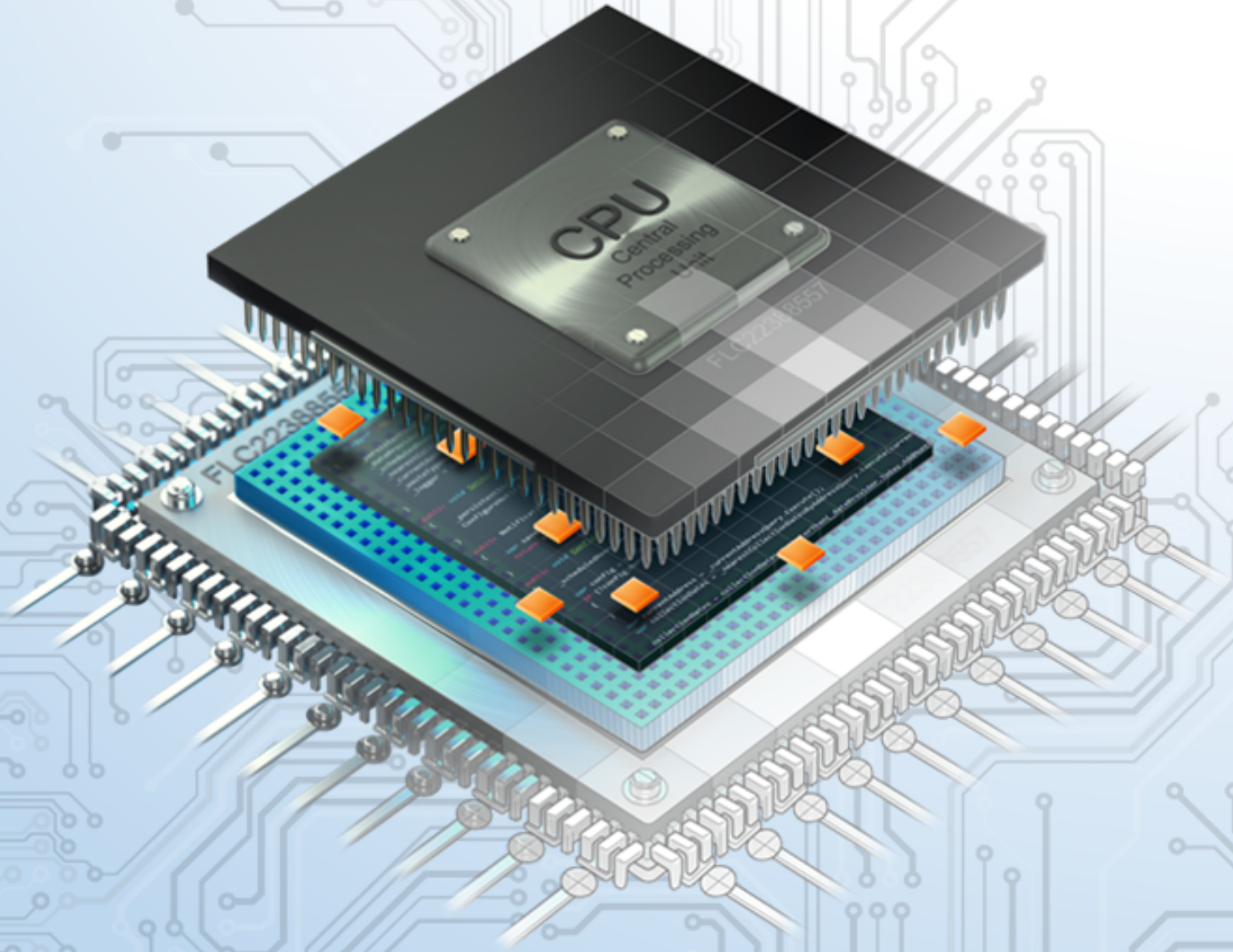
HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY
COMPUTER ENGINEERING

Microcontroller



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HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY
FACULTY OF COMPUTER SCIENCE AND ENGINEERING

REPORT
MICROCONTROLLER (CO3010)

Chapter 3: Buttons/Switches

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Ho Chi Minh City, October 2021

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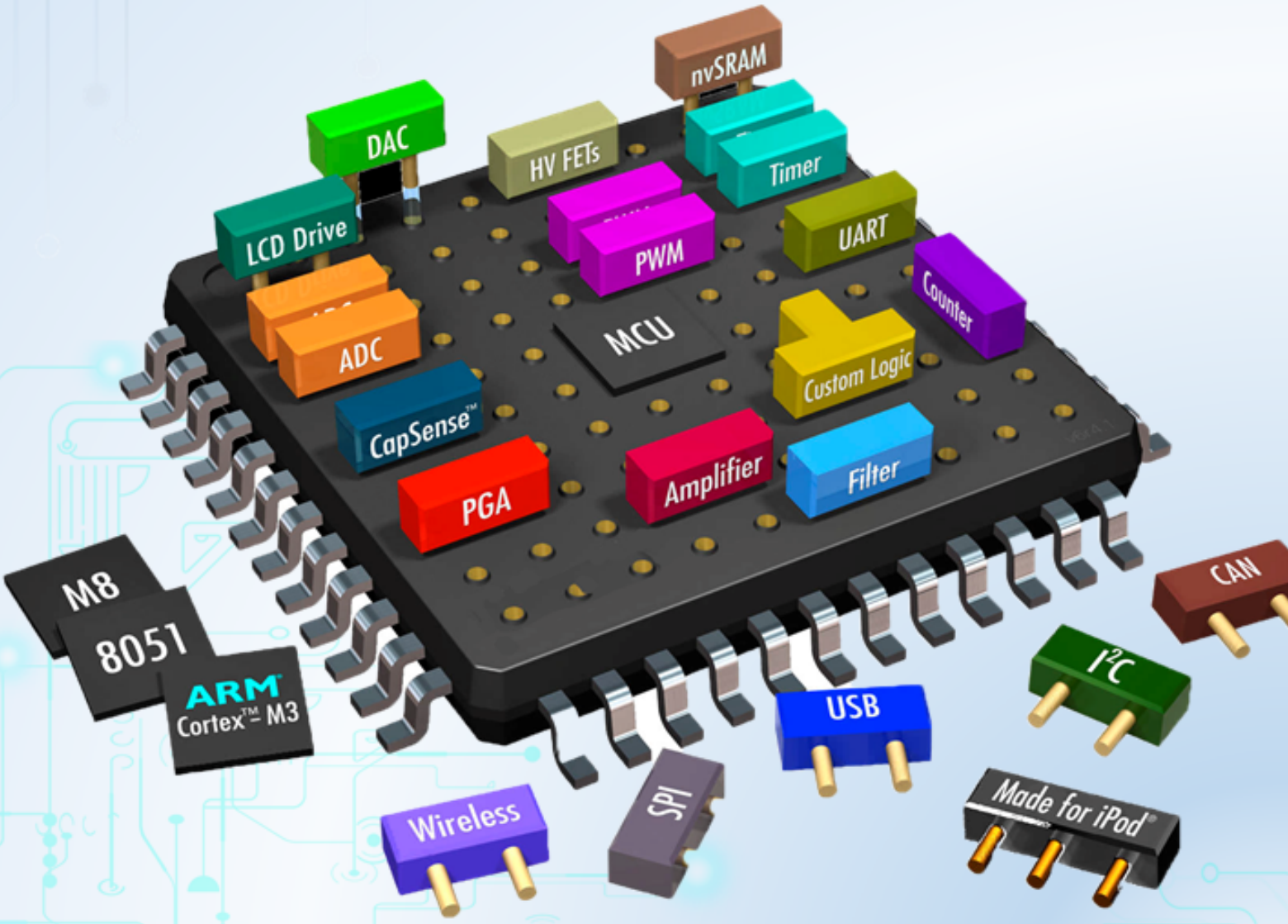
CHAPTER 1

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

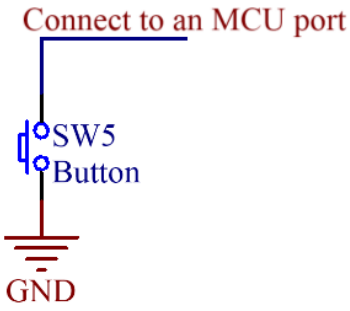


Figure 1.1: Connecting a button to an MCU

Figure 1.1 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 1.2.

