due to run
9                 // Inc. the 'RunMe' flag
10                SCH_tasks_G[Index].RunMe += 1;
11                if (SCH_tasks_G[Index].Period) {
12                    // Schedule periodic tasks to run again
13                    SCH_tasks_G[Index].Delay = SCH_tasks_G[Index].
14                    Period;
15                }
16            } else {
17                // Not yet ready to run: just decrement the delay
18                SCH_tasks_G[Index].Delay -= 1;
19            }
20        }
21    }
22
23 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim) {
24     SCH_Update();
```

Program 4.9: Example of how to write an SCH_Update function

2.3.5 The 'Add Task' function

As the name suggests, the 'Add Task' function is used to add tasks to the task array, to ensure that they are called at the required time(s). Here is the example of add task function: **unsigned char SCH_Add_Task (Task_Name , Initial_Delay, Period)**

The parameters for the 'Add Task' function are described as follows:

- **Task_Name**: the name of the function (task) that you wish to schedule
- **Initial_Delay**: the delay (in ticks) before task is first executed. If set to 0, the task is executed immediately.
- **Period**: the interval (in ticks) between repeated executions of the task. If set to 0, the task is executed only once

Here are some examples.

This set of parameters causes the function Do_X() to be executed once after 1,000 scheduler ticks:

SCH_Add_Task(Do_X,1000,0);

This does the same, but saves the task ID (the position in the task array) so that the task may be subsequently deleted, if necessary (see SCH_Delete_Task() for further information about the removal of tasks from the task array):

Task_ID = SCH_Add_Task(Do_X,1000,0);

This causes the function Do_X() to be executed regularly every 1,000 scheduler ticks; the task will first be executed as soon as the scheduling is started:

SCH_Add_Task(Do_X,0,1000);

This causes the function Do_X() to be executed regularly every 1,000 scheduler ticks; task will be first executed at T = 300 ticks, then 1,300, 2,300 etc:

SCH_Add_Task(Do_X,300,1000);

```

1 /* -----
2 SCH_Add_Task() Causes a task (function) to be executed at regular
3 intervals
4 or after a user-defined delay
5 -----
6 */
7 unsigned char SCH_Add_Task(void (* pFunction)(), unsigned int DELAY
8   , unsigned int PERIOD)
9 {
10    unsigned char Index = 0;
11    // First find a gap in the array (if there is one)
12    while ((SCH_tasks_G[Index].pTask != 0) && (Index <
SCH_MAX_TASKS))
13    {
14      Index++;
15    }

```

```

13 // Have we reached the end of the list?
14 if (Index == SCH_MAX_TASKS)
15 {
16     // Task list is full
17     // Set the global error variable
18     Error_code_G = ERROR_SCH_TOO_MANY_TASKS;
19     // Also return an error code
20     return SCH_MAX_TASKS;
21 }
22 // If we're here, there is a space in the task array
23 SCH_tasks_G[Index].pTask = pFunction;
24 SCH_tasks_G[Index].Delay = DELAY;
25 SCH_tasks_G[Index].Period = PERIOD;
26 SCH_tasks_G[Index].RunMe = 0;
27 // return position of task (to allow later deletion)
28 return Index;
29 }
```

Program 4.10: An implementation of the scheduler ‘add task’ function

2.3.6 The ‘Dispatcher’

As we have seen, the ‘Update’ function does not execute any tasks: the tasks that are due to run are invoked through the ‘Dispatcher’ function.

```

1 void SCH_Dispatch_Tasks(void)
2 {
3     unsigned char Index;
4     // Dispatches (runs) the next task (if one is ready)
5     for (Index = 0; Index < SCH_MAX_TASKS; Index++) {
6         if (SCH_tasks_G[Index].RunMe > 0) {
7             (*SCH_tasks_G[Index].pTask)(); // Run the task
8             SCH_tasks_G[Index].RunMe -= 1; // Reset / reduce RunMe
9             flag
10                // Periodic tasks will automatically run again
11                // - if this is a ‘one shot’ task, remove it from the
12                // array
13                if (SCH_tasks_G[Index].Period == 0)
14                {
15                    SCH_Delete_Task(Index);
16                }
17            }
18        // Report system status
19        SCH_Report_Status();
20        // The scheduler enters idle mode at this point
21        SCH_Go_To_Sleep();
22    }
```

Program 4.11: An implementation of the scheduler ‘dispatch task’ function

The dispatcher is the only component in the Super Loop:

```

1 void main(void)
2 {
```

```

3 ...
4 while(1)
5 {
6     SCH_Dispatch_Tasks();
7 }

```

Program 4.12: The dispatcher in the super loop

Do we need a Dispatch function?

At first inspection, the use of both the ‘Update’ and ‘Dispatch’ functions may seem a rather complicated way of running the tasks. Specifically, it may appear that the Dispatch function is unnecessary and that the Update function could invoke the tasks directly. However, the split between the Update and Dispatch operations is necessary, to maximize the reliability of the scheduler in the presence of long tasks. Suppose we have a scheduler with a tick interval of 1 ms and, for whatever reason, a scheduled task sometimes has a duration of 3 ms.

If the Update function runs the functions directly then – all the time the long task is being executed – the tick interrupts are effectively disabled. Specifically, two ‘ticks’ will be missed. This will mean that all system timing is seriously affected and may mean that two (or more) tasks are not scheduled to execute at all.

If the Update and Dispatch function are separated, system ticks can still be processed while the long task is executing. This means that we will suffer task ‘jitter’ (the ‘missing’ tasks will not be run at the correct time), but these tasks will, eventually, run.

2.3.7 The ‘Delete Task’ function

When tasks are added to the task array, SCH_Add_Task() returns the position in the task array at which the task has been added: Task_ID = SCH_Add_Task(Do_X,1000,0); Sometimes it can be necessary to delete tasks from the array. To do so, SCH_Delete_Task() can be used as follows: SCH_Delete_Task(Task_ID)

