Exclusive Tutorial for

MSP430 Development Board (MSP-EXP430G2)

This e-book contains all the necessary information for everyone that is interested in learning C programming to control variety of cool stuff and do awesome works. Suitable for beginners.

Brought to you by:
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About the Author

Good day everyone!!

I am Hunter K, the author of this e-book. Thank you for downloading this e-book and please feel free to email me if you have any concern regarding this e-book.

If you never heard of MSP430 Launchpad or its microcontroller, this e-book suits you perfectly. For more projects, you can visit my blog – Embedded Project Hunter (EPH) blog at www.embeddedprojecthunter.com.

This book is free because I think that knowledge should be shared. Behind the scene, I have put a lot of effort in making sure this e-book can be completed and try to explain the codes as detail as possible. If you think that I deserve a cup of coffee, you are more than welcome to donate by PayPal.

Feel free to share this e-book, and hope that you enjoy reading!!

Sincerely,
Hunter K.

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Table of Content

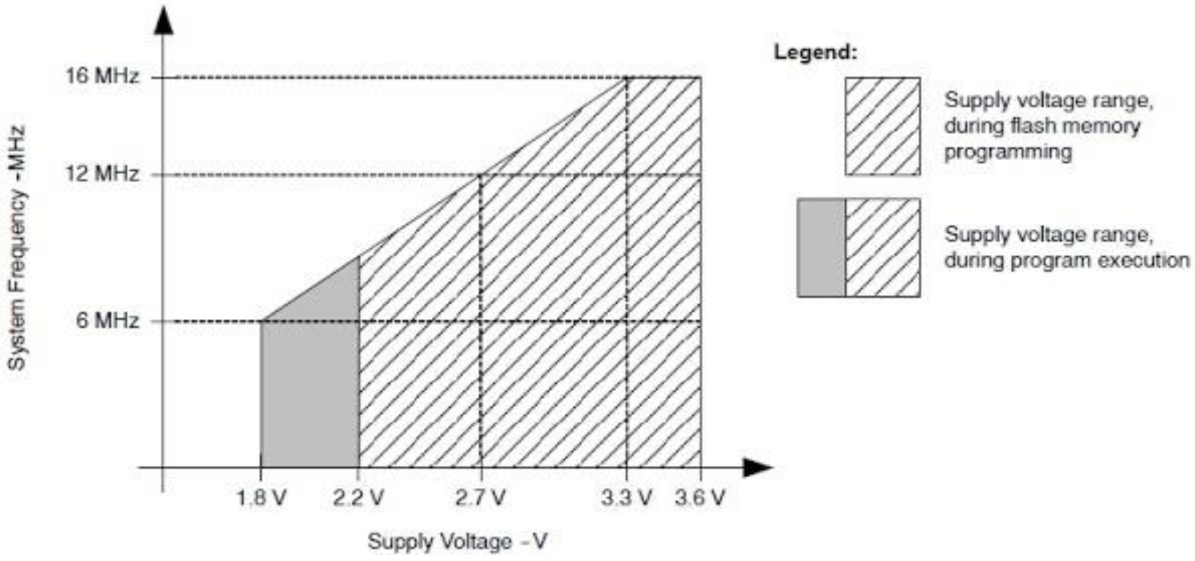
CHAPTER 1- WELCOME ABOARD

This Chapter will cover the introduction to MSP-EXP430G2, LED & Button Programming, Concept of Pull-up & Pull-down Resistor, Debouncing, Important Coding Syntax, and Digital Operation.

"When you affirm big, believe big, and pray big, big things happen."

-Norman Vincent Peale-

1.0 Introduction



1. In MSP430 Value Line LaunchPad Development Tool, there is:
   (i) **10 GPIO in a 14-pin MCU**
   (ii) **16 GPIO in a 20-pin MCU**.
2. GPIO = **G**eneral **P**ort **I**nput **O**utput
3. What you want to program is the MCU (the chip)?

   INPUT → MCU → OUTPUT

4. MSP430G2211/MSP430G2231/MSP430G2452/MSP430G2553 is some common microcontroller chips used. MSP430G2553 is the best in term of FLASH and RAM size.
5. The MSP430 will run with anywhere between 1.8 V and 3.6 V, though at least 2.2 V is needed to do any programming to the chip. Keep in mind that the speed at which the chip is able to run also depends on the voltage; though it's capable of running up to 16 MHz, at 1.8 V an MSP430 cannot run any faster than 6 MHz.

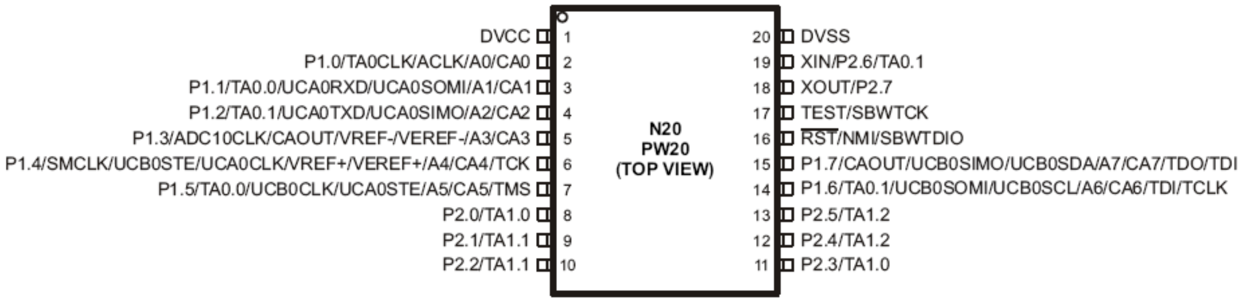


Figure showing 20-pin MCU configuration –

eg. MSP430G2553 or MSP430G2452

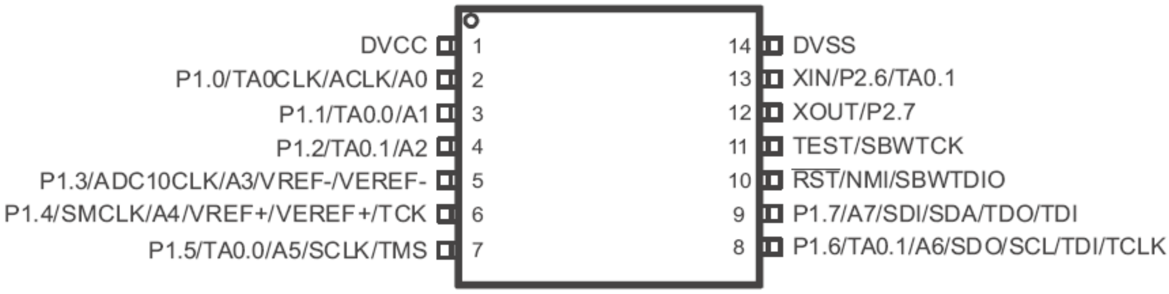


Figure showing 14-pin MCU configuration –

eg. MSP430G2211 or MSP430G2231

SOFTWARE TO PROGRAM MSP430 LAUNCHPAD

1. **IAR Embedded Workbench Kickstart**
   a. The free version is limited to 4 kb code size
   b. Another possibility is a 30-day Evaluation version that has no limitation.
2. **Code Composer Studio**
   a. TI's own MSP430 development suite.
   b. Free version is limited to 16 kb code size.
3. **Energia**
   a. Easy to use. Arduino-compatible.

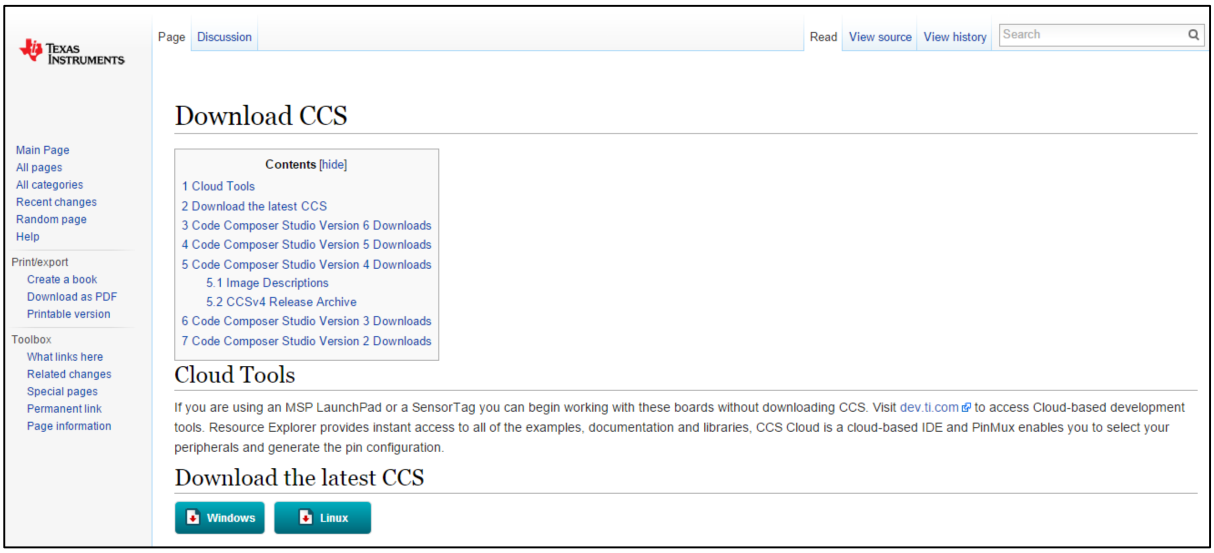
Note: Code Composer Studio will be used in this e-book because the software is more powerful, and equipped with tools to troubleshoot the codes.

1.1 Start Programming

"I hear and I forget; I see and I remember; I do and I understand."
- Old Chinese Proverb-

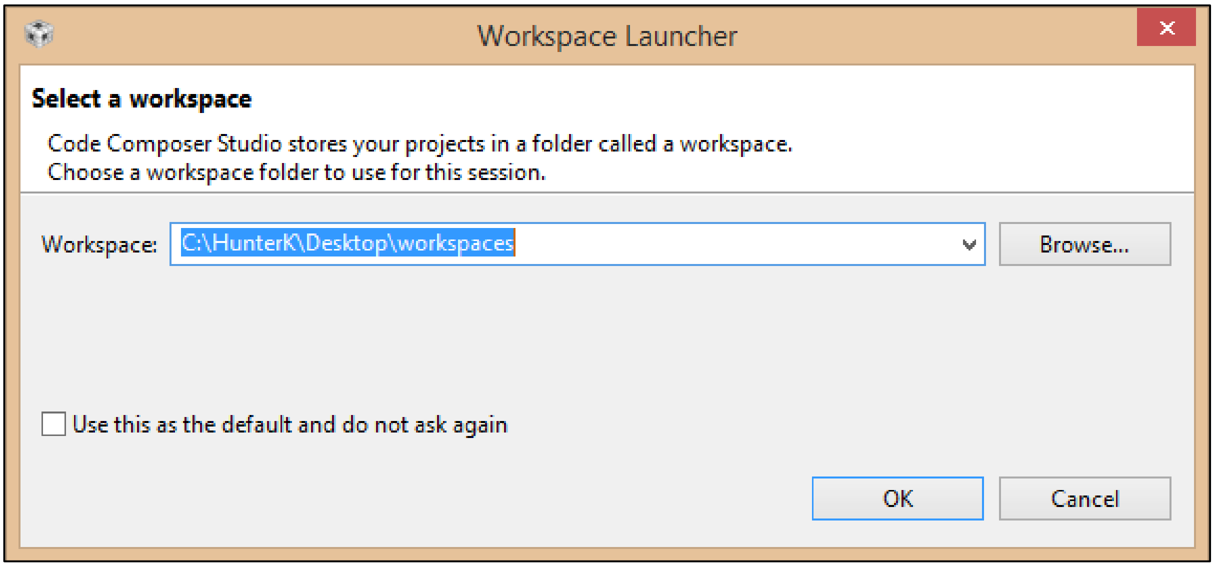
It is always more efficient for you to move your hand, and code the MSP430 chips by yourself. If you haven't buy the development board, you can buy at TI store or from any other reseller or distributor.

To download the software (Code Composer Studio), go to TI Wiki. Click to download the latest CCS. Currently the software is supported only in Windows and Linux.

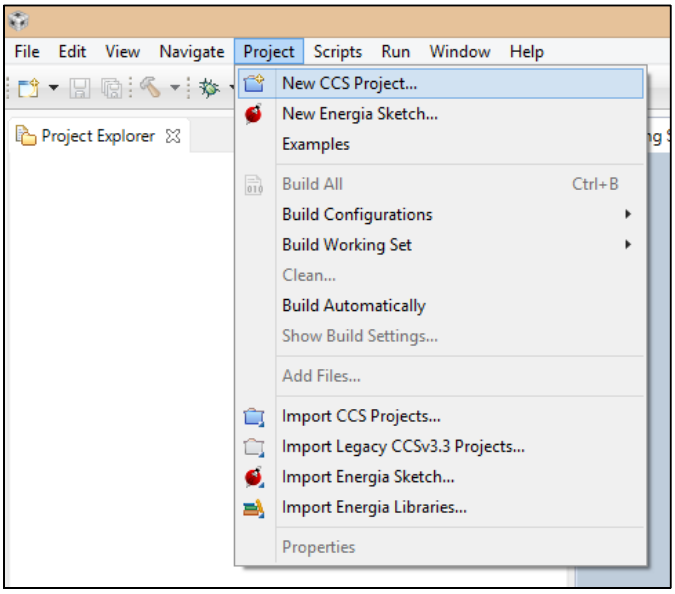


To install CCS, simply follow the instruction on the GUI after you clicking the installation file you downloaded. It should not be any problem installing the software.