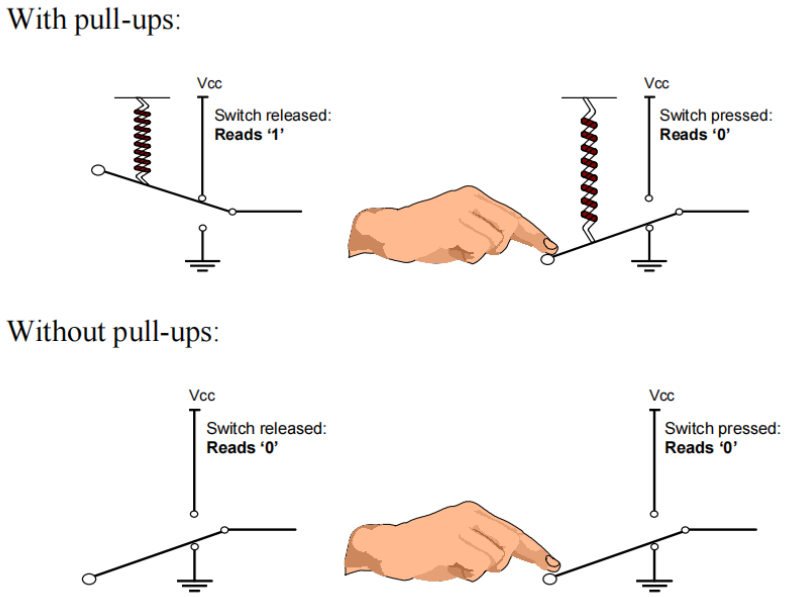


Figure 1.2: The need of pull up resistors

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 1.3.

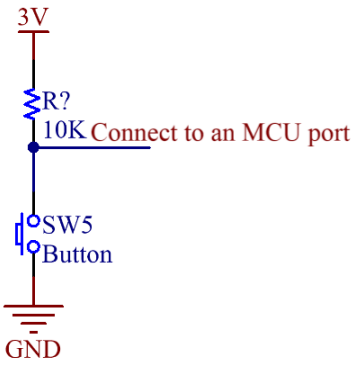


Figure 1.3: A reliable way to connect a button to an MCU

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 1.4.

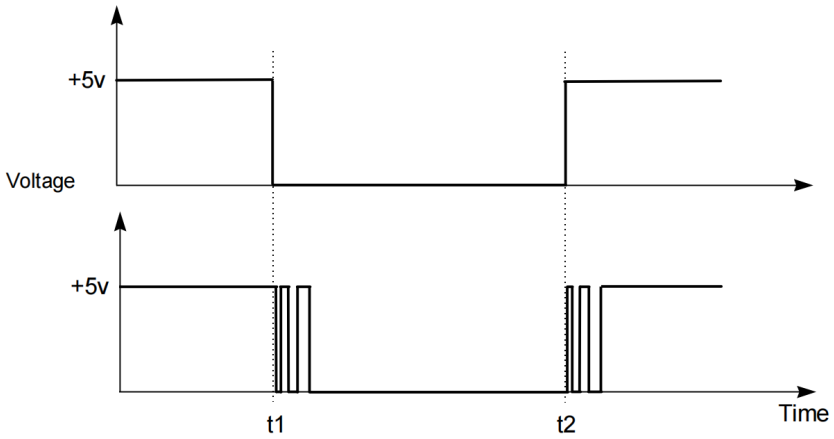


Figure 1.4: Switch bounces

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 > 10ms (our specified button bounce upper limit) and N <= 50ms (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:

```
void button_reading(void){
    static unsigned char last_button;
    unsigned char raw_button;
    unsigned char filtered_button;
    last_button = raw_button;
    raw_button = HAL_GPIO_ReadPin(BUTTON_1_GPIO_Port,
   BUTTON_1_Pin);
    if(last_button == raw_button){
        filtered_button = raw_button;
    }
}
```

Program 1.1: Read port pin and deboucing

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 reseting 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.

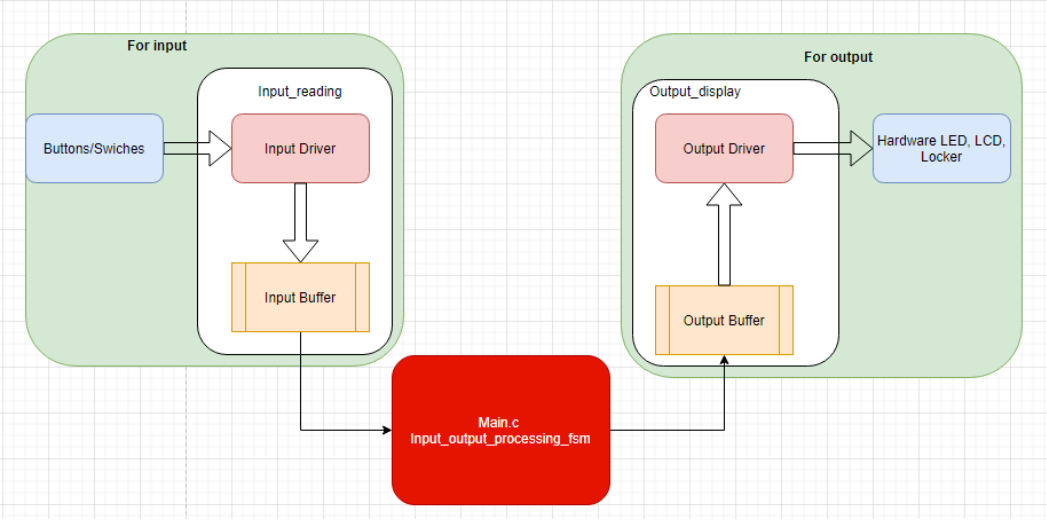


Figure 1.5: Input Output Processing Patterns

Figure 1.5 shows that we should have an *input_reading* module to processing 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 1.6.

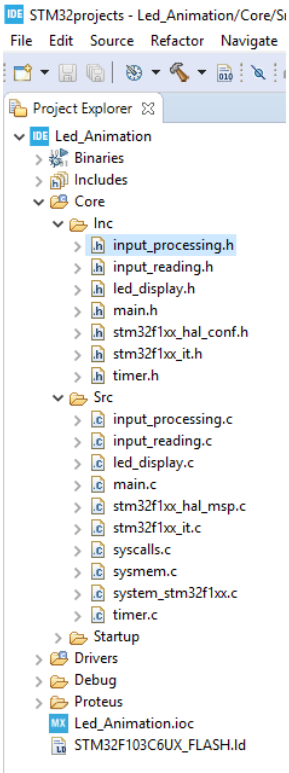


Figure 1.6: File Organization

Steps 1 (Figure 1.7): 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 1.8): Do the same for the C header file in the folder **Inc**.