```

1 /*
2  *
3  *  -----
4  *  -----
5  *  -----
6  *  -----
7  *  -----
8  *  -----
9  *  -----
10 *  -----
11 *  -----
12 *  -----
13 *  -----
14 *  -----
15 *  -----
16 *  -----
17 *  -----
18 *  -----
19 */

```

```

2 unsigned char SCH_Delete_Task(const tByte TASK_INDEX) {
3     unsigned char Return_code;
4     if (SCH_tasks_G[TASK_INDEX].pTask == 0) {
5         // No task at this location ...
6         //
7         // Set the global error variable
8         Error_code_G = ERROR_SCH_CANNOT_DELETE_TASK
9
10        // ... also return an error code
11        Return_code = RETURN_ERROR;
12    } else {
13        Return_code = RETURN_NORMAL;
14    }
15    SCH_tasks_G[TASK_INDEX].pTask = 0x0000;
16    SCH_tasks_G[TASK_INDEX].Delay = 0;
17    SCH_tasks_G[TASK_INDEX].Period = 0;
18    SCH_tasks_G[TASK_INDEX].RunMe = 0;
19    return Return_code; // return status

```

20 }

Program 4.13: An implementation of the scheduler ‘delete task’ function

2.3.8 Reducing power consumption

An important feature of scheduled applications is that they can lend themselves to low-power operation. This is possible because all modern MCU provide an ‘idle’ mode, where the CPU activity is halted, but the state of the processor is maintained. In this mode, the power required to run the processor is typically reduced by around 50%

This idle mode is particularly effective in scheduled applications because it may be entered under software control, and the MCU returns to the normal operating mode when any interrupt is received. Because the scheduler generates regular timer interrupts as a matter of course, we can put the system ‘to sleep’ at the end of every dispatcher call: it will then wake up when the next timer tick occurs.

This is an optional feature. Students can do by yourself by looking at the reference manual of the MCU that is used.

```
1 void SCH_Go_To_Sleep () {  
2     // todo: Optional  
3 }
```

Program 4.14: An implementation of the scheduler ‘go to sleep’ function

2.3.9 Reporting errors

Hardware fails; software is never perfect; errors are a fact of life. To report errors at any part of the scheduled application, we can use an (8-bit) error code variable Error_code_G

```
unsigned char Error_code_G = 0;
```

To record an error we include lines such as:

- Error_code_G = ERROR_SCH_TOO_MANY_TASKS;
- Error_code_G = ERROR_SCH_WAITING_FOR_SLAVE_TO_ACK;
- Error_code_G = ERROR_SCH_WAITING_FOR_START_COMMAND_FROM_MASTER;
- Error_code_G = ERROR_SCH_ONE_OR_MORE_SLAVES_DID_NOT_START;
- Error_code_G = ERROR_SCH_LOST_SLAVE;
- Error_code_G = ERROR_SCH_CAN_BUS_ERROR;
- Error_code_G = ERROR_I2C_WRITE_BYTE_AT24C64;

To report these error codes, the scheduler has a function **SCH_Report_Status()**, which is called from the Update function.

```
1 void SCH_Report_Status (void) {  
2 #ifdef SCH_REPORT_ERRORS  
3     // ONLY APPLIES IF WE ARE REPORTING ERRORS  
4     // Check for a new error code  
5     if (Error_code_G != Last_error_code_G) {
```

```

6      // Negative logic on LEDs assumed
7      Error_port = 255 - Error_code_G;
8      Last_error_code_G = Error_code_G;
9      if (Error_code_G != 0){
10          Error_tick_count_G = 60000;
11      } else {
12          Error_tick_count_G = 0;
13      }
14  } else {
15      if (Error_tick_count_G != 0){
16          if (--Error_tick_count_G == 0)    {
17              Error_code_G = 0; // Reset error code
18          }
19      }
20  }
21 #endif
22 }
```

Program 4.15: An implementation of the ‘report status’ function

Note that error reporting may be disabled via the main.h header file:

```

1 // Comment this line out if error reporting is NOT required
2 //#define SCH_REPORT_ERRORS
3 //Where error reporting is required, the port on which error codes
4 //will be displayed
5 //is also determined via main.h:
6 #ifdef SCH_REPORT_ERRORS
7 // The port on which error codes will be displayed
8 // ONLY USED IF ERRORS ARE REPORTED
9 #define Error_port PORTA
# endif
```

Program 4.16: Define a constant to allow errors are reported

Note that, in this implementation, error codes are reported for 60,000 ticks (1 minute at a 1 ms tick rate). The simplest way of displaying these codes is to attach eight LEDs (with suitable buffers) to the error port, as discussed in IC DRIVER [page 134]: Figure 14.3 illustrates one possible approach.

What does that error code mean? The forms of error reporting discussed here are low-level in nature and are primarily intended to assist the developer of the application or a qualified service engineer performing system maintenance. An additional user interface may also be required in your application to notify the user of errors, in a more user-friendly manner.

2.3.10 Adding a watchdog

The basic scheduler presented here does not provide support for a watchdog timer. Such support can be useful and is easily added, as follows:

- Start the watchdog in the scheduler Start function.
- Refresh the watchdog in the scheduler Update function.