After installing CCS, double-click the CCS icon. The "Workspace Launcher" shown below will appear.



I like to create my workspace (which is the folder where all the programming codes and necessary files saved) in the Desktop. You can save your workspace in any other directory. Click "OK" after you have define the directory for workspace. CCS main interface will pop-up after taking some time to setup.



Now, click on "Project" → "New CCS Project…", then, "New CCS Project" window will be shown.

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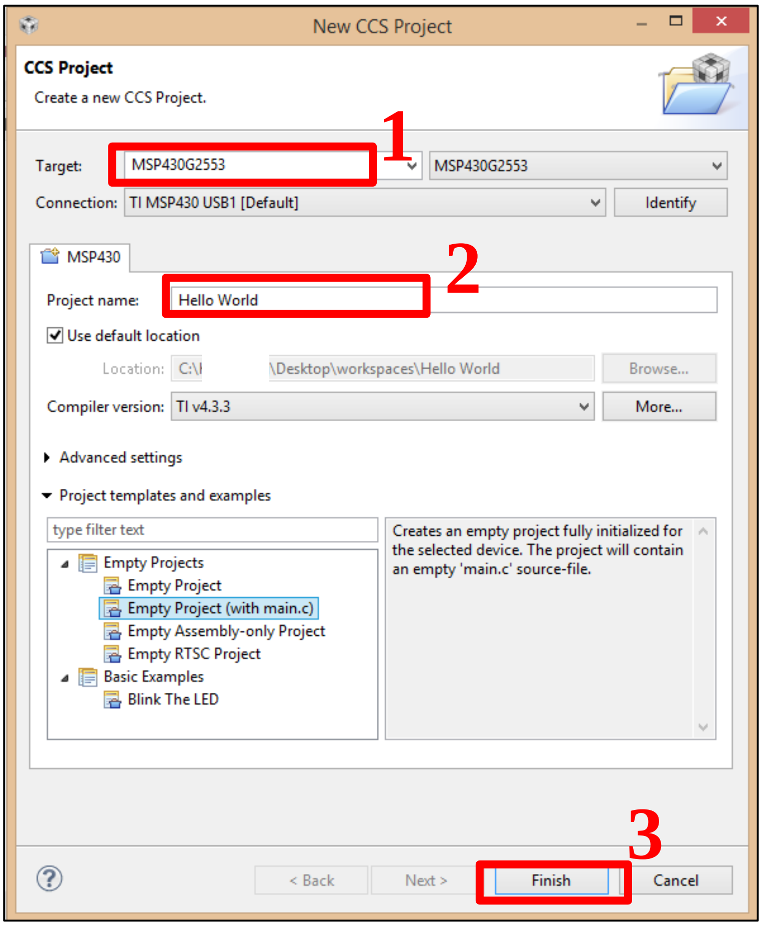


__Step 1:__

In the Target tab, key-in the chip number that you plan to use. If you are unsure, check the chip label.

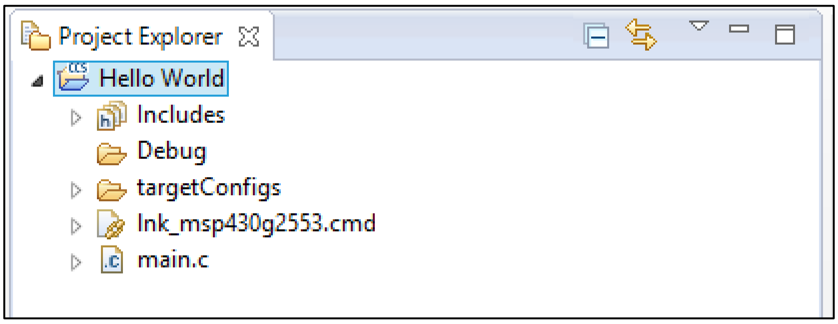
__Step 2:__

Name your project so that you can identify and access your project next time.

__Step 3:__

Click the "Finish" button to complete the setup.

If your steps are all correct, then your project files should be visible at the Project Explorer Window:

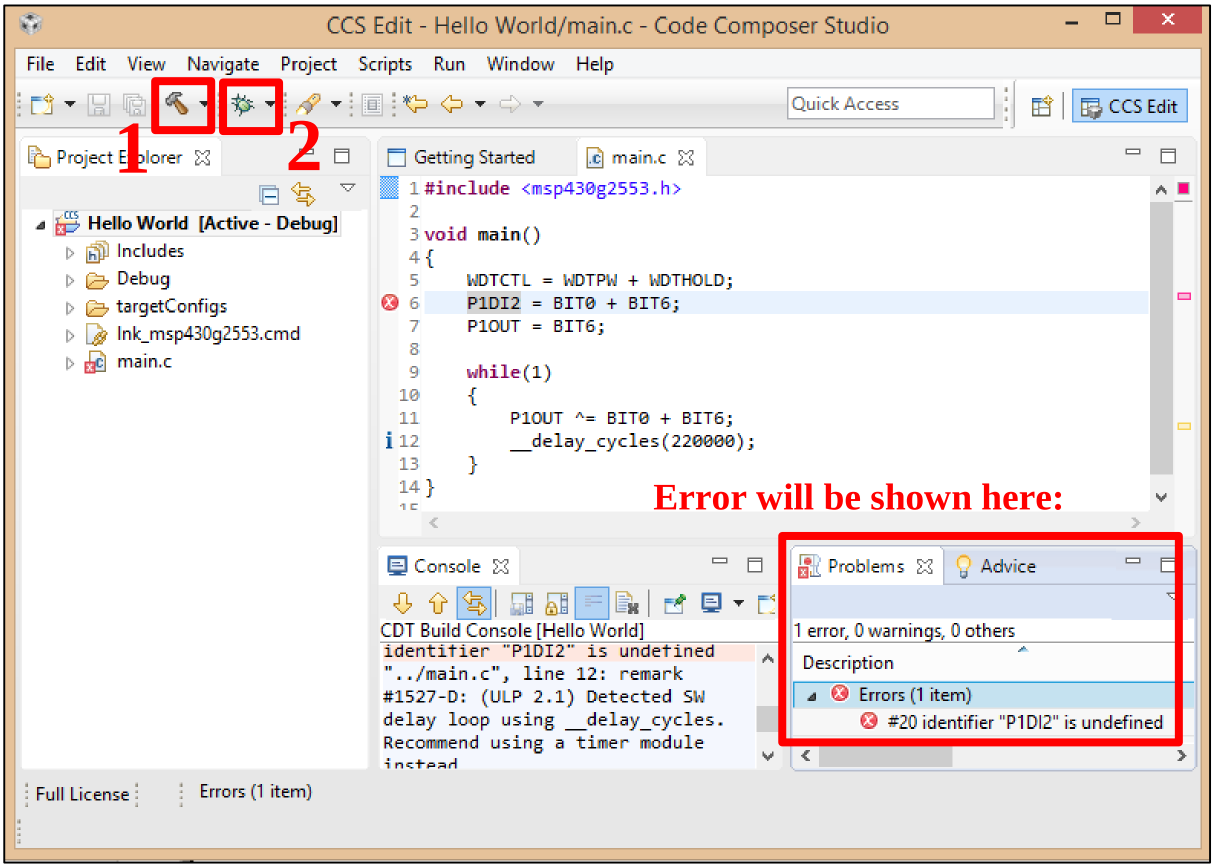


The main programming code that we will learn later on will be created and amended in the main.c file. Note that the .c extension indicates that we are using C language. We can however, program the chip using assembly language. But it will not be covered in this e-book.

1.1.0 Simple LED Programming

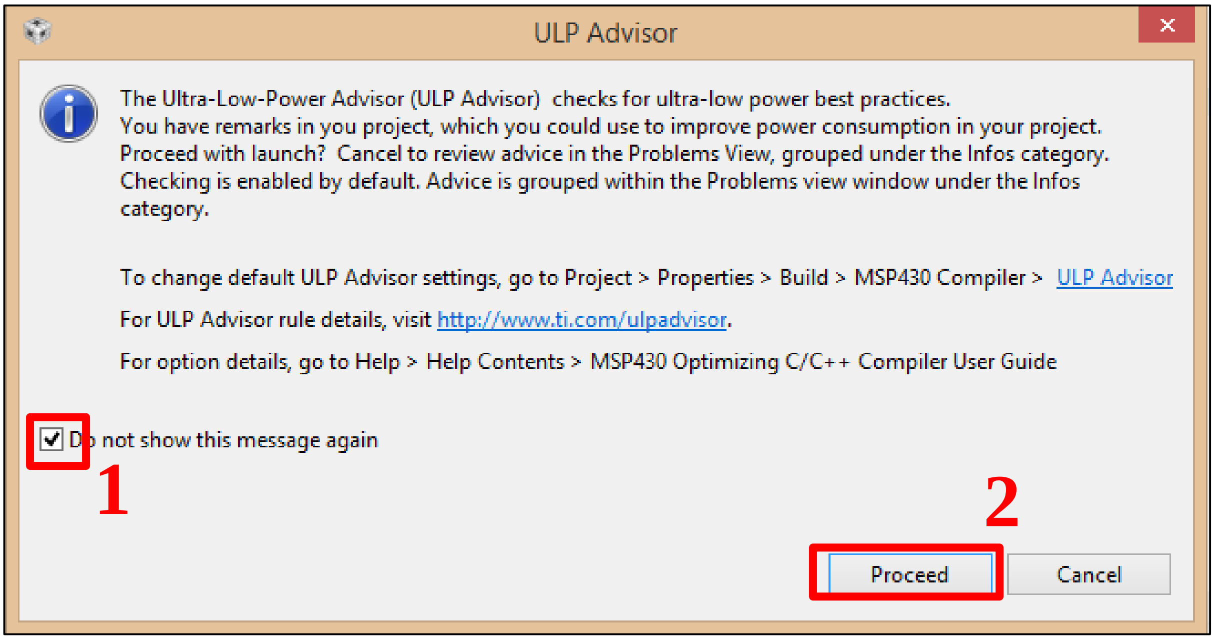
```c
#include <msp430g2553.h>

void main()
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR = BIT0 + BIT6;
	P1OUT = BIT6;

	while(1)
	{
		P1OUT ^= BIT0 + BIT6;
		__delay_cycles(220000);
	}
}
```

You may copy the code above, and paste it into main.c file.

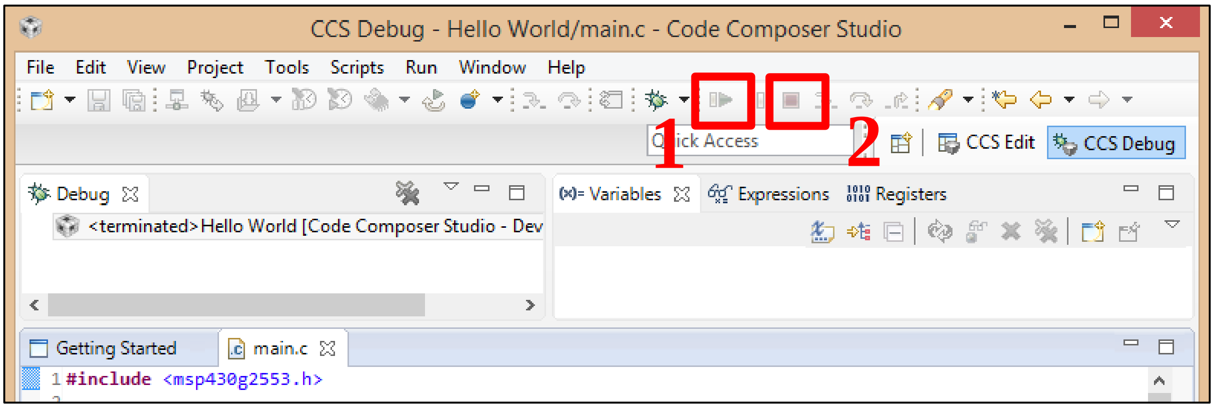


Then click on the "Build" button (which is the Hammer icon). This will build your code and check for errors. If there is error in the code, then it will be shown in the "Problems" tab. In this case, I should change P1DI2 to P1DIR in line 6.

After that, click on the “Debug” button (which is the Bug icon). This will debug and program the code into the chip.



“ULP Advisor” window will pop-up. It will checks for ultra-low power best practices and suggest to you when you program. Nonetheless, if you are not planning on low power application, then this shall not bother you. Simply tick “Do not show this message again”, and click “Proceed”. The graphical user interface (GUI) will changed to debug perspective, as shown below:



Click on the “Resume” button, to run the codes on the chip. Then click “Terminate” button, to stop the debug mode and changed back to edit perspective. Now your LED should be blinking alternately. If so, congratulation!!