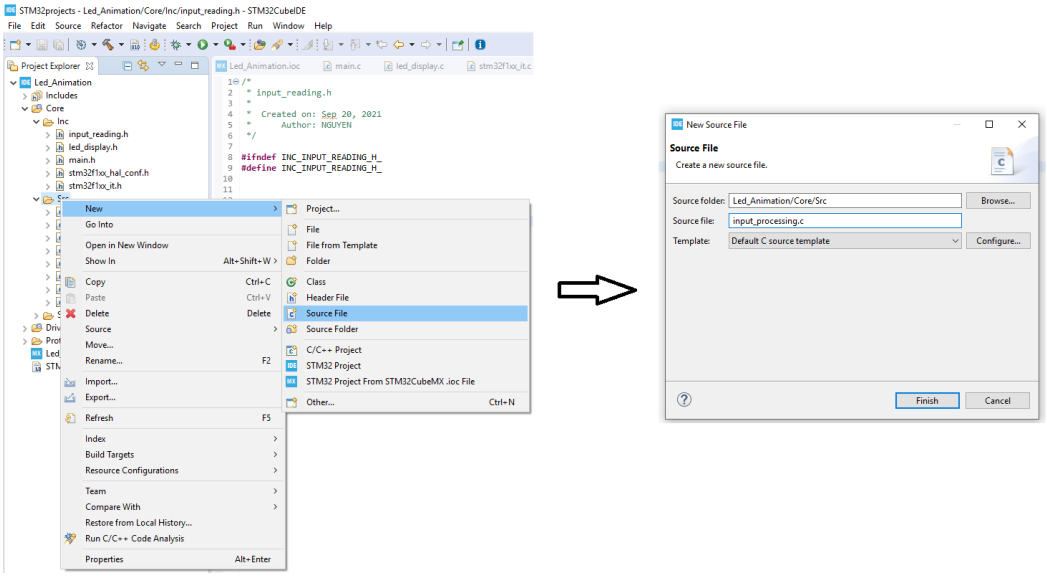


Figure 1.7: Step 1: Create a C source file for input reading

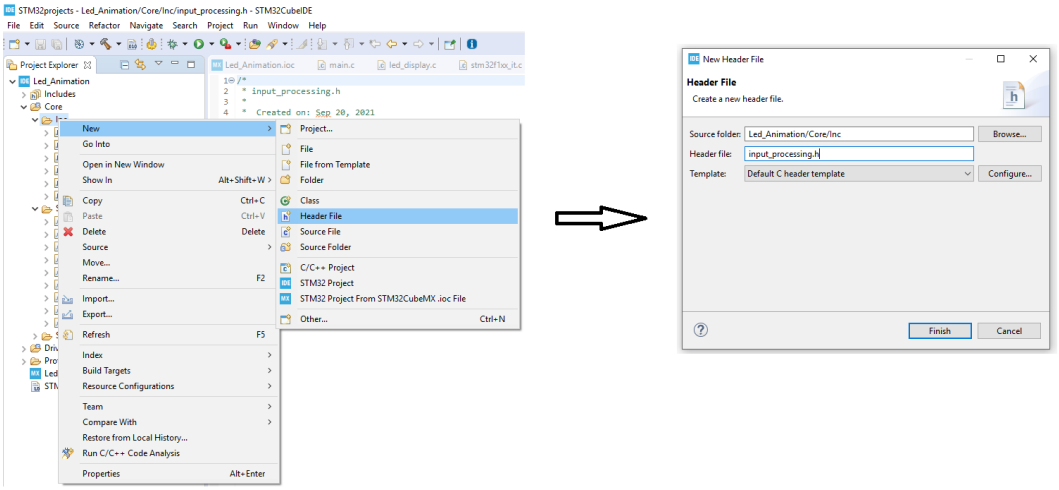


Figure 1.8: Step 2: Create a C header file for input processing

4.3 Code For Read Port Pin and Debouncing

4.3.1 The code in the input_reading.c file

```
#include "main.h"
//we aim to work with more than one buttons
#define NO_OF_BUTTONS                 1
//timer interrupt duration is 10ms, so to pass 1 second,
//we need to jump to the interrupt service routine 100 time
#define DURATION_FOR_AUTO_INCREASING     100
#define BUTTON_IS_PRESSED                  GPIO_PIN_RESET
#define BUTTON_IS_RELEASED                 GPIO_PIN_SET
//the buffer that the final result is stored after
//debouncing
static GPIO_PinState buttonBuffer[NO_OF_BUTTONS];
//we define two buffers for debouncing
static GPIO_PinState debounceButtonBuffer1[NO_OF_BUTTONS];
static GPIO_PinState debounceButtonBuffer2[NO_OF_BUTTONS];
//we define a flag for a button pressed more than 1 second.
static uint8_t flagForButtonPress1s[NO_OF_BUTTONS];
//we define counter for automatically increasing the value
//after the button is pressed more than 1 second.
static uint16_t counterForButtonPress1s[NO_OF_BUTTONS];
void button_reading(void){
  for(char i = 0; i < NO_OF_BUTTONS; i ++){
    debounceButtonBuffer2[i] =debounceButtonBuffer1[i];
    debounceButtonBuffer1[i] = HAL_GPIO_ReadPin(
   BUTTON_1_GPIO_Port, BUTTON_1_Pin);
    if(debounceButtonBuffer1[i] == debounceButtonBuffer2[i
   ])
       buttonBuffer[i] = debounceButtonBuffer1[i];
       if(buttonBuffer[i] == BUTTON_IS_PRESSED){
       //if a button is pressed, we start counting
         if(counterForButtonPress1s[i] <
   DURATION_FOR_AUTO_INCREASING){
           counterForButtonPress1s[i]++;
         } else {
         //the flag is turned on when 1 second has passed
         //since the button is pressed.
           flagForButtonPress1s[i] = 1;
           //todo
         }
       } else {
         counterForButtonPress1s[i] = 0;
         flagForButtonPress1s[i] = 0;
       }
  }
}
```

Program 1.2: Define constants buffers and button_reading function

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

Program 1.3: Checking a button is pressed or not

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

Program 1.4: Checking a button is pressed more than a second or not

4.3.2 The code in the input_reading.h file

```c
#ifndef INC_INPUT_READING_H_
#define INC_INPUT_READING_H_
void button_reading(void);
unsigned char is_button_pressed(unsigned char index);
unsigned char is_button_pressed_1s(unsigned char index);
#endif /* INC_INPUT_READING_H_ */
```

Program 1.5: Prototype in input_reading.h file

4.3.3 The code in the timer.c file

```c
#include "main.h"
#include "input_reading.h"

void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
{
  if(htim->Instance == TIM2){
    button_reading();
  }
}
```

Program 1.6: 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.

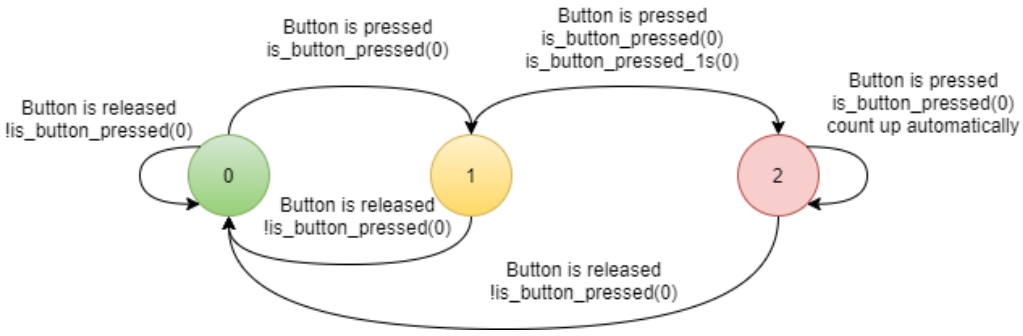


Figure 1.9: An FSM for processing a button

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.

```
#include "main.h"
#include "input_reading.h"

enum ButtonState{BUTTON_RELEASED, BUTTON_PRESSED,
   BUTTON_PRESSED_MORE_THAN_1_SECOND} ;
enum ButtonState buttonState = BUTTON_RELEASED;
void fsm_for_input_processing(void){
  switch(buttonState){
  case BUTTON_RELEASED:
    if(is_button_pressed(0)){
      buttonState = BUTTON_PRESSED;
      //INCREASE VALUE OF PORT A BY ONE UNIT
    }
    break;
  case BUTTON_PRESSED:
    if(!is_button_pressed(0)){
      buttonState = BUTTON_RELEASED;
    } else {
      if(is_button_pressed_1s(0)){
        buttonState = BUTTON_PRESSED_MORE_THAN_1_SECOND;
      }
    }
    break;
  case BUTTON_PRESSED_MORE_THAN_1_SECOND:
    if(!is_button_pressed(0)){
      buttonState = BUTTON_RELEASED;
    }
    //todo
    break;
  }
}
```

Program 1.7: The code in the input_processing.c file

4.4.3 The code in the input_processing.h

```
#ifndef INC_INPUT_PROCESSING_H_
#define INC_INPUT_PROCESSING_H_

void fsm_for_input_processing(void);

#endif /* INC_INPUT_PROCESSING_H_ */
```

Program 1.8: Code in the input_processing.h file

4.4.4 The code in the main.c file

```c
#include "main.h"
#include "input_processing.h"
//don't modify this part
int main(void){
    HAL_Init();
    /* Configure the system clock */
    SystemClock_Config();
    /* Initialize all configured peripherals */
    MX_GPIO_Init();
    MX_TIM2_Init();
    while (1)
    {
        //you only need to add the fsm function here
        fsm_for_input_processing();
    }
}
```

Program 1.9: 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.