```

1 IWDG_HandleTypeDef hiwdg;
2 static uint32_t counter_for_watchdog = 0;
3
4 void MX_IWDG_Init(void){
5     hiwdg.Instance = IWDG;
6     hiwdg.Init.Prescaler = IWDG_PRESCALER_32;
7     hiwdg.Init.Reload = 4095;
8     if (HAL_IWDG_Init(&hiwdg) != HAL_OK) {
9         Error_Handler();
10    }
11 }
12 void Watchdog_Refresh(void){
13     HAL_IWDG_Refresh(&hiwdg);
14 }
15 unsigned char Is_Watchdog_Reset(void){
16     if(counter_for_watchdog > 3){
17         return 1;
18     }
19     return 0;
20 }
21 void Watchdog_Counting(void){
22     counter_for_watchdog++;
23 }
24
25 void Reset_Watchdog_Counting(void){
26     counter_for_watchdog = 0;
27 }
```

Program 4.17: An implementation of the ‘watchdog’ functions

2.3.11 Reliability and safety implications

- Make sure the task array is large enough
- Take care with function pointers
- Dealing with task overlap

Suppose we have two tasks in our application (Task A, Task B). We further assume that Task A is to run every second and Task B every three seconds. We assume also that each task has a duration of around 0.5 ms.

Suppose we schedule the tasks as follows (assuming a 1ms tick interval):

```
SCH_Add_Task(TaskA, 0, 1000);
SCH_Add_Task(TaskB, 0, 3000);
```

In this case, the two tasks will sometimes be due to execute at the same time. On these occasions, both tasks will run, but Task B will always execute after Task A. This will mean that if Task A varies in duration, then Task B will suffer from ‘jitter’: it will not be called at the correct time when the tasks overlap.

Alternatively, suppose we schedule the tasks as follows:

```
SCH_Add_Task(TaskA, 0, 1000);
```

```
SCH_Add_Task(TaskB, 5, 3000);
```

Now, both tasks still run every 1,000 ms and 3,000 ms (respectively), as required. However, Task A is explicitly scheduled always to run 5 ms before Task B. As a result, Task B will always run on time.

In many cases, we can avoid all (or most) task overlaps simply by the judicious use of the initial task delays.

2.3.12 Portability

3 Objectives

The aim of this lab is to design and implement a cooperative scheduler to accurately provide timeouts and trigger activities. You should add a file for the scheduler implementation and modify the main system call loop to handle timer interrupts.

4 Problem

- Your system should have at least four functions:

- **void SCH_Update(void)**: This function will be updated the remaining time of each tasks that are added to a queue. It will be called in the interrupt timer, for example 10 ms.
- **void SCH_Dispatch_Tasks(void)**: This function will get the task in the queue to run.
- **uint32_t SCH_Add_Task(void (* pFunction)(), uint32_t DELAY, uint32_t PERIOD)**: This function is used to add a task to the queue. It should return an ID that is corresponding with the added task.
- **uint8_t SCH_Delete_Task(uint32_t taskID)**: This function is used to delete the task based on its ID.

You should add more functions if you think it will help you to solve this problem. Your main program must have 5 tasks running periodically in 0.5 second, 1 second, 1.5 seconds, 2 seconds, 2.5 seconds.

5 Demonstration

You should be able to show some test code that uses all the functions specified in the driver interface.

Specifically set up and demonstrate:

- A regular 10ms timer tick.
- Register a timeout to fire a callback every 10ms.
- Then, print the value returned by get_time every time this callback is received.

- Note: Your timestamps must be at least accurate to the nearest 10ms.
- Register another timeout at a different interval in addition to the 500ms running concurrently (i.e. demo more than one timeout registered at a time).
- Before entering the main loop, set up a few calls to SCH_Add_Task. Make sure the delay used is long enough such that the loop is entered before these wake up. These callbacks should just print out the current timestamp as each delay expires.

Note this is not a complete list. The following designs are considered unsatisfactory:

- Only supporting a single timeout registered at a time.
- Delivering callbacks in the wrong order
- $O(n)$ searches in the SCH_Update function.
- Interrupt frequencies greater than 10Hz, if your timer ticks regularly.

6 Submission

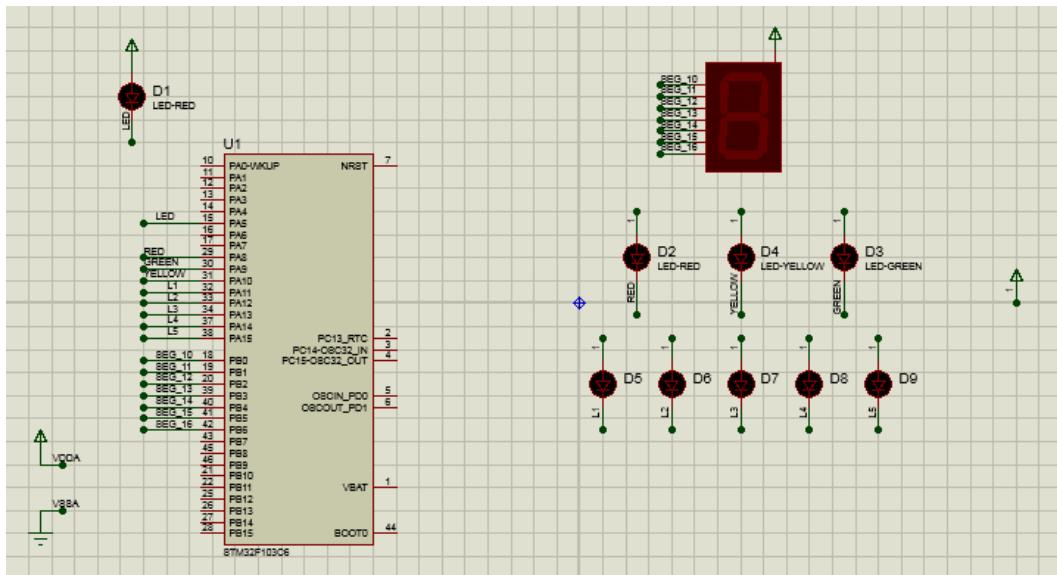
You need to

- Demonstrate your work in the lab class and then
- Submit your source code to the BKeL.

7 References

8 Report

8.1 Proteus schematic



Hình 4.1: Schematic in proteus of project

Trong đó led LED_RED dùng cho việc Debug, các Led đơn còn lại và Led 7 đoạn thì mỗi một task sẽ thực hiện điều khiển một Led.

8.2 Idea

Ý tưởng chính của em đó là dựa vào source code hướng dẫn và cải tiến nó thành O(1) mà không đổi sang dùng các cấu trúc dữ liệu khác, do có thể làm tăng đáng kể độ phức tạp ở hàm Add và Dispatch task.

