

Working Electrical Engineering Projects with STM32 + Fun Kit

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Abstract

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1 Introduction

The work developed here focuses on the needs of my clients. The job needed a micro-controller to manage a device to drive large power loads. Therefore, this document focuses on primal microcontroller features. These features form the backbone of the internet of things. This work falls in a series that I call ‘Back to the Basics.’

So, what do I want out of a back to the basics book? I prefer to develop a cross platform the first time. I require understanding of the code stacks deployed on these devices from the kernel up. I want to deliver a good product.

So what makes for a good product? The architectures selected tell an engineer the product’s goodness score. Object oriented design stands on the pillars of design patterns. A computer engineer applies algorithms, design patterns, and analysis engines. These things give the engineer confidence.

To do this, this work focuses on the mBed system of development. This document shows this project utilizing the STM32 product line. In some cases, I also utilize the Arduino products just to demonstrate a cross manufacture approach to testing designs. Lastly, this document shows how to do this work on the MacOS, Windows, and Linux (ARM) platform.

2 The Base Line Integrated Development Environment Part 1

The Eclipse Foundation and Advanced RISC Machines Limited (ARM) together produced mBed Studio. The mBed Studio provides an Integrated Development Environment (IDE)¹. ARM designed their IDE for micro-controller developers to simplify complex projects.

ARM included a hardware abstract layer (HAL) to connect common features from many producers. Thus, I can develop a simple program, compile it for each board, and that program will run. ARM connects these HALs together by communication methods.

Mbed Studios (a modified Eclipse Theia) released in June 2019. It is derived from the Eclipse ‘Theia’ line shown in a YouTube video².

ARM supplies a tutorial on installing the mBed Theia environment on MS Windows 10³.

This background topic shall show examine basic mBed tasks on Intel based processor machines running MacOS and Windows. This work also demonstrates the same tasks on Raspberry Pi. A later chapter shows a related topic, MCU talks with iPad.

2.1 ST Microelectronics Libraries

ST Microelectronics (STM) started as a French company. Now, STM operates out of many countries. In addition to the boards themselves, they also produce support libraries for their boards⁴.

For example, STM and Texas Instruments (TI) produce ARM based boards with digital signal processor (DSP)⁵ support. A DSP provides acceleration to vector math. These architectures enhance a MCU’s ability to quickly match patterns and make adjustments.

2.2 Hardware Abstraction Layer(s)

STM, TI, and Arduino all benefit from mBedOS’ Hardware Abstraction Layer(s)(HAL) to access key MCU capabilities. The mbedOS is not the only real time operating system (RTOS) for micro-controllers. ARM’s mbedOS does support many implementations of its chip set⁶ design. The mBed compilers build both the mBedOS and specific project code into a tidy size. This good support makes ARM chipsets a safe bet for many manufacturers.

¹<https://os.mbed.com>

²<https://www.youtube.com/watch?v=HsTtzqL-GP8>

³<https://os.mbed.com/teams/ST-Americas-mbed-Team/wiki/Getting-Started-with-mbed-and-the-STM32F>

⁴<http://www.emcu.it/STM32F4xx/STM32F4-Library/STM32F4-Library.html>

⁵https://www.st.com/content/st_com/en/products/embedded-software/mcu-mpu-embedded-software/stm32-embedded-software/stm32-standard-peripheral-libraries/stsw-stm32065.html

⁶<https://os.mbed.com/questions/53876/CMSIS-vs-STM32CUBEHAL-vs-MBED/>

The mBed website carries white paper references for each of the boards it supports. For example, this document utilizes the Nucleo-F413ZH⁷ as an example. This platform and others can be found at ⁸. Alternative cards include:

- Discovery F413H ⁹
- Nucleo L4R5ZI-P ¹⁰
- Nucleo WB55RG ¹¹

Some of the main library sources from STM are provided on the STM32f4 Discovery web site¹² forum.

2.3 It is about the Libraries, Shhsss.

For any task associated with a MCU, ARM based micro-controllers require the libraries. ARM MCUs require the frameworks of the RTOS itself, in this case mBedOS.