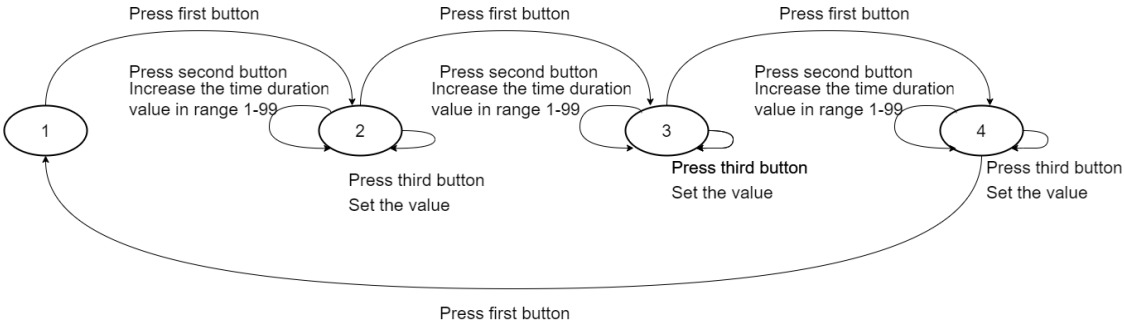


Figure 1.10: An FSM for processing a button

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.

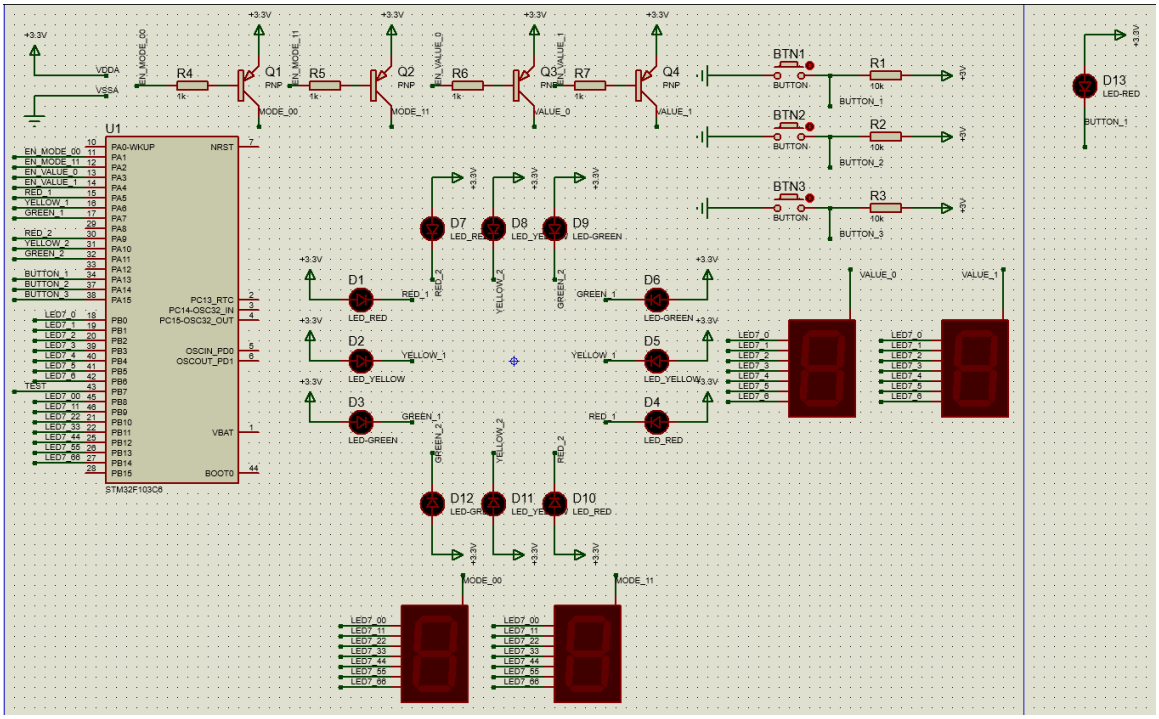


Figure 1.11: Proteus Schematic

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.