Ta thấy nhiệm vụ chính của hàm SCH_Update là lập qua mỗi task và giảm delay của nó. Giả sử trong hàng đợi tất cả các task đều có delay như nhau thì việc lập qua các task và giảm delay là việc làm không được tối ưu, giải pháp tốt hơn là chỉ dùng một biến delay thôi, nó sẽ là delay cho tất cả các task, lúc này nhiệm vụ của hàm SCH_Update chỉ là giảm delay của một biến, độ phức tạp là O(1).

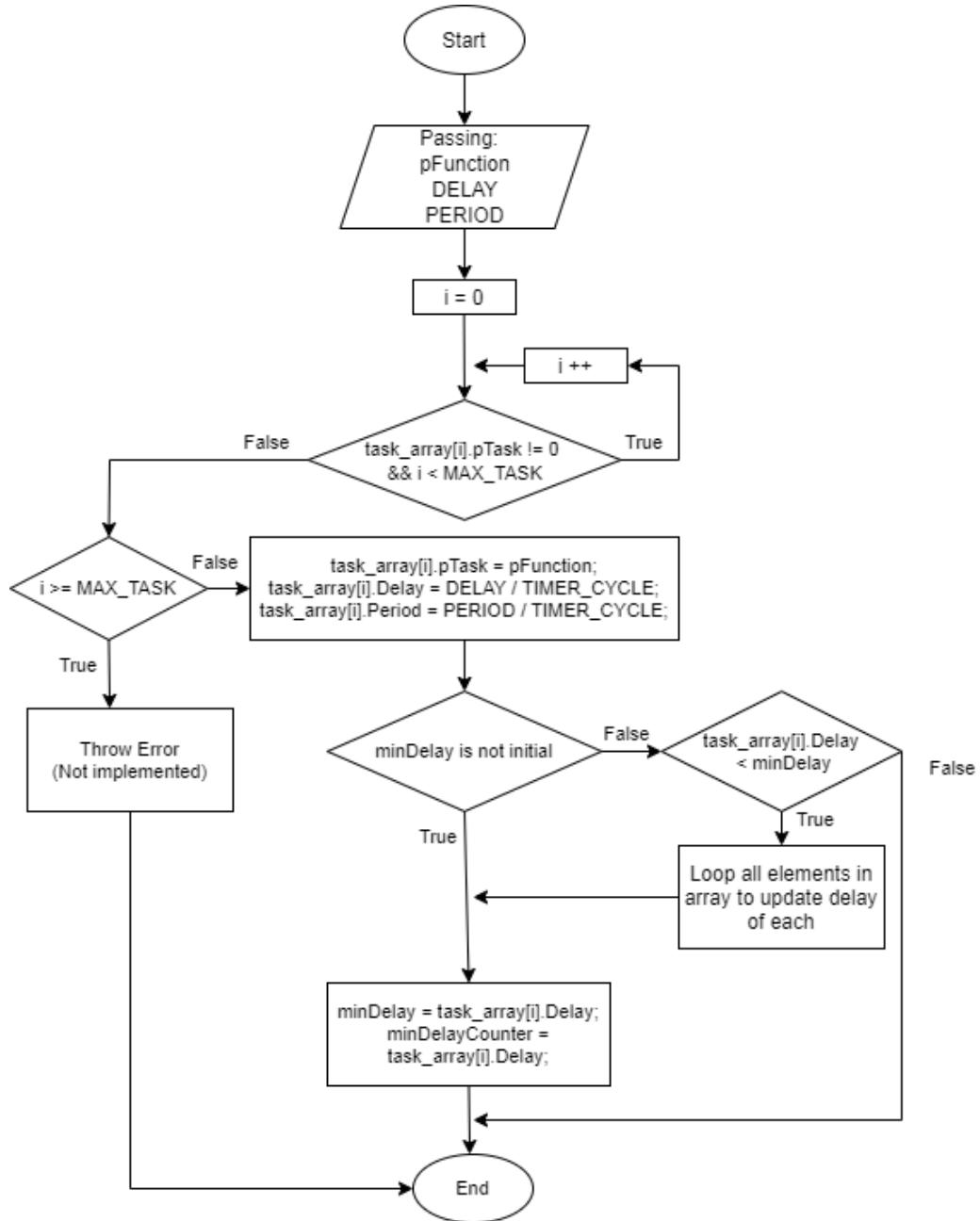
Trường hợp trong hàng đợi, các task đều có delay khác nhau thì sao? Trong trường hợp này ta sẽ tiến hành chọn trong hàng đợi task nào hiện đang có delay nhỏ nhất và gán delay của task đó cho một biến, minDelayCounter, để hàm SCH_Update sẽ thực hiện trừ dần biến đó và biến minDelay để lưu giá trị delay đó. Khi minDelayCounter bằng 0 thì ta sẽ thực hiện task đó và cập nhật delay cho các task khác bằng cách trừ delay của mỗi task cho minDelay, và cập nhật delay cho cả task vừa mới hiện thực, sau đó ta tiến hành tìm minDelay, minDelayCounter mới sau khi delay của các task đã được cập nhật.

Trường hợp có nhiều hơn 1 task có cùng minDelay thì sao? Khi đó ta sẽ lặp qua các task và trừ delay của nó cho minDelay, task nào có kết quả là 0, ta sẽ thực hiện task đó, không thì ta sẽ cập nhật delay cho task đó, và sau đó cập nhật minDelay, minDelayCounter. Ta thấy khi minDelayCounter chưa bằng 0 thì việc gọi liên tục hàm SCH_Dispatch_Tasks rất lãng phí, lúc này ta thêm điều kiện khi minDelayCounter bằng 0 mới gọi SCH_Dispatch_Tasks.

Trường hợp tại thời điểm thêm một task mới, thì delay của task đó nhỏ hơn minDelayCounter thì sao? Lúc này ta sẽ cập nhật delay cho các task cũ bằng cách trừ delay của nó cho ($\text{minDelay} - \text{minDelayCounter}$), đây là khoảng thời gian mà nó đã chờ được, và cập nhật minDelay, minDelayCounter.

8.3 Flow Chart

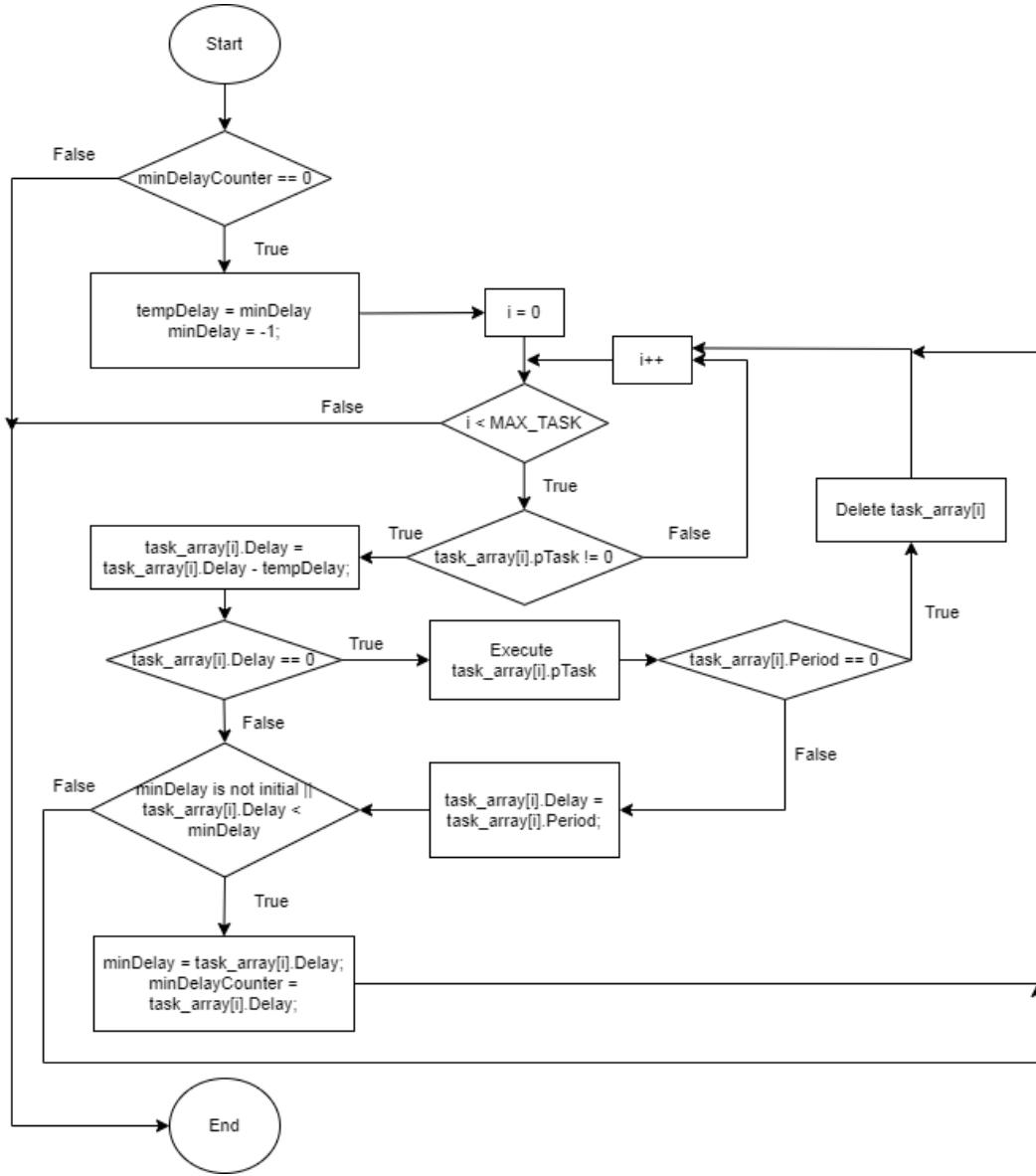
1. Function *SCH_Add_Task*



Hình 4.2: Flow chart Function *SCH_Add_Task*

1. Nhận các đối số đầu vào: pFunction, DELAY, PERIOD.
2. Tìm vị trí trống trên mảng để thêm task mới. Nếu không có thì thông báo lỗi (Chức năng này em không hiện thực, em chỉ xử lí kết thúc hàm) và chuyển sang bước 8.
3. Thêm task vào vị trí vừa tìm được.
4. Nếu minDelay chưa được khởi tạo thì khởi tạo cho minDelay và minDelayCounter, Chuyển sang bước 8. Nếu đã được khởi tạo thì sang bước 5.
5. Nếu task mới thêm vào có delay nhỏ hơn minDelayCounter thì sang bước 6, không thì sang bước 8.
6. Cập nhật delay của các task cũ, bằng cách trừ delay của nó cho (minDelay - minDelayCounter).
7. Cập nhật minDelay và minDelayCounter.
8. Kết thúc hàm.

2. Function *SCH_Dispatch_Tasks*



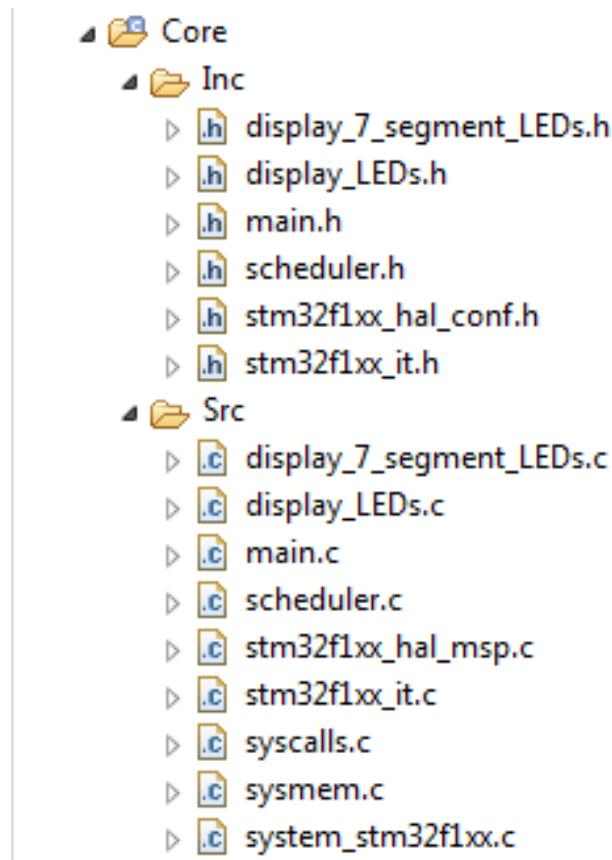
Hình 4.3: Flow chart Function *SCH_Dispatch_Tasks*

1. Nếu $\text{minDelayCounter} == 0$ thì chuyển sang bước 2, không thì chuyển sang bước 9.
2. Lưu minDelay vào tempDelay , reset $\text{minDelay} = -1$. chuyển sang bước 3 với phần tử đầu tiên của mảng.
3. Nếu task không có trên phần tử đó thì chuyển sang phần tử khác, không thì sang bước 4.
4. Cập nhật delay của task, trừ delay cho tempDelay . Nếu delay mới là 0 thì sang bước 5, không thì sang bước 7.
5. Thực hiện task. Nếu period của nó là 0 thì sang bước 6, không thì cập nhật delay và sang bước 7.
6. Xóa task khỏi array.

7. Nếu minDelay chưa được cập nhật lại hoặc task có delay mới nhỏ hơn minDelay thì cập nhật minDelay và minDelayCounter. chuyển sang bước 8.
8. Chuyển sang phần tử tiếp theo và quay lại bước 3. Nếu đã hết mảng thì sang bước 9.
9. Kết thúc hàm.

8.4 STM32 Project

8.4.1 Project organization



Hình 4.4: Project file organization

8.4.2 Function *main*