Developers refactor their code as they get into development. These libraries serve as building blocks. This product explores basic library creation to benefit fellow developers and makers of products.

As we create libraries and programs, it behoves us to consider license programs and how to market our productions. We want the fruits of our labor to bring us profit. If we never make and sell things then we certainly shall not build profit. If we horde what we make then we won't make profit, either.

So we explore creating programs, importing existing libraries, and creating new libraries. Documentation of such products contributes to our fellow makers. We make money from establishing those connections and making the software that connect to real life.

2.3.1 Create a Repository

We present software creation from a independent producers point of view. Many corporations and government entities insist on their own repository tools. For these entities, we can comprehend the need of such restrictions. They have assests to protect and the finances to provide on property protection.

On the other hand, your work is often times things that you want the privilege to reuse. Reuse is one of the tenets of object-oriented programming. When we restrict one of these tenets, we risk detriment to our profession.

So, we go through a typical arrangement with to produce a repository for use in embedded development. Providers can vary such as BeanStalk and GitHub. Resources such as GitHub come in handy as mBed has much of their resources

⁷<https://os.mbed.com/platforms/ST-Nucleo-F413ZH/>

⁸<https://os.mbed.com/platforms/>

⁹<https://os.mbed.com/platforms/ST-Discovery-F413H/>

¹⁰<https://os.mbed.com/platforms/ST-Nucleo-L4R5ZI-P/>

¹¹<https://os.mbed.com/platforms/ST-Nucleo-WB55RG/>

¹²<http://stm32f4-discovery.net/2014/05/all-stm32f429-libraries-at-one-place/>

available through this resource. However, ARM can just as easily backup their repositories via other outlets, including the hosting of their own.

2.3.2 Workspaces

The notion of a workspace simply gives provides some directory on the development computer. A workspace is merely a directory in the user's home directory. You can select any directory to act as a workspace.

This space allows developers to produce code and keep it organized. By default, the installation of Mbed Studios produces the installation user's first workspace in their workspace. For example, you might store a common MbedOS source for programs you build in the workspace. Likewise, you can use the workspace to connect a library or several libraries used by programs written in the workspace.

2.3.3 Creating A Program

The mBed Suite documentation provides an excellent how-to guide on creating a program ¹³. This process works out in a very straight forward way.

2.3.4 Importing A Program

This process is a simple file system operation combined with applications for your favorite version control system. In this example, this work presents GitHub. For the reader's purposes, any version control system can work. Teaching these version control systems is outside the scope of this work.

2.3.5 Importing Libraries

ARM made importing a program rather simple by utilizing the Eclipse Theia platform. The most common set of libraries import is the mBedOS itself. This framework contains both the real-time operating system (RTOS) mBedOS and its fundamental C/C++ libraries. It also contains libraries for other languages such as Python.

Demo:

¹⁴

2.4 Your Workspace

Borland made workspace directories a thing back in the 1980s and the Eclipse Foundation formulated much of its products operation around this concept. Mbed Studio inherits this from its Eclipse Theia roots.

A workspace is simply a directory that an IDE utilizes to manage its projects. In the last 20 years, many have wrapped their version control working directory

¹³<https://os.mbed.com/docs/mbed-studio/current/create-import/index.html>

¹⁴<https://os.mbed.com/docs/mbed-studio/current/manage-libraries/index.html#importing-a-library>

into their workspace. Mbed detects the artifacts from these version control systems (VCS) to determine which VCS the developer uses. Therefore, Mbed provides tools to interface with the VCS and facilitate management thereof.

Some developers adopt tendencies from their agile web application to utilize a dedicated build system. These dedicated build systems work with version control systems to establish the notion of work code. These systems track code to determine when it is in a working state and when it is not. Many tools exist to determine what working state comprises. Does the code compile? Does the code pass unit tests? For code trees off the main branch, what new features does this separate branch examine and or present?

For some embedded systems, it makes sense to include a dedicated build system with the product or interface thereof. It provides users and technicians a mechanism to determine versions software that work together. Therefore, the technician can choose configurations that meet customer needs.