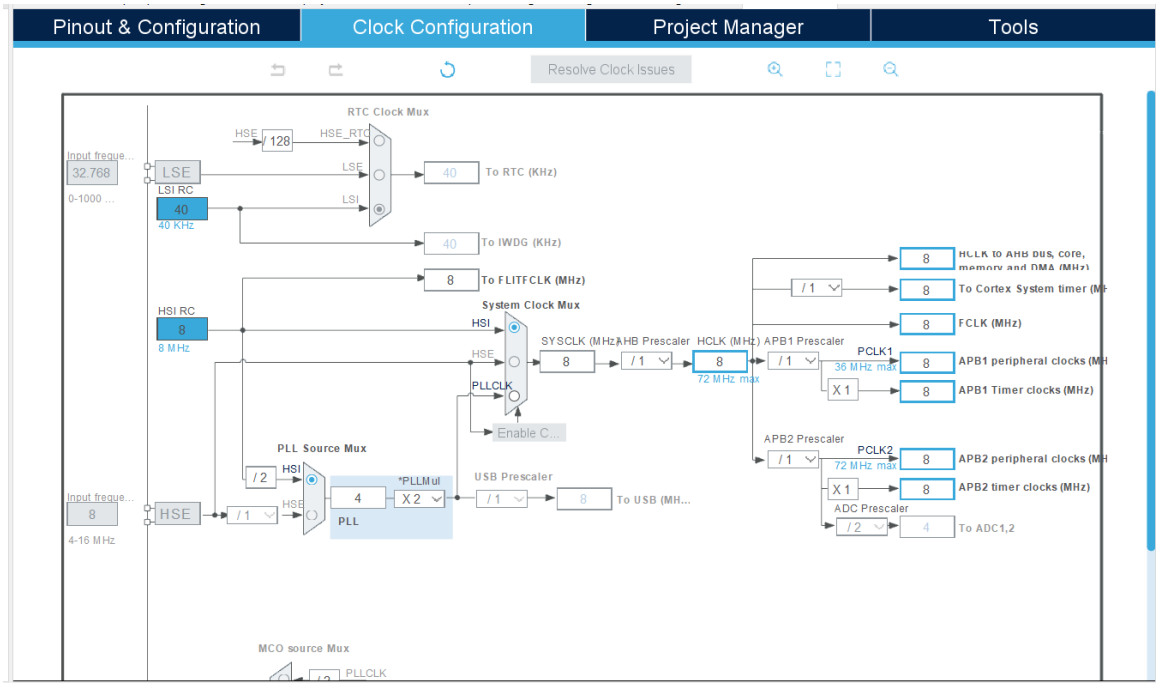


Figure 1.12: Set up timer interrupt

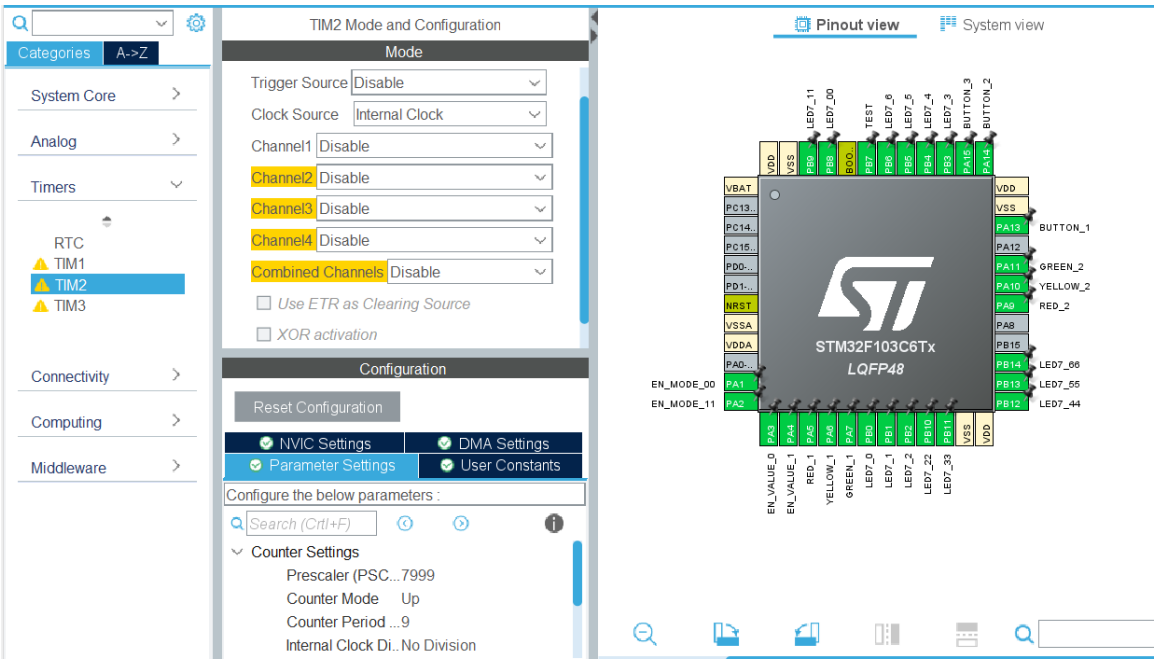


Figure 1.13: Set pin in .ioc file

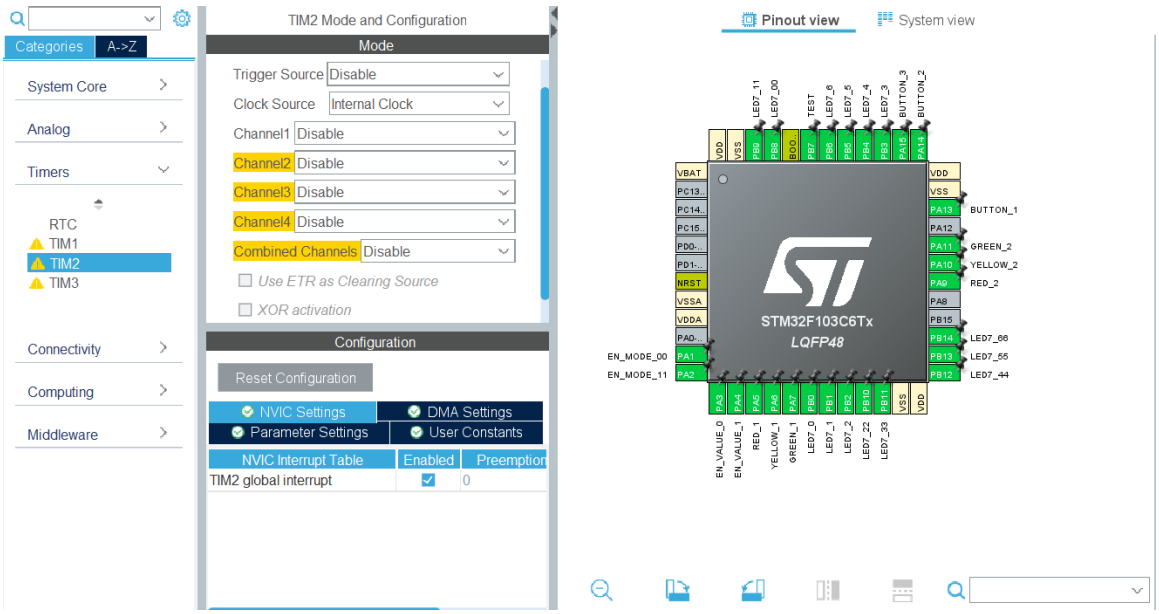


Figure 1.14: Set up timer interrupt

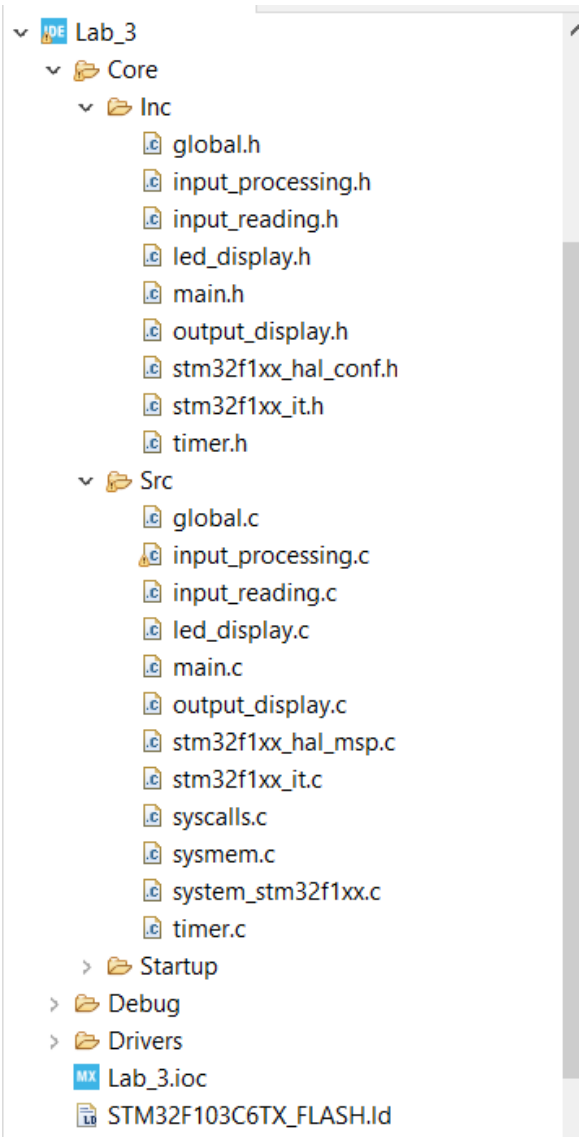


Figure 1.15: File Organization

```c
#ifndef INC_GLOBAL_H_
#define INC_GLOBAL_H_
int timer_MODE_counter;
int timer_MODE_flag;
int TIMER_CYCLE;
int timer_VALUE_counter;
int timer_VALUE_flag;
int timer_MODE1_NORMAL_counter;
int timer_MODE1_NORMAL_flag;
// Variable for function Mode1_normal
int red_timer;
int green_timer;
int yellow_timer;
int counter;
int display_1;
int display_2;
// Variable for display mode and value
int index_mode;
// Variable for value of led when press button 2
int red_temp;
int yellow_temp;
int green_temp;
#endif /* INC_GLOBAL_H_ */
```

Program 1.10: Souce code of global.h

```c
#include "global.h"
void initialize_variable(){
  // Variable for function mode1_normal()
  red_timer = 5;
  green_timer = 3;
  yellow_timer = 2;
  counter = red_timer + green_timer + yellow_timer;
  display_1 = 0;
  display_2 = 0;
  // Variable for display mode and value
  index_mode = 0;
  TIMER_CYCLE = 10;
}
```

Program 1.11: Souce code of global.c

```c
#ifndef INC_LED_DISPLAY_H_
#define INC_LED_DISPLAY_H_

void display7SEG_VALUE(int num);
void display7SEG_MODE(int num);
void update7SEG_MODE(int index, int value);
void mode1_normal();
void clearLED();
```

```
#endif /* INC_LED_DISPLAY_H_ */
```