```

1 int main(void)
2 {
3     HAL_Init();
4     SystemClock_Config();
5     MX_GPIO_Init();
6     MX_TIM2_Init();
7     HAL_TIM_Base_Start_IT(&htim2);
8     SCH_Init();
9     // Add task

```

```

10    SCH_Add_Task(increase7SegLED, 0, 1000);
11    SCH_Add_Task(toggleLEDRed, 1000, 0);
12    SCH_Add_Task(toggleLEDYellow, 2000, 0);
13    SCH_Add_Task(toggleLEDGreen, 3000, 0);
14    SCH_Add_Task(toggleLED1, 3000, 500);
15    SCH_Add_Task(toggleLED2, 3000, 1000);
16    SCH_Add_Task(toggleLED3, 3000, 1500);
17    SCH_Add_Task(toggleLED4, 3000, 2000);
18    SCH_Add_Task(toggleLED5, 3000, 2500);
19    while (1)
20    {
21        SCH_Dispatch_Tasks ();
22    }
23 }
```

Program 4.18: Source code in *main* function

8.4.3 Function Timer Interrupt

```

1 void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim) {
2     SCH_Update () ;
3     // Use for debugging
4     if(count == 50){
5         HAL_GPIO_TogglePin(GPIOA, LED_RED_Pin) ;
6     }
7     count--;
8     if(count <= 0) count = 50;
9 }
```

Program 4.19: Source code in tiemr interrupt function

8.4.4 Module *display_LEDs*

Chứa hiện thực các task trên LED đơn.

1. File *display_LEDs.h*

```

1 #ifndef INC_DISPLAY_LEDS_H_
2 #define INC_DISPLAY_LEDS_H_
3
4 void toggleLED1(void);
5 void toggleLED2(void);
6 void toggleLED3(void);
7 void toggleLED4(void);
8 void toggleLED5(void);
9 void toggleLEDRed(void);
10 void toggleLEDGreen(void);
11 void toggleLEDYellow(void);
12
13#endif
14
```

Program 4.20: Source code in file *display_LEDs.h*

2. File *display_LEDs.c*

```
1 #include "main.h"
2 #include "display_LEDs.h"
3
4 void toggleLED1() {
5     HAL_GPIO_TogglePin(GPIOA, LED1_Pin);
6 }
7
8 void toggleLED2() {
9     HAL_GPIO_TogglePin(GPIOA, LED2_Pin);
10}
11
12 void toggleLED3() {
13     HAL_GPIO_TogglePin(GPIOA, LED3_Pin);
14}
15
16 void toggleLED4() {
17     HAL_GPIO_TogglePin(GPIOA, LED4_Pin);
18}
19
20 void toggleLED5() {
21     HAL_GPIO_TogglePin(GPIOA, LED5_Pin);
22}
23
24 void toggleLEDRed() {
25     HAL_GPIO_TogglePin(GPIOA, RED_Pin);
26}
27
28 void toggleLEDGreen() {
29     HAL_GPIO_TogglePin(GPIOA, GREEN_Pin);
30}
31
32 void toggleLEDYellow() {
33     HAL_GPIO_TogglePin(GPIOA, YELLOW_Pin);
34}
```

Program 4.21: Source code in file *display_LEDs.h*

8.4.5 Module *display_7_segment_LEDs*

Chứa hiện thực các task trên LED 7 đoạn.

1. File *display_7_segment_LEDs.h*