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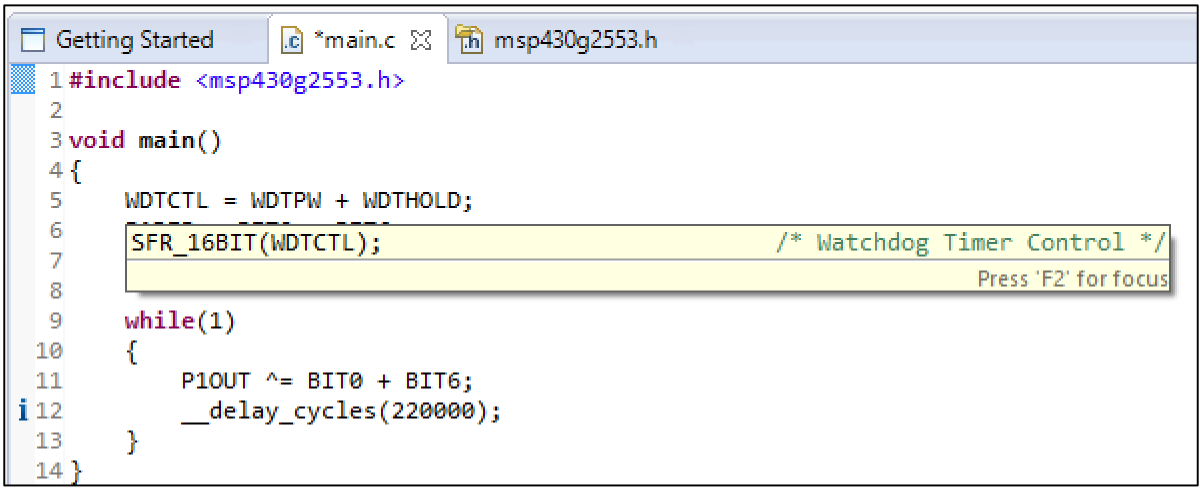
Code Explanation:

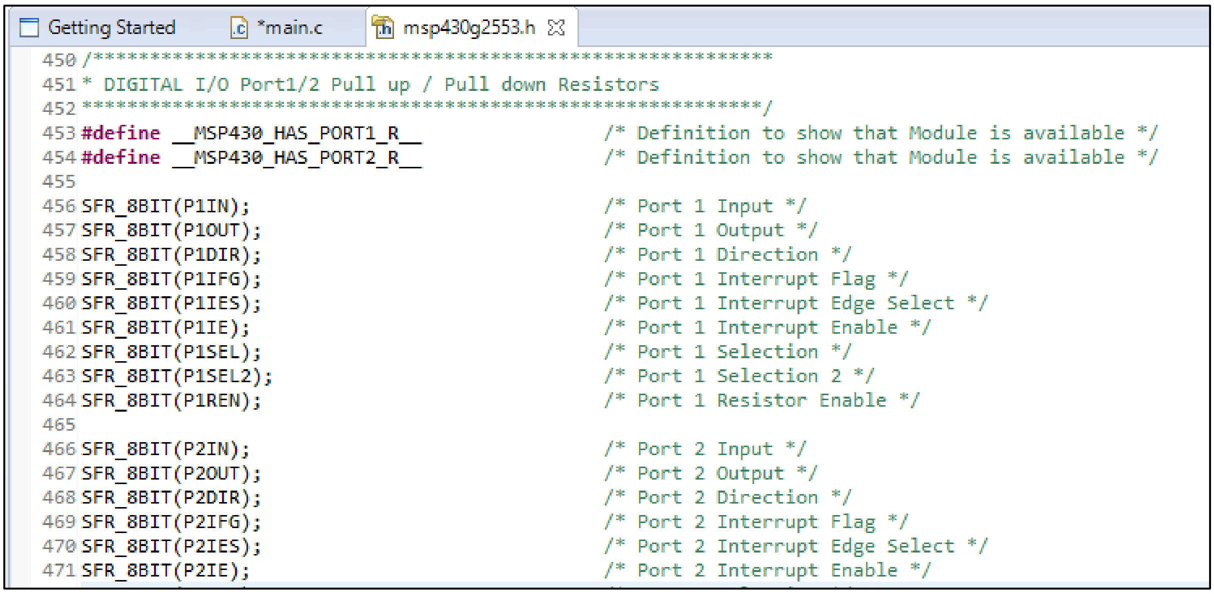
Code:	**Explanation:**
`#include <msp430g2553.h>`	Since you are using MSP430G2553 chip, then you should include all the standard register and bit definition for the microcontroller. The .h extension indicates that this is the header file for the chip.
`void main()`	All the main codes are written in side main(). This is the standard format for C Language. You may learn more in C Language text books or webpage.
`WDTCTL = WDTPW + WDTHOLD;`	Watchdog Timer control. This line is necessary every time you program your chip if you are not using the watchdog timer to prevent your chip from restarting.
`P1DIR = BIT0 + BIT6;`	P**1**DIR ➔ Port 1 Direction This line simply set BIT0 and BIT6 to be your output. Since you are programming port 1 in this case, then BIT0 and BIT6 here is referring to P1.0 and P1.6 of the chip. If you still unsure where is this pins located, kindly look at the development board (RED colour board). All the pins are labelled. *According to the datasheet, P1.0 and P1.6 are connected to the red and green LED respectively*. Therefore the LED will blink based on your programming.
`P1OUT = BIT6;`	P**1**OUT ➔ Port 1 Output This line simply turn on P1.6 and thus giving instruction to the pin to produce 3.6 V as output.
`while(1)`	C Language, while loop is normally used to run the code inside the loop infinitely until you switch off the power.
`P1OUT ^= BIT0 + BIT6;`	P**1**OUT ➔ Port 1 Output Set the output of the pins. Note the “^” sign. It basically means toggle, changing 0 to 1 and 1 to 0. If the LED is turned on previously, then it will be off now, and vice versa,
`__delay_cycles(220000);`	Delay 220000 cycles. By default, one cycle need roughly 0.9 us to execute. Thus, approximate delay timing will be: 220000 cycles x 0.9us per cycle = 0.2 s delay

Tips:

You might wonder is there any "shortcut" to learn the programming. Well, of course there is. I am going to show you some useful tips in programming the chip. If you are unsure what WDTCTL stands for, simply move your mouse pointer to the word and wait for few second. The description will be shown just like below. Thus, we know that WDTCTL stands for Watchdog Timer Control without really memorising the datasheet.



If you wish to understand more about the specific code, simply press "CTRL" while clicking on the respective code. It will bring you to the header file and show you where it located in the library.



1.1.1 Simple Button Programming

```c
#include <msp430g2553.h>

void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR = BIT0;
	P1REN = BIT3;
	P1OUT = BIT3;
	while(1)
	{
		if((P1IN & BIT3)!=BIT3)
		{
			__delay_cycles(220000);
			P1OUT ^= BIT0;
		}
	}
}
```

If you look at the MSP430 Development Board, there is two buttons on the board. The left button is user-programmable button, while the right button is RESET button. We can use the left button for variety of applications. In this example, we will demonstrate the usability of the left button. Simply copy the code above and paste in main.c. Repeat the steps for the first programming where you build and debug the codes.

The left button is connected to P1.3 of the chip. Therefore, by programming P1.3 pin, the button can be controlled. In this case, there will be both input and output. The button will be the input while the LED will be the output.

BUTTON **(INPUT)** → MSP430 CHIP (BRAIN) → LED **(OUTPUT)**

Expected Output:

When you click on the LEFT button, the RED LED will toggle. In other words, the state of the LED will be changed by pressing the button.

Code Explanation:

Code:	**Explanation:**
`P1DIR = BIT0;`	P**1**DIR ➔ Port 1 Direction This line of code simply make P1.0 as the output pin. So what happen to the other unassigned pin such as P1.1, P1.2 and so on? Well, it will automatically assigned as input. Thus, in this case, P1.3 is auto-assigned as input too.
`P1REN = BIT3;`	P**1**REN ➔ Port 1 Resistor Enable P1.3 is connected to the button. In order to make the button work, we have to add pull-up resistor to make it normally high. By writing this line, internal resistor (inside the chip) will be enabled, connecting P1.3 to the power supply (3.6V) or ground (0V). This is defined in next line. The details on the working principle of button will be discussed in next session.
`P1OUT = BIT3;`	P**1**OUT ➔ Port 1 Output Although P1OUT means setting the output state. But, if we analyse carefully, P1.3 is an input pin, and it is quite not logical to assign the pin any output state. In fact, this line of code define the connectivity of the internal resistor. If P1OUT = BIT3, then the internal resistor is connected to 3.6V. In other words, the pin now is normally high, and the internal resistor is known as pull-up resistor. Else, if P1OUT &= ~BIT3, then the internal resistor is connected to ground, and it is known as pull-down resistor. Details will be discussed in later session.
`if((P1IN & BIT3)!=BIT3)`	P1IN and BIT3 are compared. If you studied digital systems, you will know what is AND logic.

P1IN	BIT3	Output of (P1IN & BIT3)
0	0	0
0	1	0
1	0	0
1	1	1

P1IN depends on the input logic state (keep changing depends on whether you are pressing the button). If you press the button, then P1IN = 0. By default, P1IN will be 1.

P1.3 will be always 1 because it is internally connected to the pull-up resistor. Leaving only two possible conditions (highlighted in YELLOW).

If ((P1IN & BIT3) != BIT3)

"!" in this case indicates NOT. In words, this line of code means if the result of port 1 input AND P1.3 pin (ONE) is not equal to P1.3 (ONE), then it will execute the codes inside the loop.

When the button is pressed, P1IN =0, which is the second case, fulfilling the condition that (P1IN & BIT3) is not equal to 1 (which is zero). Thus, executing the code in the bracket.

Note:

It might seem difficult to understand the logic behind at first glance. But, after you read through this e-book and try more example, everything will be a lot easier. The details on the LOGIC and the symbol used such as ^, !, and etc will be discussed in the later session. On the other hand, if you are observant enough, you will notice that the LED will keep blinking when you press the button for longer period. This is not good for some cases. Thus, there is another method on programming the button – Interrupt, which is much more efficient.

1.1.2 Button Programming with Interrupt

```
#include <msp430g2553.h>

void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR = BIT6;
	P1REN = BIT3;
	P1OUT = BIT3;
	P1IE = BIT3;
	__enable_interrupt();
	while(1){  }
}

#pragma vector=PORT1_VECTOR
__interrupt void Port_1(void)
{
	__delay_cycles(500000);
	P1OUT ^= BIT6;
	P1IFG = ~BIT3;
}
```

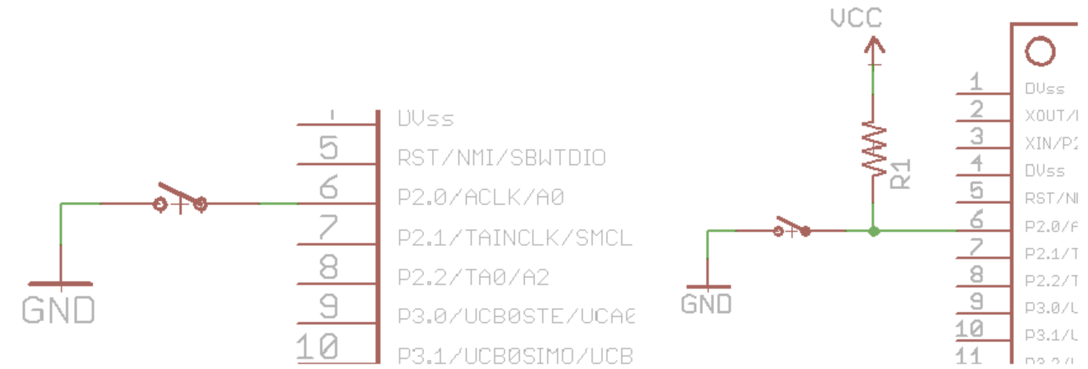
In this example, a better and more stable programming code is demonstrated. GREEN LED is used instead of RED LED as compared to previous example. Note that there is another function introduced, which is the Port_1(void). "void" means nothing.

Code Explanation:

Code:	Explanation:
`P1IE = BIT3;`	P**1**IE ➔ Port 1 Interrupt Enable This line of code simply make P1.3 as an interrupt pin. Any changes of this pin will trigger the interrupt.
`__enable_interrupt();`	Even though P1.3 is interrupt-enabled, but the interrupt algorithm is not initialized yet. This line will enable the interrupt in the codes.
`#pragma vector=PORT1_VECTOR __interrupt void Port_1(void)`	PORT1_VECTOR indicates the interrupt vector that we use, which is Port 1, since P1.3 is in Port

	1. Whenever interrupt is triggered, the codes inside this function will be executed. However, the good thing about this method is that, if you press the button for long period, the LED will only change its state once. This is because the algorithm used now is different. It detect the changes of P1.3 rather running the codes in polling method. The code inside the interrupt function will only be executed once changes is detected.
`P1IFG = ~BIT3;`	P1IFG ➔ Port 1 Interrupt Flag Disable interrupt flag. Interrupt flag will be raised when changes detected in the interrupt pin. When the flag is raised, the interrupt pin is temporarily disabled. The interrupt function will be re-enabled only when the interrupt flag is down (disabled).