Program 1.12: Source code of led_display.h

```
#include "main.h"
#include "led_display.h"
#include "global.h"
void clearLED(){
  HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|LED7_2_Pin
   |LED7_3_Pin|LED7_4_Pin|LED7_5_Pin|LED7_6_Pin, 1);
  HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_11_Pin|
   LED7_22_Pin|LED7_33_Pin|LED7_44_Pin|LED7_55_Pin|
   LED7_66_Pin, 1);
  HAL_GPIO_WritePin(GPIOA, RED_1_Pin|YELLOW_1_Pin|
   GREEN_1_Pin
              |RED_2_Pin|YELLOW_2_Pin|GREEN_2_Pin,
   GPIO_PIN_SET);
  HAL_GPIO_WritePin(GPIOA, EN_MODE_00_Pin|EN_MODE_11_Pin|
   EN_VALUE_0_Pin|EN_VALUE_1_Pin, GPIO_PIN_RESET);
}
void display7SEG_VALUE(int num){
  switch (num){
    case 0:
      HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
   LED7_2_Pin|LED7_3_Pin|LED7_4_Pin|LED7_5_Pin,
   GPIO_PIN_RESET);
      HAL_GPIO_WritePin(GPIOB, LED7_6_Pin, GPIO_PIN_SET);
      break;
    case 1:
      HAL_GPIO_WritePin(GPIOB, LED7_1_Pin|LED7_2_Pin, 0);
   //GPIO_PIN_RESET  c    t h   thay 0
      HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_3_Pin|
   LED7_4_Pin|LED7_5_Pin|LED7_6_Pin, 1); //GPIO_PIN_SET  c
     t h   thay 1
      break;
    case 2:
      HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
   LED7_3_Pin|LED7_4_Pin|LED7_6_Pin, GPIO_PIN_RESET);
      HAL_GPIO_WritePin(GPIOB, LED7_2_Pin|LED7_5_Pin,
   GPIO_PIN_SET);
      break;
    case 3:
      HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
   LED7_2_Pin|LED7_3_Pin|LED7_6_Pin, GPIO_PIN_RESET);
      HAL_GPIO_WritePin(GPIOB, LED7_4_Pin|LED7_5_Pin,
   GPIO_PIN_SET);
      break;
    case 4:
      HAL_GPIO_WritePin(GPIOB, LED7_1_Pin|LED7_2_Pin|
   LED7_5_Pin|LED7_6_Pin, GPIO_PIN_RESET);
```

```
31        HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_3_Pin|
    LED7_4_Pin, GPIO_PIN_SET);
32        break;
33      case 5:
34        HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_2_Pin|
    LED7_3_Pin|LED7_5_Pin|LED7_6_Pin, GPIO_PIN_RESET);
35        HAL_GPIO_WritePin(GPIOB, LED7_1_Pin|LED7_4_Pin,
    GPIO_PIN_SET);
36        break;
37      case 6:
38        HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_2_Pin|
    LED7_3_Pin|LED7_4_Pin|LED7_5_Pin|LED7_6_Pin,
    GPIO_PIN_RESET);
39        HAL_GPIO_WritePin(GPIOB, LED7_1_Pin, GPIO_PIN_SET);
40        break;
41      case 7:
42        HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
    LED7_2_Pin, GPIO_PIN_RESET);
43        HAL_GPIO_WritePin(GPIOB, LED7_3_Pin|LED7_4_Pin|
    LED7_5_Pin|LED7_6_Pin, GPIO_PIN_SET);
44        break;
45      case 8:
46        HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
    LED7_2_Pin|LED7_3_Pin|LED7_4_Pin|LED7_5_Pin|LED7_6_Pin,
    GPIO_PIN_RESET);
47        break;
48      case 9:
49        HAL_GPIO_WritePin(GPIOB, LED7_0_Pin|LED7_1_Pin|
    LED7_2_Pin|LED7_3_Pin|LED7_5_Pin|LED7_6_Pin,
    GPIO_PIN_RESET);
50        HAL_GPIO_WritePin(GPIOB, LED7_4_Pin, GPIO_PIN_SET);
51        break;
52      }
53  }
54  void display7SEG_MODE(int num){
55    switch (num){
56      case 0:
57        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_11_Pin|
    LED7_22_Pin|LED7_33_Pin|LED7_44_Pin|LED7_55_Pin,
    GPIO_PIN_RESET);
58        HAL_GPIO_WritePin(GPIOB, LED7_66_Pin, GPIO_PIN_SET);
59        break;
60      case 1:
61        HAL_GPIO_WritePin(GPIOB, LED7_11_Pin|LED7_22_Pin,
    GPIO_PIN_RESET);
62        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_33_Pin|
    LED7_44_Pin|LED7_55_Pin|LED7_66_Pin, GPIO_PIN_SET);
63        break;
64      case 2:
```

```
65        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_11_Pin|
    LED7_33_Pin|LED7_44_Pin|LED7_66_Pin, GPIO_PIN_RESET);
66        HAL_GPIO_WritePin(GPIOB, LED7_22_Pin|LED7_55_Pin,
    GPIO_PIN_SET);
67        break;
68      case 3:
69        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_11_Pin|
    LED7_22_Pin|LED7_33_Pin|LED7_66_Pin, GPIO_PIN_RESET);
70        HAL_GPIO_WritePin(GPIOB, LED7_44_Pin|LED7_55_Pin,
    GPIO_PIN_SET);
71        break;
72      case 4:
73        HAL_GPIO_WritePin(GPIOB, LED7_11_Pin|LED7_22_Pin|
    LED7_55_Pin|LED7_66_Pin, GPIO_PIN_RESET);
74        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_33_Pin|
    LED7_44_Pin, GPIO_PIN_SET);
75        break;
76      case 5:
77        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_22_Pin|
    LED7_33_Pin|LED7_55_Pin|LED7_66_Pin, GPIO_PIN_RESET);
78        HAL_GPIO_WritePin(GPIOB, LED7_11_Pin|LED7_44_Pin,
    GPIO_PIN_SET);
79        break;
80      case 6:
81        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_22_Pin|
    LED7_33_Pin|LED7_44_Pin|LED7_55_Pin|LED7_66_Pin,
    GPIO_PIN_RESET);
82        HAL_GPIO_WritePin(GPIOB, LED7_11_Pin, GPIO_PIN_SET);
83        break;
84      case 7:
85        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_11_Pin|
    LED7_22_Pin, GPIO_PIN_RESET);
86        HAL_GPIO_WritePin(GPIOB, LED7_33_Pin|LED7_44_Pin|
    LED7_55_Pin|LED7_66_Pin, GPIO_PIN_SET);
87        break;
88      case 8:
89        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_11_Pin|
    LED7_22_Pin|LED7_33_Pin|LED7_44_Pin|LED7_55_Pin|
    LED7_66_Pin, GPIO_PIN_RESET);
90        break;
91      case 9:
92        HAL_GPIO_WritePin(GPIOB, LED7_00_Pin|LED7_11_Pin|
    LED7_22_Pin|LED7_33_Pin|LED7_55_Pin|LED7_66_Pin,
    GPIO_PIN_RESET);
93        HAL_GPIO_WritePin(GPIOB, LED7_44_Pin, GPIO_PIN_SET);
94        break;
95      }
96  }
97
```

```
98  // LED 7 SEG - MODE
99  // Display Mode LED
100 void update7SEG_MODE(int index, int value){
101   switch (index){
102   case 0:
103     // Display the first 7 SEG - MODE with value = 0
104     HAL_GPIO_WritePin(EN_MODE_00_GPIO_Port, EN_MODE_00_Pin,
      0);
105     HAL_GPIO_WritePin(EN_MODE_11_GPIO_Port, EN_MODE_11_Pin,
      1);
106     display7SEG_MODE(0);
107     break;
108   case 1:
109     // Display the second 7 SEG - MODE with value
    parameters
110     HAL_GPIO_WritePin(EN_MODE_00_GPIO_Port, EN_MODE_00_Pin,
      1);
111     HAL_GPIO_WritePin(EN_MODE_11_GPIO_Port, EN_MODE_11_Pin,
      0);
112     display7SEG_MODE(value);
113     break;
114   default:
115     break;
116   }
117 }
118
119 // LED 7 SEG - VALUE
120 // Display Value LED
121 void update7SEG_VALUE(int index, int value){
122   int donvi = value % 10;
123   int chuc = value / 10;
124   switch (index){
125   case 0:
126     // Display the first 7 SEG - MODE with value = 0
127     HAL_GPIO_WritePin(EN_VALUE_0_GPIO_Port, EN_VALUE_0_Pin,
      0);
128     HAL_GPIO_WritePin(EN_VALUE_1_GPIO_Port, EN_VALUE_1_Pin,
      1);
129     display7SEG_VALUE(chuc);
130     break;
131   case 1:
132     // Display the second 7 SEG - MODE with value
    parameters
133     HAL_GPIO_WritePin(EN_VALUE_0_GPIO_Port, EN_VALUE_0_Pin,
      1);
134     HAL_GPIO_WritePin(EN_VALUE_1_GPIO_Port, EN_VALUE_1_Pin,
      0);
135     display7SEG_VALUE(donvi);
136     break;
```

```
137   default:
138     break;
139   }
140 }
141 
142 // MODE_1 Normal
143 // Variable is initialized in global.c
144 void mode1_normal(){
145   if(counter == red_timer + green_timer + yellow_timer){
146     //Led 1 RED
147     display_1 = red_timer;
148     HAL_GPIO_WritePin(RED_1_GPIO_Port, RED_1_Pin,
    GPIO_PIN_RESET);
149     HAL_GPIO_WritePin(YELLOW_1_GPIO_Port, YELLOW_1_Pin,
    GPIO_PIN_SET);
150     HAL_GPIO_WritePin(GREEN_1_GPIO_Port, GREEN_1_Pin,
    GPIO_PIN_SET);
151     //Led 2 GREEN
152     display_2 = green_timer;
153     HAL_GPIO_WritePin(RED_2_GPIO_Port, RED_2_Pin,
    GPIO_PIN_SET);
154     HAL_GPIO_WritePin(YELLOW_2_GPIO_Port, YELLOW_2_Pin,
    GPIO_PIN_SET);
155     HAL_GPIO_WritePin(GREEN_2_GPIO_Port, GREEN_2_Pin,
    GPIO_PIN_RESET);
156   }
157   if(counter == (red_timer + yellow_timer)){
158     //Led 2 YELLOW
159     display_2 = yellow_timer;
160     HAL_GPIO_WritePin(RED_2_GPIO_Port, RED_2_Pin,
    GPIO_PIN_SET);
161     HAL_GPIO_WritePin(YELLOW_2_GPIO_Port, YELLOW_2_Pin,
    GPIO_PIN_RESET);
162     HAL_GPIO_WritePin(GREEN_2_GPIO_Port, GREEN_2_Pin,
    GPIO_PIN_SET);
163   }
164   if (counter == (yellow_timer + green_timer)){
165     //Led 1 GREEN
166     display_1 = green_timer;
167     HAL_GPIO_WritePin(RED_1_GPIO_Port, RED_1_Pin,
    GPIO_PIN_SET);
168     HAL_GPIO_WritePin(YELLOW_1_GPIO_Port, YELLOW_1_Pin,
    GPIO_PIN_SET);
169     HAL_GPIO_WritePin(GREEN_1_GPIO_Port, GREEN_1_Pin,
    GPIO_PIN_RESET);
170   }
171   if (counter == red_timer){
172     //Led 2 RED
173     display_2 = red_timer;
```

```
174     HAL_GPIO_WritePin(RED_2_GPIO_Port, RED_2_Pin,
    GPIO_PIN_RESET);
175     HAL_GPIO_WritePin(YELLOW_2_GPIO_Port, YELLOW_2_Pin,
    GPIO_PIN_SET);
176     HAL_GPIO_WritePin(GREEN_2_GPIO_Port, GREEN_2_Pin,
    GPIO_PIN_SET);
177   }
178   if (counter == yellow_timer){
179     //Led 1 YELLOW
180     display_1 = yellow_timer;
181     HAL_GPIO_WritePin(RED_1_GPIO_Port, RED_1_Pin,
    GPIO_PIN_SET);
182     HAL_GPIO_WritePin(YELLOW_1_GPIO_Port, YELLOW_1_Pin,
    GPIO_PIN_RESET);
183     HAL_GPIO_WritePin(GREEN_1_GPIO_Port, GREEN_1_Pin,
    GPIO_PIN_SET);
184   }
185   display7SEG_VALUE(display_1);
186   display7SEG_MODE(display_2);
187   display_1 --;
188   display_2 --;
189   counter--;
190   if(counter == 0)
191     counter = red_timer + green_timer + yellow_timer;
192 }
```