All of these capabilities stem from the basic notion of a workspace. The workspace is the developers first tool of managing the software they develop on any level. Build your workspace with care.

From the workspace, you can create programs from templates. The first examples presented in this text only utilize blank and blinky template programs. Most of the others require the utilization of network establishing components. Some boards and devices build these features in and others don't. The more interconnected your product is entails the need for further cyber security to protect it from abuse.

2.4.1 The simple C++ class

The ANSI, NIST and ISO committees; who have taken an interest in C++ language; developed several iterations to capture the basic notion of a class. For many students of computer science, the C++ language is the first language learned. ANSI/ISO has governed the standard by which each generation of student has learned the notion of a class.

The basic notion of a class provides an encapsulation of member properties and action methods. Basic automata theory captures some of the basics of object oriented programming as input, states, and outputs.

So, we create a simple class to spell out Hello World.

In C++, there exists two notions of a string. Most 1980's and 1990's students of computer science remember the character array. In the 2000's the notion of a vector to dynamically adjust for growing data entered in the standard's body of attention. So, a string class entered the standard template library (STL) that exhibited traits similar to those found in Java and Objective-C. This approach does bear fruit for features useful in control devices.

A simple method of devising a C++ class includes the simplest program taught, namely "Hello World." Some also pluck silly little phrases from 1980's movies like 'Short Circuit'. To illustrate a little mastery of data types, we add to the class some simple integer and floating point members.

A few things to remember in developing a C++ class. One, we use the macro system to determine when to define a class. The define needs to differ in some way from the name of the class or struct (say an all caps form of the name, where as the name itself just starts with a capital letter). Lastly, contain either a primitive from of marshallng or overload the input and output stream operators.

Let us first start from the most basic program known, “Hello World.” This program is realitively simple. Now, let us make give this program a class. The premise is that we have some object that combines basic features together to form a cohesive sentence. Let us take that cliché from the beloved 80’s classic, “Short Circuit.” The cliché is “Please don’t disassemble number 5.” This cliché has both a sentence and number in the statement. Therefore, we want the class to assemble this sentence into something we can print.

Thus, we develop the notion of concatenation of strings. The STL string object has a `to_string` function that exists to make strings out of primitives. In later chapters, we shall utilize the string object to parse simple language statements into objects and vise versa.

2.4.2 Creating Libraries

So why did we just tell you about the C++ class. Simply put, any library we build should utilize namespaces appropriately. It should allow customers to use these libraries for their products, too. Yes, fellow developers may exist as a customer. This goes to the Object-Oriented Program mantra about sharing classes/objects.

This work demonstrates the creating a library first with the Hello World library example. Eventually, we introduce a real world example such as a Oscilloscope class.

3 Basic Hard Tools

3.1 Work on Timer

In cases where we ask the process to wait, we should ensure that the I/O pipe empties. Otherwise, we have no idea when this process takes place. It can occur in the wrong times.

There are third party USB drivers such as ¹⁵.

Also, the timer’s have issue with floating point numbers.

Lastly, the STDIO has trouble with printing floats.

3.2 Flushing The Standard Input Output

Prior to mBedOS 5, the use of the C Standard Input Output library meant opening a USB serial port. Most of the C Standard Input Output library functions

¹⁵https://os.mbed.com/users/gte1/code/STM32_USBDevice/

were methods of these singleton classes.

With mBedOS 6, the C Standard Input Output library uses the main USB serial port by default. Therefore, serial communication works the way a typical desktop/laptop environment does, with one exception. Threads and Interrupt Service Routines (especially timers) don't play nice with the buffer. The process of printing or scanning characters does not have the real time behavior when the either real time events occur. Thus, the developer does have to keep track to clear the buffer.

3.3 Blinky

For many in computer programming industries, the first program a developer writes is 'hello world.' The goal of such a program is to demonstrate that when developer runs the program that it does something the user can observe.