```
1 #ifndef INC_DISPLAY_7_SEGMENT_LEDS_H_
2 #define INC_DISPLAY_7_SEGMENT_LEDS_H_
3
4 void increase7SegLED(void);
5
6#endif
```

Program 4.22: Source code in file *display_7_segment_LEDs.h*

2. File *display_7_segment_LEDs.c*

```
1 #include "main.h"
2 #include "display_7_segment_LEDs.h"
3
4 static int value = 0;
5
6 void display7SEG_1(int num) {
7     switch(num) {
8         case 0:
9             HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_11_Pin | SEG_12_Pin |
10                SEG_13_Pin | SEG_14_Pin | SEG_15_Pin, RESET);
11                HAL_GPIO_WritePin(GPIOB, SEG_16_Pin, SET);
12                break;
13        case 1:
14            HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_13_Pin | SEG_14_Pin |
15                SEG_15_Pin | SEG_16_Pin, SET);
16            HAL_GPIO_WritePin(GPIOB, SEG_11_Pin | SEG_12_Pin, RESET);
17            break;
18        case 2:
19            HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_11_Pin | SEG_13_Pin |
20                SEG_14_Pin | SEG_16_Pin, RESET);
21            HAL_GPIO_WritePin(GPIOB, SEG_12_Pin | SEG_15_Pin, SET);
22            break;
23        case 3:
24            HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_11_Pin | SEG_12_Pin |
25                SEG_13_Pin | SEG_16_Pin, RESET);
26            HAL_GPIO_WritePin(GPIOB, SEG_14_Pin | SEG_15_Pin, SET);
27            break;
28        case 4:
29            HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_13_Pin | SEG_14_Pin,
30                SET);
31            HAL_GPIO_WritePin(GPIOB, SEG_11_Pin | SEG_12_Pin | SEG_15_Pin |
32                SEG_16_Pin, RESET);
33            break;
34        case 5:
35            HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_12_Pin | SEG_13_Pin |
36                SEG_15_Pin | SEG_16_Pin, RESET);
37            HAL_GPIO_WritePin(GPIOB, SEG_11_Pin | SEG_14_Pin, SET);
38            break;
39        case 6:
40            HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_12_Pin | SEG_13_Pin |
41                SEG_14_Pin | SEG_15_Pin | SEG_16_Pin, RESET);
42            HAL_GPIO_WritePin(GPIOB, SEG_11_Pin, SET);
43            break;
44        case 7:
45            HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_11_Pin | SEG_12_Pin,
46                RESET);
47            HAL_GPIO_WritePin(GPIOB, SEG_13_Pin | SEG_14_Pin | SEG_15_Pin |
48                SEG_16_Pin, SET);
49            break;
50        case 8:
51            HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_11_Pin | SEG_12_Pin |
```

```

42     SEG_13_Pin | SEG_14_Pin | SEG_15_Pin | SEG_16_Pin , RESET) ;
43     break;
44 case 9:
45     HAL_GPIO_WritePin(GPIOB, SEG_10_Pin | SEG_11_Pin | SEG_12_Pin |
46     SEG_13_Pin | SEG_15_Pin | SEG_16_Pin , RESET);
47     HAL_GPIO_WritePin(GPIOB, SEG_14_Pin , SET);
48     break;
49 default:
50     break;
51 }
52 void increase7SegLED () {
53     display7SEG_1 (value++);
54     if (value >= 10) value = 0;
55 }
56

```

Program 4.23: Source code in file *display_7_segment_LEDs.h*

8.4.6 Module *scheduler*

1. File *scheduler.h*

```

1 #ifndef INC_SCHEDULER_H_
2 #define INC_SCHEDULER_H_
3
4 void SCH_Init(void);
5 void SCH_Update(void);
6 uint32_t SCH_Add_Task(void(*)() , uint32_t , uint32_t);
7 uint32_t SCH_Delete_Task(uint32_t);
8 void SCH_Dispatch_Tasks(void);
9
10#endif
11

```

Program 4.24: Source code in file *scheduler.h*

2. File *scheduler.c*

```

1 #include "main.h"
2 #include "scheduler.h"
3
4 #define MAX_NUMBER_OF_TASK 40
5 #define TIMER_CYCLE 10
6
7 // Don't have RunMe
8 typedef struct{
9     void (*pTask)(void);
10    uint32_t Delay;
11    uint32_t Period;
12    uint32_t TaskID;
13} stuctTask;
14

```