Program 1.13: Source code of led_display.c

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.

```
#ifndef INC_TIMER_H_
#define INC_TIMER_H_
void setTimer_MODE(int duration);
void setTimer_VALUE(int duration);
void setTimer_MODE1_NORMAL(int duration);
void timer_run();
void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
   ;
#endif /* INC_TIMER_H_ */
```

Program 1.14: Source code of timer.h

```
#include "main.h"
#include "input_reading.h"
#include "timer.h"
#include "global.h"

void setTimer_MODE(int duration){
  timer_MODE_counter = duration / TIMER_CYCLE;
  timer_MODE_flag = 0;
}

void setTimer_VALUE(int duration){
  timer_VALUE_counter = duration / TIMER_CYCLE;
  timer_VALUE_flag = 0;
}
void setTimer_MODE1_NORMAL(int duration){
  timer_MODE1_NORMAL_counter = duration / TIMER_CYCLE;
  timer_MODE1_NORMAL_flag = 0;
}
void timer_run(){
  if(timer_MODE_counter > 0){
    timer_MODE_counter --;
    if(timer_MODE_counter == 0) timer_MODE_flag = 1;
  }
  if(timer_VALUE_counter > 0){
    timer_VALUE_counter --;
    if(timer_VALUE_counter == 0) timer_VALUE_flag = 1;
  }
  if(timer_MODE1_NORMAL_counter > 0){
    timer_MODE1_NORMAL_counter --;
```

```
30      if(timer_MODE1_NORMAL_counter == 0)
        timer_MODE1_NORMAL_flag = 1;
31    }
32  }
33
34  void HAL_TIM_PeriodElapsedCallback(TIM_HandleTypeDef *htim)
35  {
36    if(htim->Instance == TIM2){
37      button_reading();
38    }
39    timer_run();
40  }
```

Program 1.15: Source code of timer.c

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.

```
#ifndef INC_INPUT_READING_H_
#define INC_INPUT_READING_H_
void button_reading(void);
void clear_button();
unsigned char is_button_pressed(unsigned char index);
unsigned char is_button_pressed_1s(unsigned char index);
#endif /* INC_INPUT_READING_H_ */
```

Program 1.16: Souce code of input_reading.h

```
#include "main.h"
#include "input_reading.h"
//we aim to work with more than one buttons
#define NO_OF_BUTTONS                3
// i = 0 => BUTTON_1; i = 1 => BUTTON_2; i = 2 => BUTTON_3;
#define BUTTON_IS_PRESSED                GPIO_PIN_RESET
#define BUTTON_IS_RELEASED               GPIO_PIN_SET
//the buffer that the final result is stored after
//debouncing
static GPIO_PinState buttonBuffer[NO_OF_BUTTONS];
//we define two buffers for debouncing
static GPIO_PinState debounceButtonBuffer1[NO_OF_BUTTONS];
static GPIO_PinState debounceButtonBuffer2[NO_OF_BUTTONS];

void clear_button(){
  for(char i = 0; i < NO_OF_BUTTONS; i ++){
    debounceButtonBuffer1[i] = GPIO_PIN_SET; //No press
    debounceButtonBuffer2[i] = GPIO_PIN_SET; //No press
    buttonBuffer[i] = GPIO_PIN_SET; //No press
  }
  HAL_GPIO_WritePin(BUTTON_1_GPIO_Port, BUTTON_1_Pin, 1);
  HAL_GPIO_WritePin(BUTTON_2_GPIO_Port, BUTTON_2_Pin, 1);
  HAL_GPIO_WritePin(BUTTON_3_GPIO_Port, BUTTON_3_Pin, 1);
}
void button_reading(void){
  for(char i = 0; i < NO_OF_BUTTONS; i ++){
    debounceButtonBuffer2[i] = debounceButtonBuffer1[i];
    //Catch signal every time the corresponding button is
   pressed
    if(i == 0)
```

```
30        debounceButtonBuffer1[i] = HAL_GPIO_ReadPin(
    BUTTON_1_GPIO_Port, BUTTON_1_Pin);
31      else if (i == 1)
32        debounceButtonBuffer1[i] = HAL_GPIO_ReadPin(
    BUTTON_2_GPIO_Port, BUTTON_2_Pin);
33      else if (i == 2)
34        debounceButtonBuffer1[i] = HAL_GPIO_ReadPin(
    BUTTON_3_GPIO_Port, BUTTON_3_Pin);
35      if(debounceButtonBuffer1[i] == debounceButtonBuffer2[i
    ])
36        buttonBuffer[i] = debounceButtonBuffer1[i];
37    }
38  }
39
40  unsigned char is_button_pressed(uint8_t index){
41    if(index >= NO_OF_BUTTONS) return 0;
42    return (buttonBuffer[index] == BUTTON_IS_PRESSED);
43  }
```