In this example, we develop a program called blinky. This programs main objective seeks to show some observable work. In this case, the developer can put together a external circuit or use on board lights of the Nucleo to show the program doing work.

```
Setup DigitalOut Class for pin PC_1
Setup DigitalOut Class for pin PC_0
while Always true do
    Toggle PC_1
    Wait
    Toggle PC_0
    Wait
end while
```

We can also do basic threads to allow the OS to handle wake up times. The basic algorithm for the thread control function is similar. The pin object needs to be relatively global to the name space. A good exercise is to build a class for blinky with pin and timer value for members. The actions of this class need to include its initiation with pin number id and default timer values. More actions entail starting and stopping the thread.

The ARM team changed the thread library to use the standard chrono space for its time measurements. For those of us who trained first on C/C++ 99 and earlier, use of this library seems foreign. As shown in the listing, an object can be created from this Standard Chrono namespace. mBed Studio also allows compound interpretation of number and unit as the same namespace object as shown in the main body.

```
#include "PinNames.h"
#include "mbed.h"
#include "rtos.h"
#include <chrono>
#include <ratio>

DigitalOut LEDA (PC_1);
```

```

DigitalOut LEDB(PC_0);
Thread thread1, thread2;

void LEDAControl()
{
    while(true){
        LEDA = !LEDA;
        std::chrono::seconds d(1);
        ThisThread::sleep_for(d);
    }
}

void LEDBControl()
{
    while(true){
        LEDB = !LEDB;
        std::chrono::milliseconds d(500);
        ThisThread::sleep_for(d);
    }
}

// main() runs in its own thread in the OS
int main()
{
    thread1.start(LEDAControl);
    thread2.start(LEDBControl);
    while (true) {
        ThisThread::sleep_for(10s);
    }
}

```

3.4 Seven Segment LED

The seven segment light emitting diode circuit example yields some interesting issues for a microcontroller. One, the basic digit requires one digital out pin per segment (in other words seven). Two, the circuit also requires a common ground. Three, if the circuit multiple digits involves multiple digits, these devices store logic levels. This allows another digital pin out set to determine which digit to change.

This issue is a classic issue dating back to early micro-controllers. This issue allows most instructors of micro-controller theory to segway a lesson from basic digital design into the curriculum. Therefore, we see a simple software definition of a seven segment LED structure to determine the digital output pins.

The mBedOS boards allow software to address whole port families. We can address ports A, B, C, etc. as a whole register. This makes the development of libraries and classes a much simpler exercise.

One word of advice, pick your use of ports carefully. If the controller needs to read in analog to digital, produce pulse width modulation, or digital to analog out then these operations can't share the port devoted to managing the seven segment LED.

The basic digital design portion of this exercise requires one to map the each digit to what pins must be turned on. This map must then be applied to an 8-bit word that controls the pins. Note, the designer can do this with individual digital out operations. It simply requires on the order of 8 sets operations more to do so by individual digital out instructions. Where as, assigning a single 8-bit word requires fewer instructions.

In this example, we use 5161AS seven segment LED provided in the Rex Qualis Uno R3 Project Starter Kit. There are other seven segment LED models made, and one must identify the segments to build the circuit properly.

The pins for the Nucleo-F413ZH can be found online¹⁶. The pins for a basic bread board with the 5161AS seven segment LED can be found in figure ??.

Table 1: Seven Segment Display Port Values

Number	PC 7	PC 6	PC 5	PC 4	PC 3	PC 2	PC 1	PC 0	Hex Value
0	0	0	1	1	1	1	1	1	0x3F
1	0	0	0	0	0	1	1	0	0x06
2	0	1	0	1	1	0	1	0	0x5b
3	0	1	0	0	1	1	1	1	0x4F
4	0	1	1	0	1	1	1	0	0x66
5	0	1	1	0	1	1	0	1	0x6D
6	0	1	1	1	r5c6	1	0	1	0x7D
7	0	0	0	0	0	1	1	1	0x07
8	0	1	1	1	1	1	1	1	0x7f
9	0	1	1	0	1	1	1	1	0x6f