1.2 What is Pull-Up and Pull-Down Resistor?



(a) No Pullup Resistor (b) External Pullup Resistor

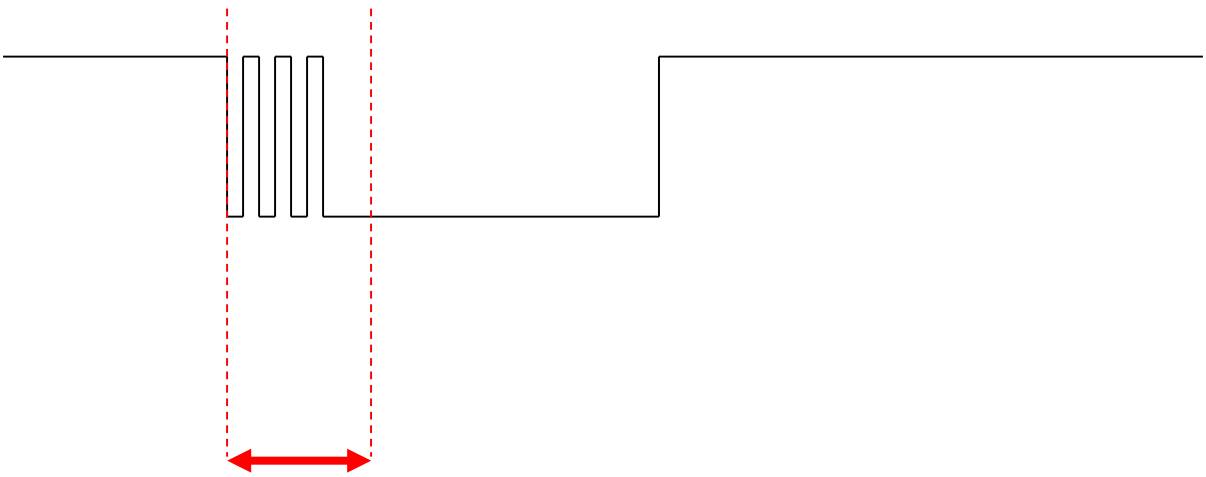
Let's think a bit about what happens when the system is powered up. Here, the switch is normally open and the P2.0 is left floating and this is very bad. When the switch is pressed, P2.0 is connected to ground. There is no clear voltage transition because the initial condition is floating. Similar designs have been used by many newcomers and should be avoided. A design such as that is possible if there is an internal pull-up resistor.

Let's analyze the second case (b), where the designer included an external pull-up resistor. Here, the switch is also open initially, but P2.0 is connected to VCC through the resistor. The resistor limits the current significantly (considering a resistor with 100k or so). When the user presses the switch, one end of the resistor and P2.0 get connected to ground. P2.0 experiences a transition from high to low. The resistor has current flowing through it and although it is wasted as heat, it is very small and lasts for only a few moments for the duration of the switch press.

Many microcontrollers include internal pull-up or even pull-down, which free the designer from having to include them. In this case, simply connect the button to either VCC or GND and it should work.

1.3 Debounce… Bounce... Bounce…

Up to now, we've assumed that the switch is perfect. In reality that is not so. The mechanical construction of the switch results in internal vibrations (bouncing) in which the metals bounce until they settle and make contact. During this time, a switch can result in many connections/disconnections that a microcontroller will interpret as multiple presses when in fact a user only pressed once. The end result is that multiple interrupts will be generated and can cause issues in the end application. What to do? In general there are two approaches to doing debouncing: Analog and Software.



The analog approach uses a capacitor and a schmitt trigger. When a capacitor is added to the switch input, the capacitor is pulled high by the pull-up resistor and therefore is charged. When the key is pressed, the capacitor will resist the change in voltage (the switch is grounding the input). The capacitor will discharge, preventing the bouncing of the switch contact. This depends heavily on the size of the capacitor and resistor (on their RC time constant). The larger the RC time constant, the more bouncing will be reduced. However, the switches responsiveness will be affected. When the user releases the button, the capacitor slowly charges and therefore any bounces are also filtered. However, because of the slow transition, the I/O input will transition in an unknown state which could cause issues. A schmitt trigger is then required to avoid any problems. This is typically not an issue because the MSP430 includes a schmitt trigger at the I/O inputs.

The other solution that can be done is in software. Using interrupts we can detect the switches high to low and low to high transitions and ignore those that are inside of the bounce window by waiting for a set amount of time (using a timer or a for loop to waste cycles) before accepting new transitions as actual user switch presses. The amount of time to wait depends on the switch to be used, but 40ms is a safe bet in many cases. If you can't wait that long, measure the bouncing time using an oscilloscope and create a worse case estimate. We must also ensure that the first bounce of the switch was not a momentary malfunction (as could be the case if the switch is malfunctioning or the board was dropped creating an accidental contact.

1.4 Important Coding Syntax

PxIN

The input register for a port is a read-only value. When a pin is selected to be an input, reading the value of the bit tells you the voltage currently on that pin. The entire byte PxIN reads the value of all of the inputs on that port at once. Keep in mind this is a digital system, so there are only two values that can be read; a 0 or a 1. These values correspond to the voltages on Vss (0) and Vcc (1), which are generaly 0 V and between 1.8 and 3.6 V respectively. There is a particular threshold built into the device such that any voltage over that value is read as a 1 and any voltage read below is read as a 0. To prevent any damage to the chip, you should certainly *never* try to read any voltages outside the range between Vss and Vcc directly.

PxOUT

The output register for a port is writeable. When a pin is selected to be an output, we can change the voltage on that pin by writing a 0 or a 1 to its corresponding bit in PxOUT. Like the input, a 0 corresponds to the voltage on Vss, and a 1 corresponds to the voltage on Vcc.

PxDIR

The direction register determines whether a pin is an input (bit is low, or 0) or an output (bit is high, or 1). At the beginning of your program, you should configure the port pins to their values as inputs or outputs. That's not to say you can't change a pin's behavior in the middle of your program, of course.

PxIE, PxIES, and PxIFG

These three registers are the interrupt enable, interrupt edge select, and interrupt flag registers for the ports. We'll look at these three registers together, as they work together. You can use the port pins as a way to flag special circumstances to the processor and trigger an interrupt. For now, think of an interrupt as a message to the CPU to hold on what it's currently doing and take care of the special circumstance. Once the interrupt has been satisfied, the CPU returns to where it was before. You enable this behavior by setting the PxIE bit for the pin being used to 1. PxIES bits determine if the flag is triggered by the pin going from 0 to 1 (IES bit set to 0) or from 1 to 0 (IES bit set to 1). In other words, a flag is triggered when it detects a positively sloped, rising edge or a negatively sloped, falling edge. When the interrupt is triggered, it sets the corresponding bit in PxIFG.

PxSEL

Looking back at the pinout diagram on page 3, you can see that most of the port pins have multiple functions. The selection register determines what function a pin takes on. The default function is listed first, so P1 defaults to general I/O pins, whereas the P2 pins default to connections to a crystal oscillator. Changing the bits in PxSEL changes the behavior of the pins. We'll look at the particular settings later; for now, plan on using the default values in PxSEL.

PxREN

The resistor enable register is a very useful feature for the ports. Sometimes it is helpful to pull the voltage up to Vcc or down to Vss, such as when you attach a push button to a pin. The resistor enable register lets you turn on that ability. When a PxREN bit is enabled, you can select it as a pull-up or pull-down resistor by setting the corresponding bit in PxOUT, 1 for up, 0 for down.

1.5 Digital Operation

A	B	A | B
0	0	0
0	1	1
1	0	1
1	1	1

(a) OR

A	B	A & B
0	0	0
0	1	0
1	0	0
1	1	1

(b) AND

A	Ã
0	1
1	0

(a) NOT

A	B	A ∧ B
0	0	0
0	1	1
1	0	1
1	1	0

(b) XOR

Now, in our program we need to initialize the pin to be an output:

P1DIR = BIT0; //assignment

OR

P1DIR |= BIT0; // logic operator

The difference between assignment and logic operator method in initializing the pin is that:

(i) Assignment:

P1.0 is output, other pins will be automatically assigned as input

(ii) Logic Operator:

P1.0 is output, while other pins is undefined and unaffected.

To turn off every pins:

P1OUT = 0;

To turn the RED LED on:

P1OUT |= BIT0;

To turn the RED LED off:

P1OUT &= ~BIT0;

To toggle its state (off if on, on if off):

P1OUT ^= BIT0;

Let's try another example:

First, let's configure the two pins as outputs with an initial state off:

P1DIR = BIT0 + BIT6;

P1OUT = 0;

We can turn each one on and off individually:

```
P1OUT |= BIT0;    // P1.0 on
P1OUT &= ~BIT0;   // P1.0 off
P1OUT |= BIT6;    // P1.6 on
P1OUT &= ~BIT6;   // P1.6 off
```

Or we can turn them on and off together:

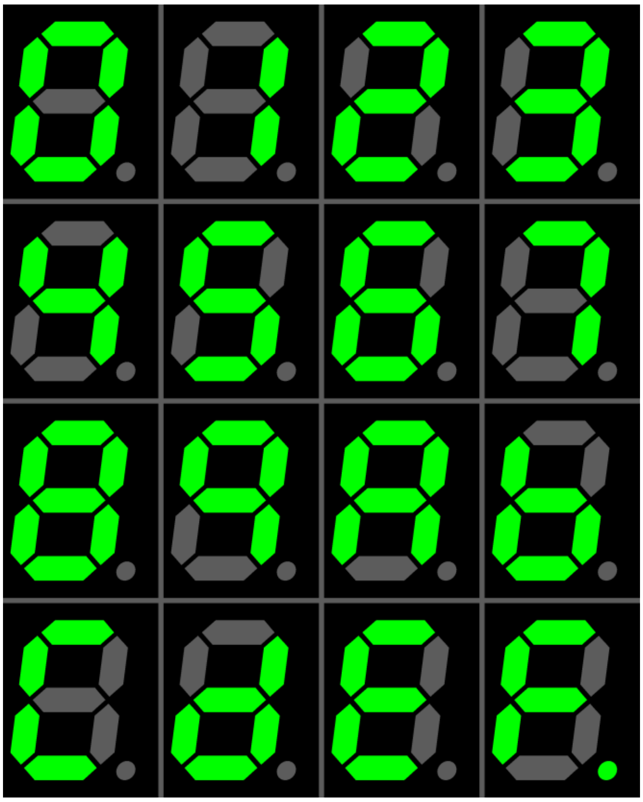
```
P1OUT |= BIT0 + BIT6;     // both on
P1OUT &= ~(BIT0 + BIT6);  // both off
```

And finally, toggle them simultaneously:

```
P1OUT ^= BIT0 + BIT6;     // toggle both
```

Note: Put some delay in between the lines to observe the state changes.

CHAPTER 2– INDICATORS AND DISPLAYS



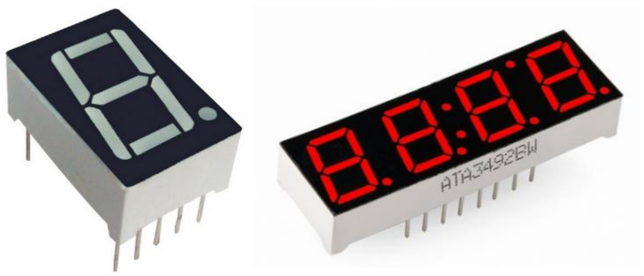
This Chapter will cover the implementation of 7-Segment, Liquid Crystal Display (LCD), RGB LED, and Dot Matrix.

"Even a mistake may turn out to be
the one thing necessary to a worthwhile achievement"
- Henry Ford-

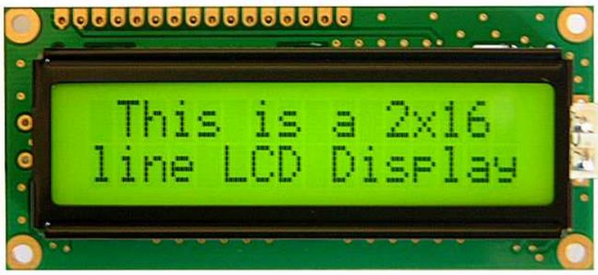
2.0 Introduction

Indicators and displays are very important in projects. It allows us to know whether the data (input) has been processed correctly or not. The previous chapter introduce the ways to control simple LEDs. There are much more awesome displays in the market that you can find easily.