Program 1.17: Source code of input_reading.c

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.

```
void fsm_for_input_processing(void){
  switch(buttonState){
    case STATE_1:
       // Display the traffic light application is running normally
      if(timer_MODE1_NORMAL_flag == 1){
        mode1_normal();
      }
      // When button 1 is pressed, go to the next state
      if(is_button_pressed(PRESS_BUTTON_1) && timer_MODE_flag == 1){
        clearLED();
        buttonState = STATE_2;
        red_temp = red_timer;
      }
      break;
    case STATE_2:
      // Display 2 red LEDS, LED7-SEG for mode and LED7_SEG for value
      HAL_GPIO_WritePin(GPIOA, RED_1_Pin|RED_2_Pin, GPIO_PIN_RESET);
      if(timer_MODE_flag == 1){
        update7SEG_VALUE(index_mode, red_temp);
        update7SEG_MODE(index_mode, 2);
        index_mode++;
      }
      // When button 1 is pressed, go to the next state
      if(is_button_pressed(PRESS_BUTTON_1) && timer_MODE_flag == 1){
        clearLED();
        buttonState = STATE_3;
        yellow_temp = yellow_timer;
      }
      break;
    case STATE_3:
      // Display 2 yellow LEDS, LED7-SEG for mode and LED7_SEG for value
      HAL_GPIO_WritePin(GPIOA, YELLOW_1_Pin|YELLOW_2_Pin, GPIO_PIN_RESET);
      if(timer_MODE_flag == 1){
        update7SEG_VALUE(index_mode, yellow_temp);
        update7SEG_MODE(index_mode, 3);
```

```
36          index_mode++;
37        }
38        // When button 1 is pressed, go to the next state
39        if(is_button_pressed(PRESS_BUTTON_1) &&
    timer_MODE_flag == 1){
40          clearLED();
41          buttonState = STATE_4;
42          green_temp = green_timer;
43        }
44        break;
45      case STATE_4:
46        // Display 2 green LEDS, LED7-SEG for mode and
    LED7_SEG for value
47        HAL_GPIO_WritePin(GPIOA, GREEN_1_Pin|GREEN_2_Pin,
    GPIO_PIN_RESET);
48        if(timer_MODE_flag == 1){
49          update7SEG_VALUE(index_mode, green_temp);
50          update7SEG_MODE(index_mode, 4);
51          index_mode++;
52        }
53        // When button 1 is pressed, go to the next state
54        if(is_button_pressed(PRESS_BUTTON_1) &&
    timer_MODE1_NORMAL_flag == 1){
55          clearLED();
56          buttonState = STATE_1;
57        }
58        break;
59      default:
60        break;
61    }
```

Program 1.18: Code for display mode and blinking LEDS depending on the mode 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.

```
// When button 2 is pressed, red light value temporarily
   increased by 1 in a range of 1-99
if(is_button_pressed(PRESS_BUTTON_2) && timer_MODE_flag ==
   1){
  red_temp += 1;
}
// When button 3 is pressed, set temporary red light value
   to red light value
if(is_button_pressed(PRESS_BUTTON_3) && timer_MODE_flag ==
   1){
  red_timer = red_temp;
}
```

Program 1.19: Source code for use second button and third button for the red LEDS

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.

```
// When button 2 is pressed, yellow light value temporarily
    increased by 1 in a range of 1-99
if(is_button_pressed(PRESS_BUTTON_2) && timer_MODE_flag ==
   1){
  yellow_temp += 1;
}
// When button 3 is pressed, set temporary yellow light
   value to yellow light value
if(is_button_pressed(PRESS_BUTTON_3) && timer_MODE_flag ==
   1){
  yellow_timer = yellow_temp;
}
```

Program 1.20: Source code for use second button and third button for the yellow LEDS

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.

```
// When button 2 is pressed, green light value temporarily
   increased by 1 in a range of 1-99
if(is_button_pressed(PRESS_BUTTON_2) && timer_MODE_flag ==
   1){
  green_temp += 1;
}
// When button 3 is pressed, set temporary green light
   value to green light value
if(is_button_pressed(PRESS_BUTTON_3) && timer_MODE_flag ==
   1){
  green_timer = green_temp;
}
```

Program 1.21: Source code for use second button and third button for the green LEDS

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

```
#ifndef INC_INPUT_PROCESSING_H_
#define INC_INPUT_PROCESSING_H_

void fsm_for_input_processing(void);

#endif /* INC_INPUT_PROCESSING_H_ */
```

Program 1.22: Source code of input_processing.h

```
#include "main.h"
#include "input_reading.h"
#include "input_processing.h"
#include "timer.h"
#include "led_display.h"
#include "global.h"
enum ButtonState{STATE_1=0, STATE_2=1, STATE_3=2, STATE_4
   =3} ;
enum ButtonState buttonState = STATE_1;
enum ButtonIndex{PRESS_BUTTON_1 = 0, PRESS_BUTTON_2=1,
   PRESS_BUTTON_3=2};

void fsm_for_input_processing(void){
  switch(buttonState){
    case STATE_1:
       // Display the traffic light application is running
   normally
      if(timer_MODE1_NORMAL_flag == 1){
        mode1_normal();
      }
      // When button 1 is pressed, go to the next state
      if(is_button_pressed(PRESS_BUTTON_1) &&
   timer_MODE_flag == 1){
        clearLED();
        buttonState = STATE_2;
        red_temp = red_timer;
      }
      break;
    case STATE_2:
      // Display 2 red LEDS, LED7-SEG for mode and LED7_SEG
    for value
```

```
27      HAL_GPIO_WritePin(GPIOA, RED_1_Pin|RED_2_Pin,
    GPIO_PIN_RESET);
28      if(timer_MODE_flag == 1){
29        update7SEG_VALUE(index_mode, red_temp);
30        update7SEG_MODE(index_mode, 2);
31        index_mode++;
32      }
33      // When button 2 is pressed, red light value
    temporarily increased by 1 in a range of 1-99
34      if(is_button_pressed(PRESS_BUTTON_2) &&
    timer_MODE_flag == 1){
35        red_temp += 1;
36      }
37      // When button 3 is pressed, set temporary red light
    value to red light value
38      if(is_button_pressed(PRESS_BUTTON_3) &&
    timer_MODE_flag == 1){
39        red_timer = red_temp;
40      }
41      // When button 1 is pressed, go to the next state
42      if(is_button_pressed(PRESS_BUTTON_1) &&
    timer_MODE_flag == 1){
43        clearLED();
44        buttonState = STATE_3;
45        yellow_temp = yellow_timer;
46      }
47      break;
48    case STATE_3:
49      // Display 2 yellow LEDS, LED7-SEG for mode and
    LED7_SEG for value
50      HAL_GPIO_WritePin(GPIOA, YELLOW_1_Pin|YELLOW_2_Pin,
    GPIO_PIN_RESET);
51      if(timer_MODE_flag == 1){
52        update7SEG_VALUE(index_mode, yellow_temp);
53        update7SEG_MODE(index_mode, 3);
54        index_mode++;
55      }
56      // When button 2 is pressed, yellow light value
    temporarily increased by 1 in a range of 1-99
57      if(is_button_pressed(PRESS_BUTTON_2) &&
    timer_MODE_flag == 1){
58        yellow_temp += 1;
59      }
60      // When button 3 is pressed, set temporary yellow
    light value to yellow light value
61      if(is_button_pressed(PRESS_BUTTON_3) &&
    timer_MODE_flag == 1){
62        yellow_timer = yellow_temp;
63      }
```

```
64        // When button 1 is pressed, go to the next state
65        if(is_button_pressed(PRESS_BUTTON_1) &&
    timer_MODE_flag == 1){
66          clearLED();
67          buttonState = STATE_4;
68          green_temp = green_timer;
69        }
70        break;
71      case STATE_4:
72        // Display 2 green LEDS, LED7-SEG for mode and
    LED7_SEG for value
73        HAL_GPIO_WritePin(GPIOA, GREEN_1_Pin|GREEN_2_Pin,
    GPIO_PIN_RESET);
74        if(timer_MODE_flag == 1){
75          update7SEG_VALUE(index_mode, green_temp);
76          update7SEG_MODE(index_mode, 4);
77          index_mode++;
78        }
79        // When button 2 is pressed, green light value
    temporarily increased by 1 in a range of 1-99
80        if(is_button_pressed(PRESS_BUTTON_2) &&
    timer_MODE_flag == 1){
81          green_temp += 1;
82        }
83        // When button 3 is pressed, set temporary green
    light value to green light value
84        if(is_button_pressed(PRESS_BUTTON_3) &&
    timer_MODE_flag == 1){
85          green_timer = green_temp;
86        }
87        // When button 1 is pressed, go to the next state
88        if(is_button_pressed(PRESS_BUTTON_1) &&
    timer_MODE1_NORMAL_flag == 1){
89          clearLED();
90          buttonState = STATE_1;
91        }
92        break;
93      default:
94        break;
95    }
96  }
```

Program 1.23: Source code of input_processing.c

```
1  initialize_variable();
2  clear_button();
3  clearLED();
4  setTimer_MODE(10);
5  setTimer_VALUE(10);
6  setTimer_MODE1_NORMAL(10);
```

```
while (1)
{
//you only need to add the fsm function here
fsm_for_input_processing();
if(timer_MODE_flag == 1){
  setTimer_MODE(500);
  if(index_mode >= 2)
    index_mode = 0;
}
if(timer_MODE1_NORMAL_flag == 1){
  setTimer_MODE1_NORMAL(1000);
}
}
```

Program 1.24: Soucece code of main.c

Link video demo: https://youtu.be/oVnxzZxzavY