Configure Port C Lower Byte as a group

Define segment patterns

Set Count to 0

while Always **true do**

Send count to display

Wait 1 second

if Count is greater or equal to 10 **then**

set count to 0

end if

end while

¹⁶<https://os.mbed.com/platforms/ST-Nucleo-F413ZH/>

```

/*
    This 7-Segment Counter is based on a textbook
    example from Dogan Ibrahim's ARM-based Microcontroller Projects Using mbed.

    Modifications were made by Dan Beatty to adjust to mBed Studio and mBedO

*/

#include "mbed.h"
#include "rtos.h"

PortOut Segments(PortC, 0xFF);
int LEDS[] = {0x3f, 0x06, 0x5b, 0x4f, 0x66, 0x6d, 0x7d, 0x07, 0x7f, 0x6f};

// main() runs in its own thread in the OS
int main()
{
    int count = 0;

    while (true) {
        Segments = LEDS[count];
        wait_us(1000000);
        count++;
        if (count >= 10) count = 0;
        printf("%d \n", count);
    }
}

```

3.5 Basic Digital Input

Basic digital input can be demonstrated by an 3 sets of switch input. The input goes low when the switch is closed and high when the switch is open. The switches are simple buttons provided in the Rex Qualis Electronic Component Fun Kit. This kit also has an RGB LED. The top of the LED is transparent and one can see the etching. The fat etching is the common ground. We connect the other three to red, blue, and green control pins. These pins need a 330/390 ohm resistor to establish sufficient current limits for the Nucleo Board.

Configure the RGB output

Configure the R, G, B buttons as inputs and enable them as Pull-ups

Clear all LEDs

while Forever **TRUE do**

if R is pressed **then**

 Toggle Red color for display

end if

```

if G is pressed then
    Toggle Green color for display
end if
if B is pressed then
    Toggle Blue color for display
end if
end while

```

```

/*****
In this project , an RGB LED is connect. So are 3 buttons.
Pressing a button toggles the corresponding color.

```

```

R button = PC_0
G button = PC_1
B button = PC_2

```

```

The RGB LED pin are connected as follows :
Red = PC_3
Green = PC_4
Blue = PC_5

```

```

Original Supplied by Dogan Ibrahim , August 2018 in
"ARM-based Microcontroller Projects Using mBed"
Modified by Dan Beatty for use in mBed Studio
mBed OS 6.x

```

```

*****/

```

```

#include "mbed.h"

```

```

BusOut RGB(PC_3, PC_4, PC_5);
DigitalIn R(PC_0, PullUp);
DigitalIn G(PC_1, PullUp);
DigitalIn B(PC_2, PullUp);

```

```

// main() runs in its own thread in the OS
int main()
{
    RGB = 0;
    while (true) {
        if (R == 0) {
            if (RGB & 1 == 1)
                RGB = RGB & 6;
            else
                RGB = RGB | 1;
        }
    }
}

```

```

    }
    if (G == 0) {
        if (RGB & 2 == 2)
            RGB = RGB & 5;
        else
            RGB = RGB | 2;
    }
    if (B == 0) {
        if (RGB & 4 == 4)
            RGB = RGB & 3;
        else
            RGB = RGB | 4;
    }
}
}

```

3.6 Relays

3.7 Optical Isolators

4 Analog to Digital Conversion

To test the basic idea of a Analog to Digital Conversion (ADC), we can use the concept of a voltmeter. Another way is with a thermistor circuit. Some temperature sensitive devices have a more calibrated response and we have formulae that can translate the voltage to known temperature scales easily.

4.1 Simple Analog In - Voltmeter

This example sets up two versions of the same general circuit. The first version is the simplest one can make. Often, this version does not scale to real world problems. Real world problems can include large power issues that would damage the microcontroller in the process. The second version compensates for circuits with larger currents by placing a optical isolator in between the test circuit and the microcontroller.

I learned to look up the pin name and its location on the board. There pin names that don't necessarily correspond to the label next pin itself. The A0 pin on the CN9 pin set is actually PA_3. It is easy to make the mistake in calling this pin PA_0. This distinction can lead to massive mistakes and cause to operate the board in a wrong manner.