The display components that we are going to use and program are:



Seven Segment Display



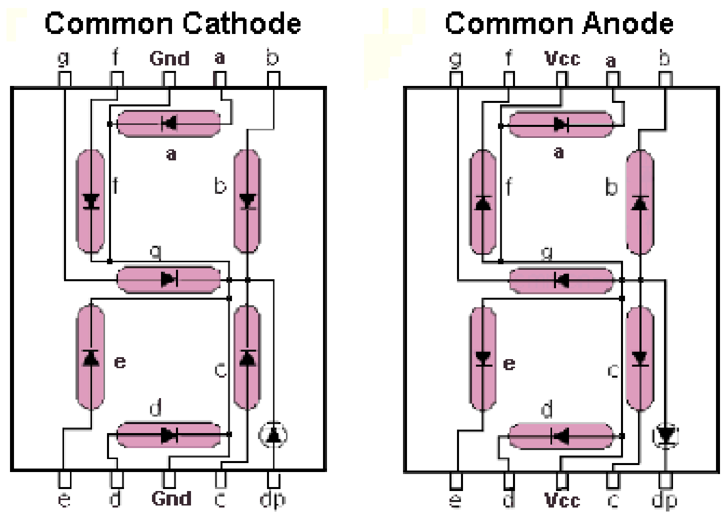
Liquid Crystal Display

RGB LED

Dot Matrix LED Display

2.1 Seven-Segment Display

Seven-Segment display got their name because of it consists of seven segments LED that can be controlled to display variety of numbers and pattern. So how many LEDs are there in the seven-segment? Seven… Nope… In total there are eight LEDs which includes the small dots at the bottom right. Also, we have two types of seven-segment – Common Cathode and Common Anode. Common Cathode means all the LEDs share the same ground, while LEDs on common anode seven-segment display share the same power supply as shown in the figure below.



In this chapter, we are going to use common cathode seven-segment display. Basically, we are just going to on and off the LEDs just like what we do in the previous chapter, but in a more systematic way.

2.1.0 Simple Display One Two Three

Connections:

Based on the pin layout shown previously, connect:

Pin a → P1.1

Pin b → P1.2

Pin c → P1.3

Pin d → P1.4

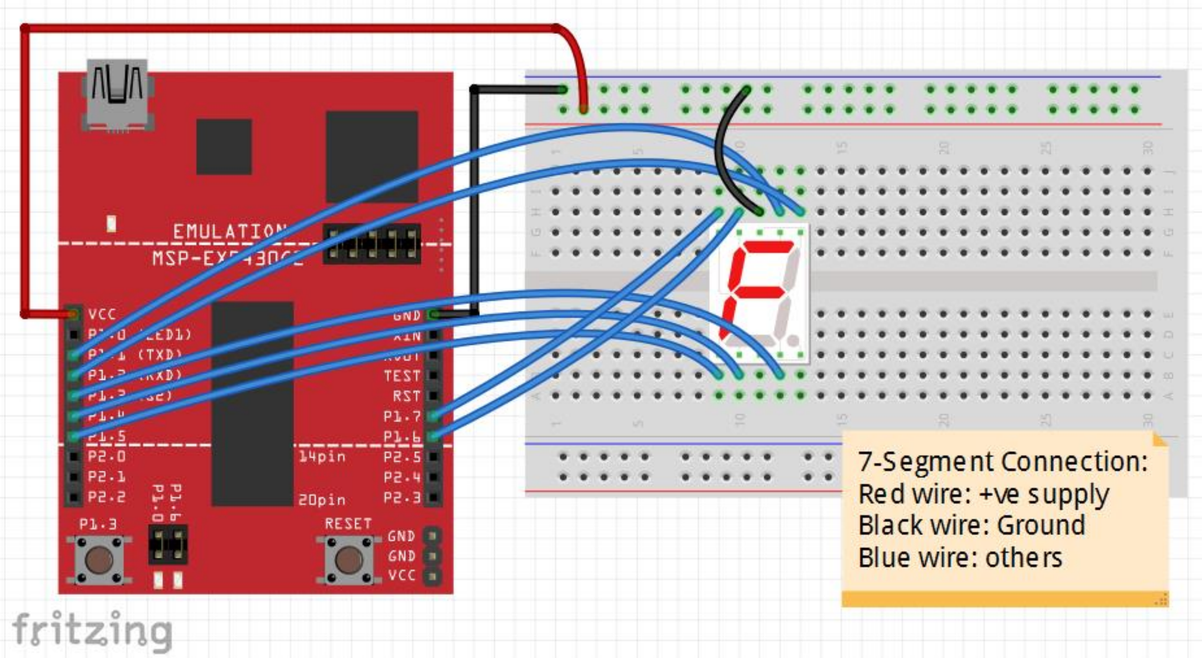
Pin e → P1.5

Pin f → P1.6

Pin g → P1.7

Pin Gnd → Gnd of the MSP430 Launchpad

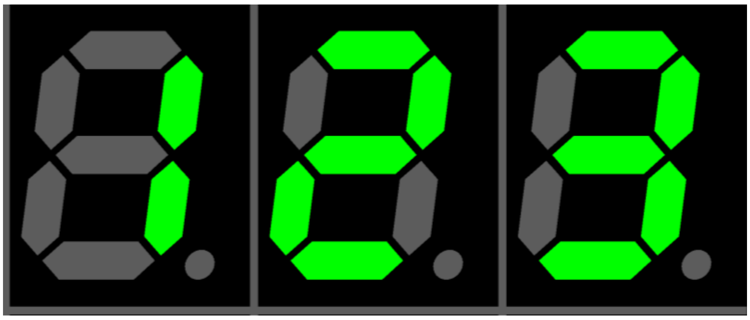
Note: I have tried connecting the 7-segment directly to the MSP430 mcu pins and it works perfectly. It depends on the components you used. Nevertheless, all the outputs should be connected to resistors to limit the current and prevent the 7-segment from burning. Also, Vcc is not connected directly to the 7-segment because the voltage needed for 7-segment will be supplied by the mcu.

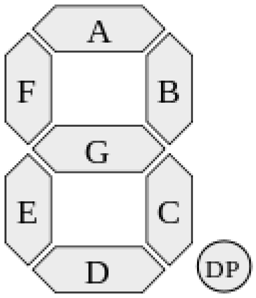


Code:

```
#include <msp430g2553.h>

#define a BIT1
#define b BIT2
#define c BIT3
#define d BIT4
#define e BIT5
#define f BIT6
#define g BIT7

void main()
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR = a+b+c+d+e+f+g;

	while(1)
	{
		P1OUT = b+c;
		__delay_cycles(500000);
		P1OUT = a+b+g+e+d;
		__delay_cycles(500000);
		P1OUT = a+b+g+c+d;
		__delay_cycles(500000);
	}
}
```

Explanation:





For instance, you wish to display “1” on the 7-segment, then only LED B and C will be turned on. For displaying “2”, LED A, B, D, E, and G will be turned on. For displaying “3”, LED A, B, C, D, and G will be turned on. Same thing happen if you want to display any other numbers.

In the code, it is made to be more systematic, whereby we do not need to write P1OUT = BIT1 + BIT2 + BIT3 + BIT4……. and so on to turn on and off the

LEDs. In this example, we use #define to represent BIT1 with “a”, BIT2 with “b” and the list continues. Hence, our code will looks more organised and easier to interpret. For example, P1OUT = b + c; simply means that LED B and C are turned on, other pins are off, which eventually displaying “1” on the 7-segment.

Expected Output:

It continually display from 1 to 3 then start all over again and again and again (since it is in while loop).

2.1.1 Seven-segment Extra Training

Task 1:

Modify the code to make the 7-Seg to count from 0-9 continuously.

Task 2:

Is there any way of reducing the number of lines in the code?? For sure, there is a way!!

By using array!! Single dimension array is sufficient enough to do the work. As for now, for the sake of simplicity and to meet the purpose of learning, the sample code is given.

Task 3:

How to make the 7 segment to change the number every time you pressed the button? Referring to the previous examples, try to write your own code before looking at the answer code.

Answer for Task 1:

```
#include <msp430g2553.h>
```

```
#define a BIT1
#define b BIT2
#define c BIT3
#define d BIT4
#define e BIT5
#define f BIT6
#define g BIT7

void main()
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR = a+b+c+d+e+f+g;

	while(1)
	{
		P1OUT = a+b+c+d+e+f;
		__delay_cycles(500000);

		P1OUT = b+c;
		__delay_cycles(500000);

		P1OUT = a+b+g+e+d;
		__delay_cycles(500000);

		P1OUT = a+b+g+c+d;
		__delay_cycles(500000);

		P1OUT = f+g+b+c;
		__delay_cycles(500000);

		P1OUT = a+f+g+c+d;
		__delay_cycles(500000);

		P1OUT = a+f+e+d+c+g;
		__delay_cycles(500000);

		P1OUT = a+b+c;
		__delay_cycles(500000);

		P1OUT = a+b+c+d+e+f+g;
		__delay_cycles(500000);

		P1OUT = a+b+c+d+f+g;
		__delay_cycles(500000);
	}
}
```

Remarks:

Finally some hands-on work can be done! This code is for common cathode 7-Seg display. Good Luck Trying! Isn't it easy?

Answer for Task 2:

```
#include <msp430g2553.h>
```

```c
#define a BIT1
#define b BIT2
#define c BIT3
#define d BIT4
#define e BIT5
#define f BIT6
#define g BIT7

int display[10]={a+b+c+d+e+f, b+c, a+b+g+e+d, a+b+g+c+d, f+g+b+c, a+f+g+c+d,
a+f+e+d+c+g, a+b+c, a+b+c+d+e+f+g, a+b+c+d+f+g};
int n = 0;

void main()
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR = a+b+c+d+e+f+g;

	while(1)
	{
		P1OUT = display[n];
		__delay_cycles(500000);
		n++;
		if (n==10)
		{
			n=0;
		}
	}
}
```

Remarks:

Bonus for all of you~~ Simplified and more efficient code for displaying 0 to 9 by using array!! Remember~ By producing same output, the shorter your code, the better you are!!

(This code is for common cathode 7-Seg display.)

Answer for Task 3:

```c
#include <msp430g2553.h>
```

```c
#define a BIT0
#define b BIT1
#define c BIT2
#define d BIT4
#define e BIT5
#define f BIT6
#define g BIT7

int display[10]={a+b+c+d+e+f, b+c, a+b+g+e+d, a+b+g+c+d, f+g+b+c, a+f+g+c+d,
a+f+e+d+c+g, a+b+c, a+b+c+d+e+f+g, a+b+c+d+f+g};
int n = 0;

void main()
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR = a+b+c+d+e+f+g;
	P1REN = BIT3;
	P1OUT = BIT3;

	while(1)
	{
		if((P1IN & BIT3)!=BIT3)
		{
			__delay_cycles(220000);
			P1OUT &= ~(a+b+c+d+e+f+g);
			P1OUT |= display[n];
			n++;
			if (n==10)
			{
				n=0;
			}
		}
	}
}
```

Remarks:

Control button is added. Noted that P1.3 is connected to the button, thus the same pin cannot be used to control the 7-segment. Hence, in this case, P1.0 is used. When you pressed the button, the number increase by 1. It is now become a digital counter!! Well done!! But it is using polling method, try it using interrupt method instead~

(This code is for common cathode 7-Seg display.)

2.1.2 Persistence of Vision (POV) Implementation

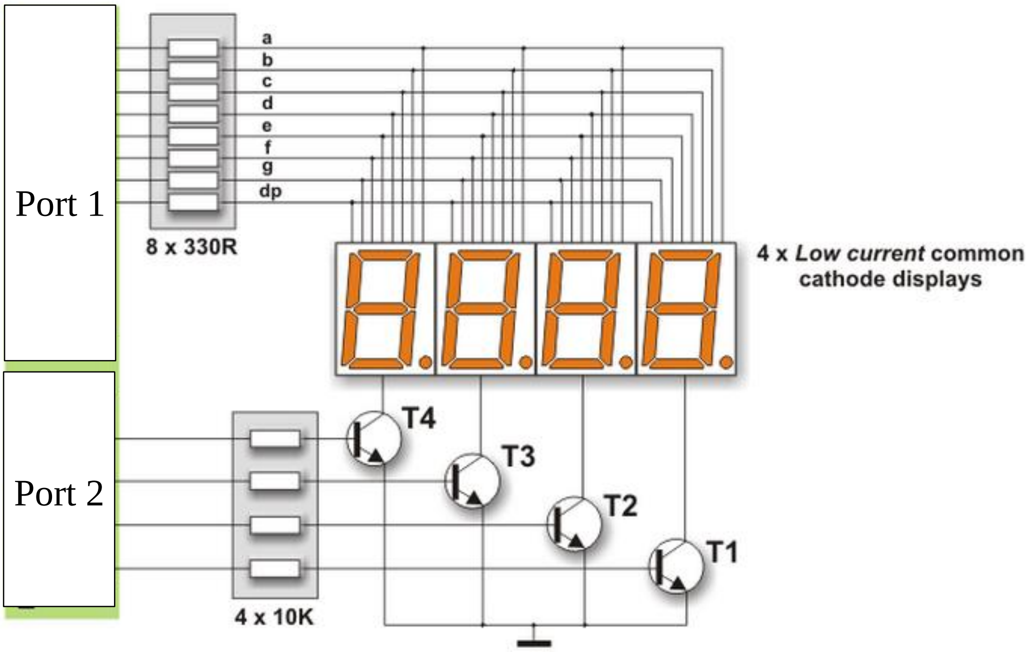
Hope that you enjoy learning so far. However, by controlling single 7-segment we needed seven GPIO pins from the microcontroller. How many pins do we need if we are going to control four 7-segment together? By simple logic, 4 multiply by 7 is 28 pins. Well, it would cost you quite a lot if you really are going to use 28 pins MCU. In fact, there are SPI-controlled 7-segment display as shown below. It only requires 5 pins to work, thus saving a lot of GPIO pins for other usage.