```

15 structTask SCH_task_array[MAX_NUMBER_OF_TASK];
16 static int minDelayCounter = -1;
17 static int minDelay = -1;
18
19 void SCH_Init() {
20     for(int i=0; i<MAX_NUMBER_OF_TASK; i++) {
21         SCH_task_array[i].pTask = NULL;
22         SCH_task_array[i].Delay = 0;
23         SCH_task_array[i].Period = 0;
24         SCH_task_array[i].TaskID = 0;
25     }
26 }
27
28 void SCH_Update() {
29     minDelayCounter--;
30 }
31
32 uint32_t SCH_Add_Task(void (*pFunction)(), uint32_t DELAY,
33                         uint32_t PERIOD) {
34     int i = 0;
35     // Find empty element
36     while((SCH_task_array[i].pTask != 0) && (i <
37           MAX_NUMBER_OF_TASK)) {
38         i++;
39     }
40     // Array is full, so I just end function
41     if(i >= MAX_NUMBER_OF_TASK) {
42         return MAX_NUMBER_OF_TASK;
43     }
44     // Add task
45     SCH_task_array[i].pTask = pFunction ;
46     SCH_task_array[i].Delay = DELAY / TIMER_CYCLE;
47     SCH_task_array[i].Period = PERIOD / TIMER_CYCLE;
48     SCH_task_array[i].TaskID = i;
49     // minDelay is not initiated
50     if(minDelay < 0) {
51         minDelayCounter = SCH_task_array[i].Delay;
52         minDelay = SCH_task_array[i].Delay;
53     }
54     // minDelay is initiated and new task's delay is smaller
55     // than minDelayCounter
56     else if(minDelay >= 0 && SCH_task_array[i].Delay <
57             minDelayCounter) {
58         // delayed is time the old tasks has waited
59         int delayed = minDelay - minDelayCounter;
60         // This if use for passing case delayed == 0
61         if(delayed > 0){
62             // Update delay of task
63             for(int i = 0; i < MAX_NUMBER_OF_TASK; i++) {
64                 if(SCH_task_array[i].pTask != 0){
65                     SCH_task_array[i].Delay -= delayed;
66                 }
67             }
68         }
69     }
70 }

```

```

63     }
64 }
65 // Update minDelay, minDelayCounter
66 minDelay = SCH_task_array[ i ].Delay;
67 minDelayCounter = SCH_task_array[ i ].Delay;
68 }
69 return i;
70 }
71
72 uint32_t SCH_Delete_Task(uint32_t taskID) {
73     uint32_t returnCode = 1;
74     if(SCH_task_array[taskID].pTask == 0){
75         returnCode = 99999; // Not finished
76     }
77     else{
78         returnCode = 0; // Not finished
79     }
80     SCH_task_array[taskID].pTask = 0;
81     SCH_task_array[taskID].Delay = 0;
82     SCH_task_array[taskID].Period = 0;
83
84     return returnCode;
85 }
86
87
88 void SCH_Dispatch_Tasks(){
89     if(minDelayCounter == 0){
90         // Save minDelay
91         int tempDelay = minDelay;
92         // Reset minDelay
93         minDelay = -1;
94
95         for(int i = 0; i < MAX_NUMBER_OF_TASK; i++){
96             if(SCH_task_array[i].pTask != 0){
97                 // Update delay of task
98                 SCH_task_array[i].Delay = SCH_task_array[i].Delay -
tempDelay;
99                 // Execute task
100                if(SCH_task_array[i].Delay == 0){
101                    (*SCH_task_array[i].pTask)();
102                    // Task is execute one time
103                    if(SCH_task_array[i].Period == 0) {
104                        SCH_Delete_Task(i);
105                        continue;
106                    }
107                    // Task has period
108                    else {
109                        SCH_task_array[i].Delay = SCH_task_array[i].Period
110 ;
111                    }
112                }
}

```

```

113     // Update minDelayTask
114     // minDelay is not initiated
115     if(minDelay < 0) {
116         minDelayCounter = SCH_task_array[ i ].Delay;
117         minDelay = SCH_task_array[ i ].Delay;
118     }
119     // minDelay is initiated
120     else{
121         if( SCH_task_array[ i ].Delay < minDelay) {
122             minDelayCounter = SCH_task_array[ i ].Delay;
123             minDelay = SCH_task_array[ i ].Delay;
124         }
125     }
126 }
127 }
128 }
129 }
130

```

Program 4.25: Source code in file scheduler

8.5 Gantt chart

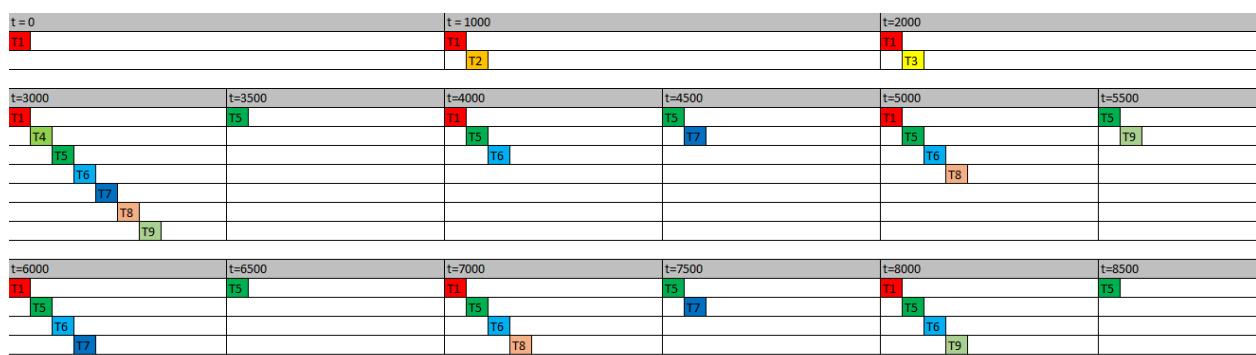
Các task được thêm vào như sau:

```

1 SCH_Add_Task(increase7SegLED , 0, 1000);
2 SCH_Add_Task(toggleLEDRed , 1000, 0);
3 SCH_Add_Task(toggleLEDYellow , 2000, 0);
4 SCH_Add_Task(toggleLEDGreen , 3000, 0);
5 SCH_Add_Task(toggleLED1 , 3000, 500);
6 SCH_Add_Task(toggleLED2 , 3000, 1000);
7 SCH_Add_Task(toggleLED3 , 3000, 1500);
8 SCH_Add_Task(toggleLED4 , 3000, 2000);
9 SCH_Add_Task(toggleLED5 , 3000, 2500);

```

Giả sử thời để thực hiện xong một task đều là 1ms. Sau đây là giản đồ gantt (Em chỉ vẽ tới giây thứ 8):



Hình 4.5: Gantt chart

8.6 Video demo

Link video: [Click here](#)