To demonstrate simple ADC in, I use a simple voltage divider circuit with three resistors. Voltage is propotional to resistance. Therefore, we can measure voltage across a resistor and expect its value. That proportion should change if we can the resistance of one of the other resistors.

Therefore, I establish this measurement across a constant $330\ \omega$ resistor. Then, I do similar across a $330\ \omega$ potentiometer. We see the voltage go from V_{in} . This helps establish a baseline for comparing the ADC readings.

I built the circuit with parts acquired from ¹⁷. The fun kit ¹⁸ provides many of the resistors I need. The UNO Project starter ¹⁹ provides some additional parts that I can use later. Also the UNO Project starter provides a Arduino UNO that I can use for comparison. Lastly, I used some competitor products to provide the potentiometers and inductors that I need for future examples.

Also, it is important to note a fix on stdio. Mbed.os by default turns off floating point parameters in stdio/UART²⁰. There is a parameter in platform/mbed_app.json. By default, a new mbed project has the value for 'minimum-printf-enable-floating-point' set to false. In order to print out floating point, this value needs to be set to true.

With this, we can see in the example that the voltage read from the potentiometer is pretty close to what a common multimeter reads. There are adjustment factors that we apply to give a rough calibration. For production, it would help to obtain a more calibrated set of values.

We see a similar case with thermistor based thermometers. I set up a simple 330ω resistor in series with a thermistor out of the fun kit. Here we can measure the voltage across the thermistor. We then can measure ratios and offsets for temperature.

$$T = \frac{(mV - 225.0)}{10.0} \quad (1)$$

4.2 Change Flashing Rate with Potentiometer

4.3 Thermostat

4.4 Light Meter

4.5 Thermo-resistor -Taking the Temperature

This is an example of an Analog in problem

¹⁷<http://www.rexqualis.com/products/>

¹⁸<http://www.rexqualis.com/product/electronics-component-fun-kit-w-power-supply-module-male-to-female-jumper-wire-830-tie-points-breadboard-precision-potentiometer-resistor-for-arduino-raspberry-pi-stm32/>

¹⁹<http://www.rexqualis.com/product/uno-project-super-starter-kit-for-arduino-w-uno-r3-development-board-detailed-tutorial/>

²⁰<https://github.com/ARMmbed/mbed-os/blob/master/platform/source/minimal-printf/README.md>

4.6 Sound Level Meter

5 Analog Out

5.1 Fixed Voltage

5.2 Sawtooth

5.3 Sine Wave Generator

5.4 Combining the Capabilities of Each Wave Generator Type

5.5 Buzzer Fun

5.6 Pulse Width Modulated Buzzers

6 Optical Isolation

I remember a lesson from my embedded computing class back in the Spring of 1998. Professors Darrel Vines, Michael Parton, and Mike Giesselman told us over and over about the importance of optical isolation. These professors worked in pulsed power, and I wish I had the wisdom back then to realize just how important this subject is.

Pulsed Power delivers a large amount of current in a very short space and time. The amount of current involved can easily melt a microcontroller and destroy it. Yet, these controllers are essential in regulating such power elements to fulfill their purpose.

The fun kit comes with a 4N35 white paper can be found at²¹. The inputs on pins 1 and 2 can be thought of as in and out for a light emitting diode (LED). The light from the LED feeds a photo-transistor that can handle much higher currents.

7 Transistor Circuits

PN2222

Transistor

8 Ethernet Web Server Libraries

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²¹<https://www.digchip.com/datasheets/parts/datasheet/161/4N35-pdf.php>

²²https://github.com/khoih-prog/EthernetWebServer_STM32

9 Digital Signal Processing

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10 Secure Digital Block Devices

11 Home Made RADAR

12 Registering the Serial Number

13 Multiplexed LED Multi-Thread

The original work for this example comes from [?]. The value in this exercise exists in the multi-thread operations. We use this lesson to construct classes that inherently use threads to gather information.

²³<http://www.emcu.it/STM32F4xx/STM32F4-Library/STM32F4-Library.html>