SPI-controlled 7-segment display

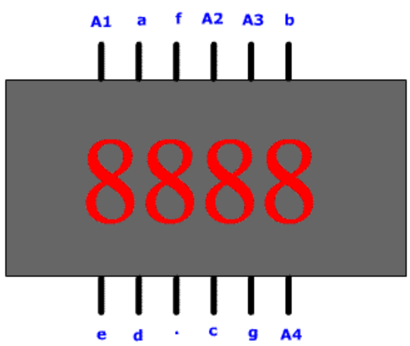
Nevertheless, we are not going to learn about SPI today. Instead, I want to introduce a very useful technique call Persistence of Vision (POV). By just using one row of LEDs, installed on a moving object such as wheel, and the LEDs are being turned on and off so quickly that it changes with position. As the beautiful outcome, different pattern or even words can be formed.

Back to our case, even though we have four 7-segment to be controlled. We can use the same pins (a to g) for all the four 7-segment. But, each of the 7-segment is controlled by four additional pins. In other words, only one 7-segment is turned on at a time, and since it is switching in fast speed, we will not notice the switching with our naked eyes. We will examine this phenomenon in the next session. In total, 10 GPIO pins are used.

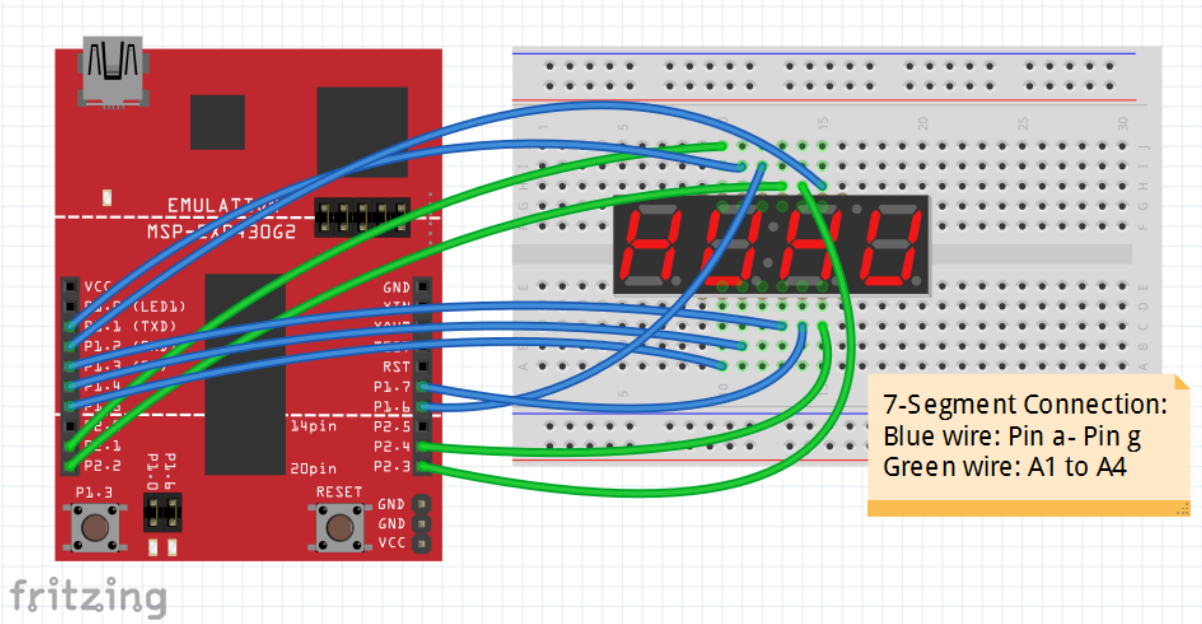
If you are going to use four separated 7-segment display, the connections can be very tedious. As shown in the figure below, all the pins (from a to dp) are paralleled and connected to port 1. Then, the common pin (which could be either common anode or common cathode) is connected to a transistor that act as switch.



Anyway, some of 7-segment display are simplified whereby all the complicated wiring is internally connected as shown in the right figure. Resistors and transistors are recommended to be used. However, the 7-segment is connected directly to the mcu for the sake of simplicity. In my case, it works perfectly.



Port 1 is connecting to a,b,c,d,e,f, and g, while Port 2 is connecting to A1, A2, A3, and A4. Note that no Vcc or ground is connected directly to the 7-segment since the 7-segment is powered up by the output pin of the mcu.



Task:

Besides numbers, we can display some of the alphebets too, such as A, b, C, d, E, F, g, H, I, J, L, O, P, S, U, and y. In this example, we will display some random alphebets on the 7-segment, let’s try U, C, S, and I. Also, we will be using common-anode 7-segment display so that both types of display will be learned.

```
#include <msp430g2553.h>

#define a BIT1
#define b BIT2
#define c BIT3
#define d BIT4
#define e BIT5
#define f BIT6
#define g BIT7

void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR|=(a+b+c+d+e+f+g);
	P1OUT|=(a+b+c+d+e+f+g);
	P2DIR|=(BIT1+BIT2+BIT3+BIT4);
	P2OUT&=~(BIT1+BIT2+BIT3+BIT4);

	while(1)
	{
		P2OUT = BIT1;
		P1OUT = a+g;
		__delay_cycles(220000);

		P2OUT = BIT2;
		P1OUT = b+c+g;
		__delay_cycles(220000);

		P2OUT = BIT3;
		P1OUT = b+e;
		__delay_cycles(220000);

		P2OUT = BIT4;
		P1OUT = a+d+e+f+g;
		__delay_cycles(220000);
	}
}
```

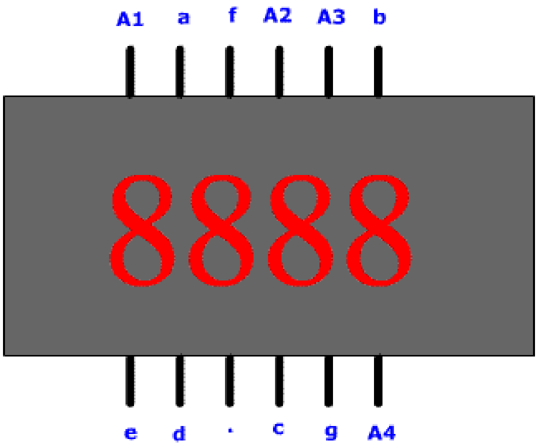
Remarks:

The alphabet U, C, S, and I will display one after another in a slow manner. But this is not we want isn't it? In order to display all the alphabets together. We can shorten the delay to __delay_cycles(2200); Since the switching happened too fast, our eyes cannot detect any of the switching. Thus, demonstrating the concept of POV. Also, since the common anode display is used, thus to display "U" for instance, we have to turn off LED A and G. In common anode, everything is the opposite of common cathode. We supply voltage to these LEDs in order to turn them off.

2.1.3 POV Extra Training

Task: Using a 4-digit (Common-Anode) 7-Segment Display, program a counter that counts 0000, 0001, 0002, 0003 up to 0100 whenever the button is pressed. Once it counts until 0100, it then reset to 0000.

Remarks: Your programming code should be user-friendly – meaning that the pin numbers assigned can be easily changed whenever necessary.



Hints: What are you supposed to do to separate the number into 4 individual number – one, ten, hundreds and thousands? By using modulus (%) perhaps? Don't forget that the 7-segment display is common anode. Don't worry, all people has different style of coding, just make sure the output is desirable.

Happy coding~ =)

Answer:

```c
#include <msp430g2553.h>

#define a BIT0
#define b BIT1
#define c BIT2
#define d BIT4
#define e BIT5
#define f BIT6
#define g BIT7

#define zero a+b+c+d+e+f
#define one b+c
#define two a+b+d+e+g
#define three a+b+c+d+g
#define four b+c+f+g
#define five a+c+d+f+g
#define six a+c+d+e+f+g
#define seven a+b+c
#define eight a+b+c+d+e+f+g
#define nine a+b+c+d+f+g
#define all a+b+c+d+e+f+g

unsigned char LED[10] = {zero,one,two,three,four,five,six,seven,eight,nine};
unsigned char n=0;
unsigned char thousand;
unsigned char hundred;
unsigned char ten;
unsigned char unit;

void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR = a+b+c+d+e+f+g; //Set all Port 1 as Output, except BIT3
	P1REN = BIT3; //Enable P1.3 Internal Resistor
	P1OUT = BIT3 + a+b+c+d+e+f+g; //Set P1.3 as Pull Up
	P2DIR = a+b+c+d; //set all P2.0, P2.1, P2.2, P2.4 as output too

	while(1)
	{
		if((P1IN & BIT3)!=BIT3)
		{
			__delay_cycles(220000);//Software Debounce
			n++;
			if (n>100)
			{
				n=0;
			}
		}
		else
		{
			thousand = (n/1000)%10;
			P2OUT = a;
			P1OUT |= all;
			P1OUT &= ~LED[thousand];
			__delay_cycles(2200);

			hundred = (n/100)%10;
```

```
                P2OUT = b;
                P1OUT |= all;
                P1OUT &= ~LED[hundred];
                __delay_cycles(2200);

                ten = (n/10)%10;
                P2OUT = c;
                P1OUT |= all;
                P1OUT &= ~LED[ten];
                __delay_cycles(2200);

                unit = n%10;
                P2OUT = d;
                P1OUT |= all;
                P1OUT &= ~LED[unit];
                __delay_cycles(2200);
            }
        }
}
```

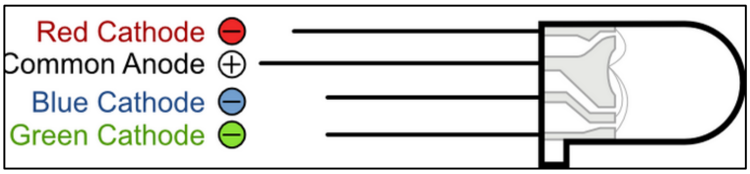
Remarks:

4-Digit Digital Counter~ Finally, nice and perfect programming to count from 0 to 100 by pressing the button. Hope you enjoy learning it.

(This code is for common-anode 7-Seg)

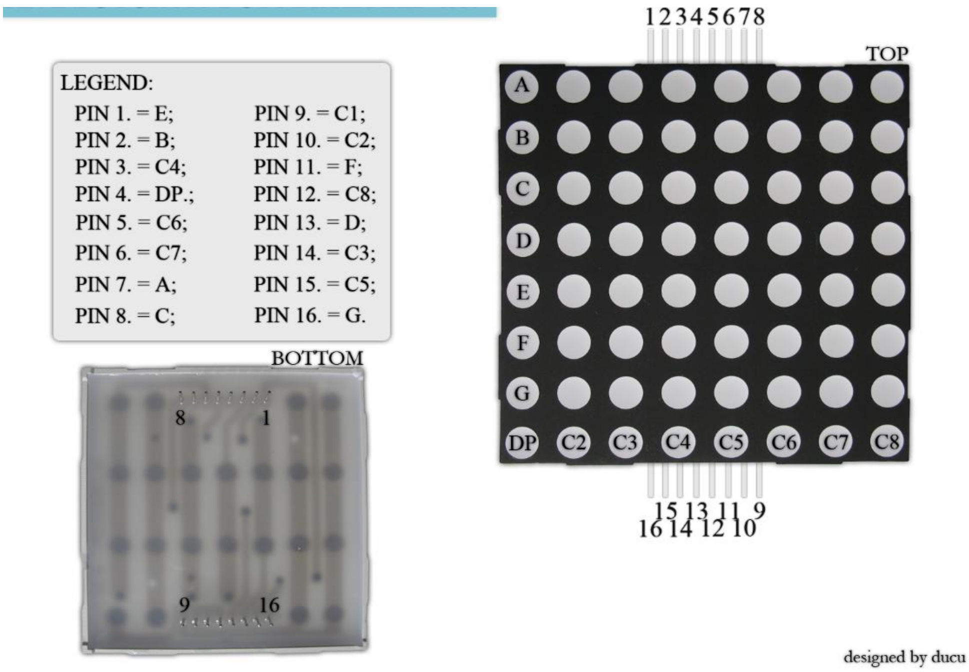
2.2 RGB LED

RGB LED stands for Red, Green, and Blue LED. In short, it is a 3-in-1 LED.

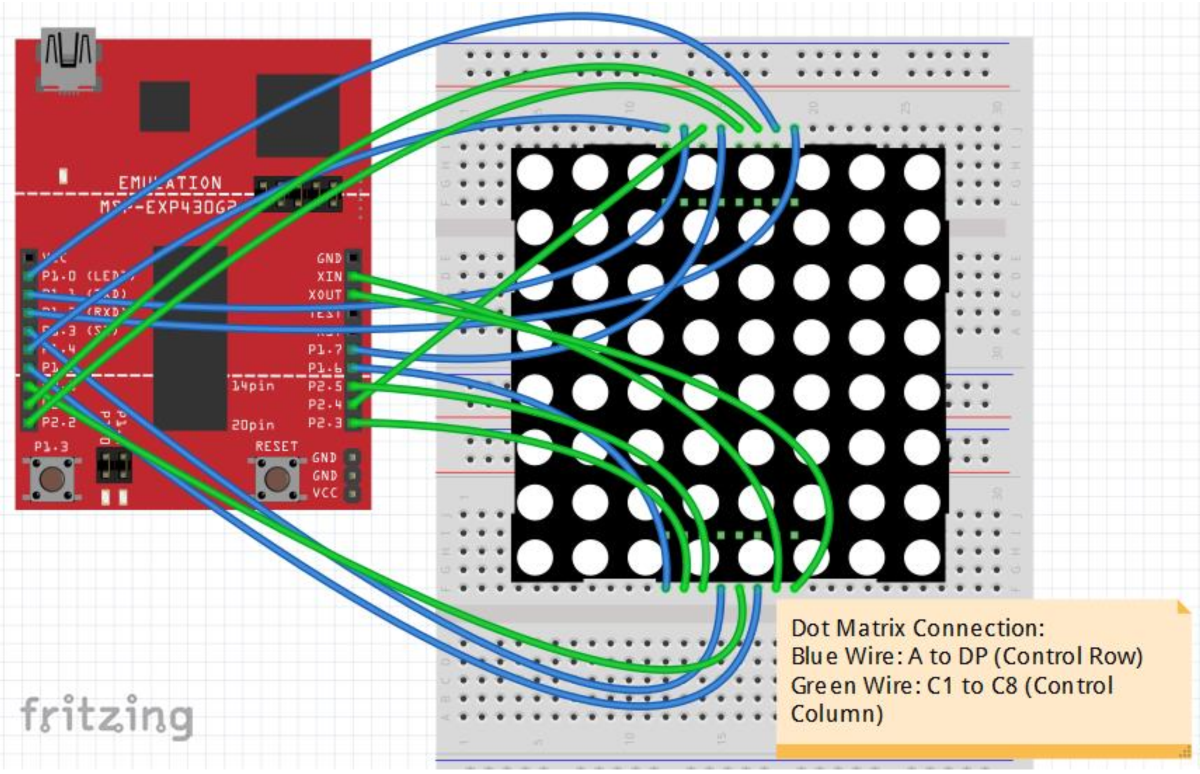


Basically, it operates just like the ordinary LED. It has two types. Common cathode and common anode. In this case, when the RGB cathode are connected to ground, then the respective colour will be lighted. The advantage of using this type of LED is its compact size. If your system need three different coloured LED as indicators. RGB LED may be your better choice.

2.3 Dot Matrix



The figure above shown the pin layout of a dot matrix. Your component might have different pin configuration. Anyway, you have to determine the pins that control the row and column of the LED respectively before you start programming. If you are going to use the code provided in this e-book, then connect A→DP to P1.0→P1.7, while C1→C8 to P2.7→P2.0. The wiring for column LEDs are in reverse manner because new programming method will be introduced in the next session and require such connection.



Explanation:

Here you can find out how to drive a LED matrix with 64 LEDs (8 rows by 8 columns - 8x8 display). The LEDs are no different to any other LEDs but it saves a huge amount of soldering as all the wiring has been done for you.

Obviously that is a tall order so the way round it is to use persistence of vision which is a way of describing how your eye works. Your eye reacts slowly to changes in light intensity so that if a light is turned on and off quickly enough then it does not notice that the light is off. Basically your eye remembers a light pulse for a short time.

The approximate time is 20ms so if the light is turned on at a frequency >50Hz (1/20ms) then your eye will not notice any flicker at all. Multiplexing uses this fact to reduce the number of pins needed to drive an LED display. You can do this by splitting the 64 led display into 8 rows and 8 columns which lets you drive it using 8 row outputs and 8 column outputs. In fact the 8x8 led matrix block used here has all the LEDs arranged in this way already. Each row is driven in turn and as long as all of the rows are driven within a time period of 20ms it will appear as though the LEDs are on continuously.

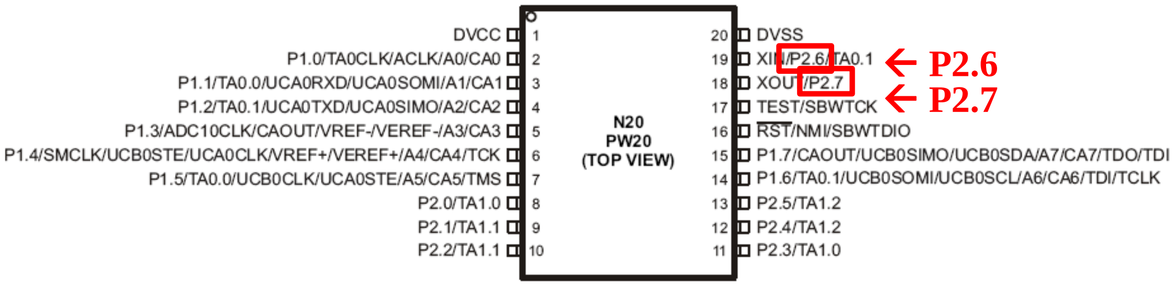
Task 1: Light up all the LEDs of Dot Matrix.

```
#include <msp430g2553.h>

#define a BIT0
#define b BIT1
#define c BIT2
#define d BIT3
#define e BIT4
#define f BIT5
#define g BIT6
#define h BIT7

void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR |= 0xFF;
	P1OUT |= 0xFF;
	P2SEL &= ~(g+h); //configure P2.6 and P2.7 pin as GPIO
	P2DIR |= 0xFF;
	P2OUT |= 0xFF;

	while(1)
	{
		P1OUT = 0xFF;
		P2OUT = 0;
	}
}
```

Remarks:

In this session, both Port 1 and Port 2 are used (In total 16 GPIOs are needed). You might notice that there is no P2.6 and P2.7 label on the development board.

According to the datasheet, P2.6 and P2.7 share the same pin with XIN and XOUT respectively. Since GPIO is NOT the primary function of these two pins, additional P2SEL code is needed to configure the pins.



What is 0xFF? Up to this session, we know that we can use define "a" to be BIT0 in order to shorten and organize the code. Yet, it is cumbersome to write P1OUT = a + b + c + d + e + f + g + h. Hence, it is better to utilize the hexadecimal (HEX) format, which is P1OUT = 0xFF, which basically mean the same thing. How does it works then?

MSB **LSB**

Registers	BIT7	BIT6	BIT5	BIT4	BIT3	BIT2	BIT1	BIT0
State	1	1	0	0	1	0	1	1
In HEX	C				B			

Let say we would like to turn on BIT7, BIT6, BIT3, BIT1, and BIT0. In the old method, we would write P1OUT = BIT7 + BIT6 + BIT3 + BIT1 + BIT0. In binary, the state would be 11001011_2, which is equivalent to CB_{16} in hexadecimal. Thus, we can then program the code as P1OUT = 0xCB, where "0x" means hexadecimal, "0b" for binary and so on.

More example:

$1010\ 1011_2 \rightarrow AB_{16}$

$1111\ 0101_2 \rightarrow F5_{16}$

$0010\ 1001_2 \rightarrow 29_{16}$

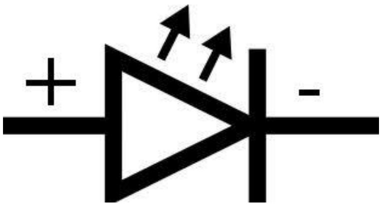
Note that MSB is on the left while LSB is on the right. The table above illustrates the reason of reversing the connection of column LEDs as mentioned. Row LEDs will not be affected. The working principle is very much related to POV. More example will be given to illustrate the functionality.

Why

```
P1OUT = 0xFF;
P2OUT = 0;
```

will turn all the LEDs ON?

Port 1 will control the ROWS while Port 2 control the COLUMNS. Remember that you are controlling LEDs, when you give HIGH in one end, the other end must be LOW in order to turn on the LED.



Task 2: Turn on the LEDs row-by-row.

```
#include <msp430g2553.h>
#define a BIT0
```

```c
#define b BIT1
#define c BIT2
#define d BIT3
#define e BIT4
#define f BIT5
#define g BIT6
#define h BIT7

void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR |= 0xFF;
	P1OUT |= 0xFF;
	P2SEL &= ~(g+h);
	P2DIR |= 0xFF;
	P2OUT |= 0xFF;

	while(1)
	{
		P1OUT = a;
		P2OUT = 0xFF;
		__delay_cycles(220000);
		P1OUT = b;
		P2OUT = 0x81;
		__delay_cycles(220000);
		P1OUT = c;
		P2OUT = 0x81;
		__delay_cycles(220000);
		P1OUT = d;
		P2OUT = 0x81;
		__delay_cycles(220000);
		P1OUT = e;
		P2OUT = 0x81;
		__delay_cycles(220000);
		P1OUT = f;
		P2OUT = 0x81;
		__delay_cycles(220000);
		P1OUT = g;
		P2OUT = 0x81;
		__delay_cycles(220000);
		P1OUT = h;
		P2OUT = 0xFF;
		__delay_cycles(220000);
	}
}
```

Remarks:

This code is created to emphasize the theory of POV in pin multiplexing. A red bar rolling down from row 2 to row 7 will be shown. When the delay cycles is reduced, the output changed. A Red box is then appeared. Nice demo of POV isn't it?

BUT, the code is not optimized and lengthy. Can you think of any way to improve the codes? Hint: Use array. It is a good practice that you can try it yourself before looking at the answer provided.

```
#include <msp430g2553.h>

#define a BIT0
#define b BIT1
#define c BIT2
#define d BIT3
#define e BIT4
#define f BIT5
#define g BIT6
#define h BIT7

int x[] = {a,b,c,d,e,f,g,h};
int y[] = {0xFF,0x81,0x81,0x81,0x81,0x81,0x81,0xFF};
int z=0;

void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;
	P1DIR |= 0xFF;
	P1OUT |= 0xFF;
	P2SEL &= ~(g+h);
	P2DIR |= 0xFF;
	P2OUT |= 0xFF;

	while(1)
	{
		P1OUT = x[z];
		P2OUT = y[z];
		z++;
		if (z==8)
		{
			z=0;
		}
		__delay_cycles(2200);
	}
}
```

You can display your own names, add some animation and so many more. If you are observant enough, some lift are using dot matrix to display its current location.

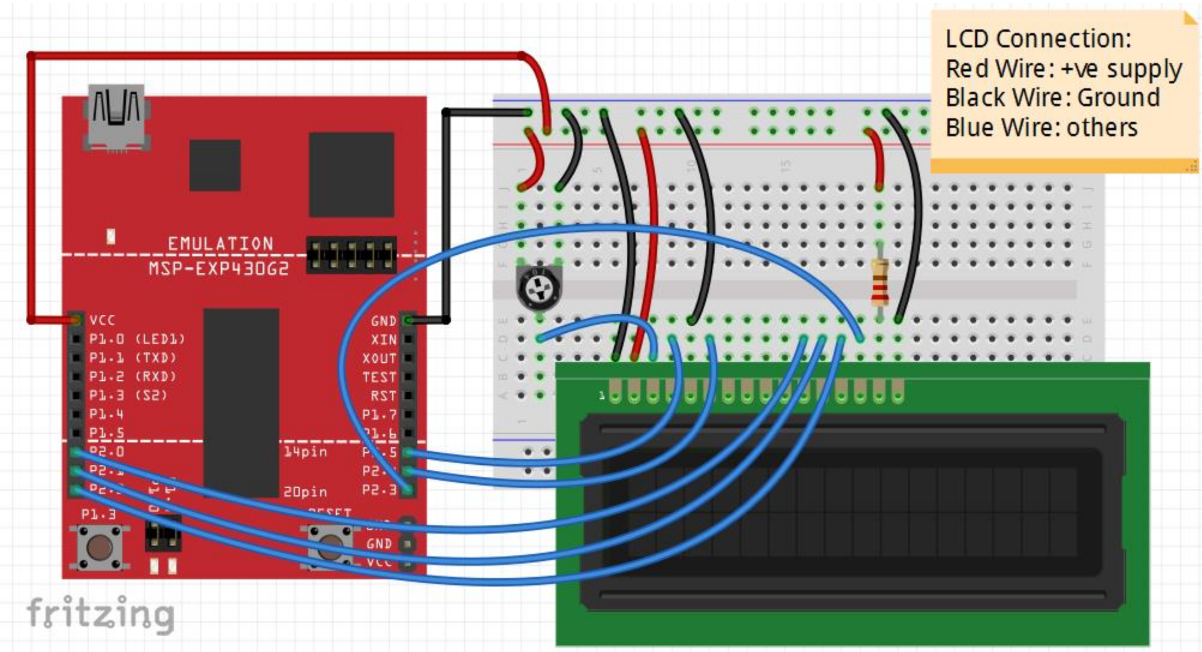
As the bonus for all the readers, an animation is coded specially to express my cheeriness when the number of subscriber for *Embedded Project Hunter* blog increases. You may subscribe at www.embeddedprojecthunter.com if you are yet to subscribe. Subscribers will get first-hand information on the latest project updates. Run the code below to find out what is the animation all about. Hope you guys enjoy it.

```
#include <msp430g2553.h>

#define a BIT0
#define b BIT1
#define c BIT2
#define d BIT3
#define e BIT4
#define f BIT5
#define g BIT6
#define h BIT7

int row[] = {a,b,c,d,e,f,g,h};
int box1col[] = {0xFF,0x81,0x81,0x81,0x81,0x81,0x81,0xFF};
int box2col[] = {0xFF,0xFF,0xC3,0xC3,0xC3,0xC3,0xFF,0xFF};
int box3col[] = {0xFF,0xFF,0xFF,0xE7,0xE7,0xFF,0xFF,0xFF};
int box4col[] = {0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF,0xFF};
int love1col[] = {0xFF,0xFF,0xEB,0xC1,0xC1,0xE3,0xF7,0xFF};
int love2col[] = {0xFF,0x99,0x00,0x00,0x00,0x81,0xC3,0xE7};
int z=0;
int loop;

void init(void)
{
        z++;
        if (z==8)
        {
                z=0;
        }
        __delay_cycles(2200);
}

void main(void)
{
        WDTCTL = WDTPW + WDTHOLD;
        P1DIR |= 0xFF;
        P1OUT |= 0xFF;
```

```
        P2SEL &= ~(g+h);
        P2DIR |= 0xFF;
        P2OUT |= 0xFF;

        while(1)
        {
                P1OUT = 0xFF;
                P2OUT = 0;
                __delay_cycles(220000);

                for(loop=0;loop<200;loop++)
                {
                        P1OUT = row[z];
                        P2OUT = box1col[z];
                        init();
                }

                for(loop=0;loop<200;loop++)
                {
                        P1OUT = row[z];
                        P2OUT = box2col[z];
                        init();
                }

                for(loop=0;loop<200;loop++)
                {
                        P1OUT = row[z];
                        P2OUT = box3col[z];
                        init();
                }

                for(loop=0;loop<200;loop++)
                {
                        P1OUT = row[z];
                        P2OUT = box4col[z];
                        init();
                }

                for(loop=0;loop<200;loop++)
                {
                        P1OUT = row[z];
                        P2OUT = love1col[z];
                        init();
                }

                for(loop=0;loop<300;loop++)
                {
                        P1OUT = row[z];
                        P2OUT = love2col[z];
                        init();
                }
        }
}
```

2.4 Liquid Crystal Display (LCD)

1. Ground
2. VCC (+3.3 to +5V)
3. Contrast adjustment (sweeper of 10k potentiometer with opposing contacts connected to VCC and GND respectively)
4. Register Select (RS). ->MSP430 P2.5
5. Read/~Write (R/W). ->GND
6. Clock (Enable). ->MSP430 P2.4
7. Data 0 (N.C.)
8. Data 1 (N.C.)
9. Data 2 (N.C.)
10. Data 3 (N.C.)
11. Data 4 -> MSP430 P2.0
12. Data 5 -> MSP430 P2.1
13. Data 6 -> MSP430 P2.2
14. Data 7 -> MSP430 P2.3
15. Backlight Anode (+) -> 100Ω resistor to VCC
16. Backlight Cathode (-) -> GND



It has two type of register inbuilt that is Command Register and Data Register. Two types of operation: 8-bit or 4-bit. The difference between 4 bit and 8 bit operation is that data is sent out as nibbles instead of as one byte. The most significant nibble should be transferred first, followed by the least significant nibble.

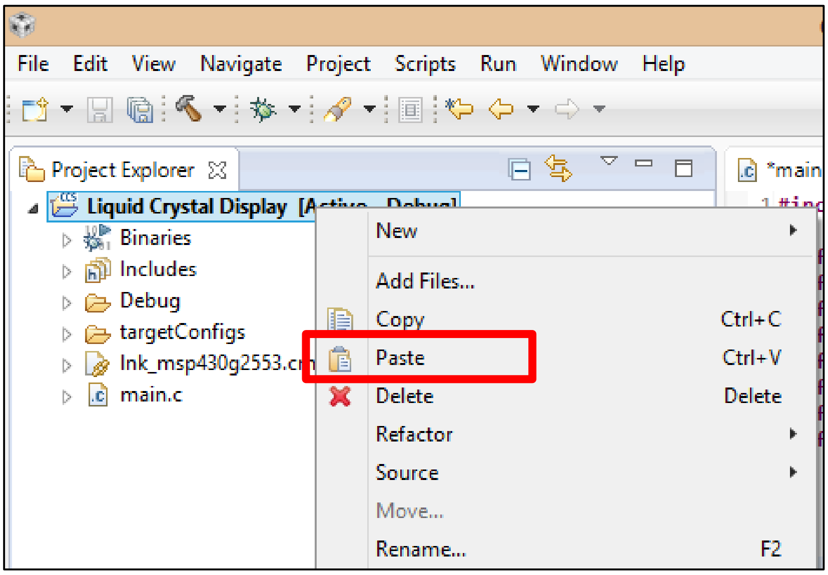
The programming codes for LCD might be tedious as it involves two registers - command register and data register. Fortunately, there is a LCD library well-written by Elliott Gurrola and Luis Carlos Bañuelos-Chacon. For more information and downloading the library, click here.

The LCD library consists of TWO files:

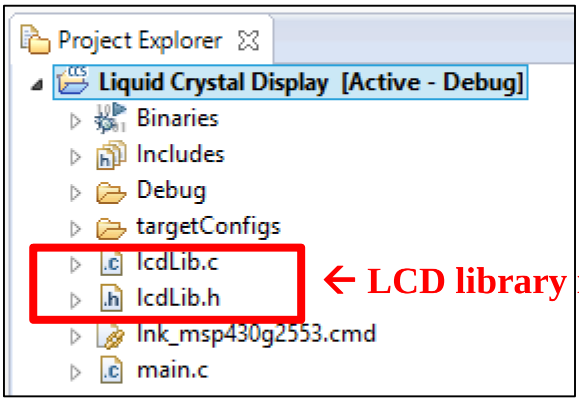
(i) lcdLib.h

(ii) lcdLib.c

Copy both file that you downloaded (Do not need to open the file) and then right-click → Paste in the project directory as shown below:



Make sure that both files are pasted successfully in the project folder. Once successful, you should observe the following:



← **LCD library is successfully included**

Also, make sure the file name and extension are exactly the same as shown above. Sometimes the extension might be inaccurate when you download it. You can always change the file name and extension by right-clicking the file and click "Rename".

After adding the necessary library, copy the following code and paste in main.c.

```c
#include <msp430g2553.h>
#include "lcdLib.h"

void main(void)
{
	WDTCTL = WDTPW + WDTHOLD;

	lcdInit();

	lcdSetText("Emb. Pro. Hunter", 0, 0);
	lcdSetText("  Happy Coding  ", 0,1);
}
```

You should be able to see the text displayed on the LCD. What if there is nothing displying there? What could possibly be the problem?

Possible Cause 1: The contrast is not properly adjusted.

Make sure the connections are correct. Adjust the variable resistor until you see something on the screen.

Possible Cause 2: Voltage incompatibility

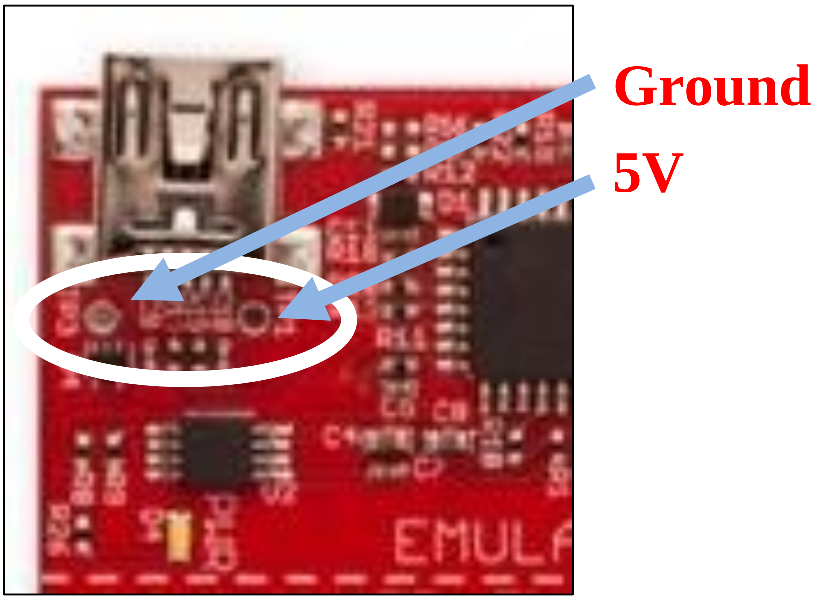
Some LCD need 5V to operate. It depends on the component you bought. If there is nothing being display, then most probably your LCD is not 3.6V compatible. Bear in mind that the Vcc of the microcontroller is 3.6 V.

If this is the case, you have three choices:

(i) Buy another LCD that can operate at 3.6V

(ii) Add an additional 5V power supply for the LCD

(iii) Use the short-cut. If you carefully observe the MSP430 development board, there are two small holes right below the USB connector. These are the test pin and if you measure the voltage using voltmeter, you will get 5V. Your problem can be solved by simply solder a wire out of the test pin and connect to the Vcc of your LCD.



Possible Cause 3: Others

Check your connections, wire connectivity, and programming codes (whether the library is correctly imported). Make sure the components that you use are not faulty. Otherwise, everything should work perfectly.

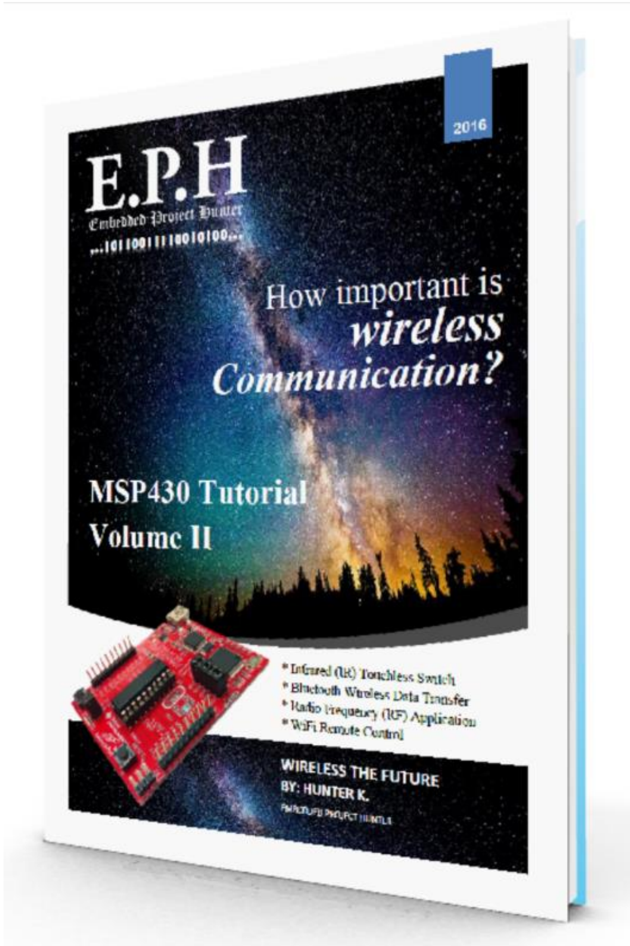
Final Thought

Yes… you have reach the last page of this e-book. Congratulation that you have completed the tutorials. To summarize everything, you have learned:

(i) Simple LED programming
(ii) Button programming (both polling and interrupt method)
(iii) Theory on pull-up/down resistor
(iv) Working principle of button (input)
(v) Basic MSP430G2553 coding syntax
(vi) Seven-Segment Display (single and multiple)
(vii) Theory on Persistence of Vision (POV)
(viii) RGB LED
(ix) Dot Matrix LED Grid
(x) Liquid Crystal Display (LCD)

Yet, there are so much more topics to be covered, such as Analog-to-Digital Converter (ADC), Pulse Width Modulation (PWM), and Timer. To make things more interesting, wireless communication will be added into the list too, which includes, Infrared (IR) line-of-sight (LOS) communication, Bluetooth communication, Radio Frequency (RF) communication, and WiFi. Theory of web-server and client will be discussed, together with HyperText Markup Language (HTML) tutorials. On top of everything, you will have full control of your WiFi-enabled devices anywhere and anytime. These topic will be covered in *Embedded Project Hunter* e-book Part 2. So, stay tune!

Subscribe to *Embedded Project Hunter* blog to get latest updates on the new projects. If you have any questions or thoughts, feel free to email me at embeddedprojecthunter@gmail.com. Hope you enjoy reading this e-book and good luck with all your projects.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Volume II
WIRELESS THE FUTURE
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