ECEN 5803

Mastering Embedded System Architecture

(Fall-2023)

PROJECT-1 : MODULE 6

BARE METAL FLOWMETER SIMULATION

Date

10/24/2023

Guided By

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Submitted By

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1. What is the frequency estimate from your provided sample ADC data?

We found a frequency estimate for samples around 40 Hz using our frequency estimation algorithm. We got around 250 samples per period.

Period = 250 * sample time

Period = 250 * 100us

Period = 25ms

Frequency = 1 / 25ms = 40Hz

```
      MESA Project-1 Module-6!


System Reset
Code ver. 3.0 2016/10/25
Copyright (c) University of Colorado

 *********** Select Mode ***********
 1] Hit NOR - Normal
 2] Hit QUI - Quiet
 3] Hit DEB - Debug
 4] Hit REG - Register: R0-R15
 5] Hit MEM - Memory: Data Section
 6] Hit STA - Stack: 16 words
 7] Hit V   - Version#

 ***********************************
 Enter Mode:  NOR
Mode=NORMAL
            Flow: 1537.45 Temp: 37.67 C Freq: 40 Hz
NORMAL  Flow: 1537.43 Temp: 38.37 C Freq: 40 Hz
NORMAL  Flow: 1537.43 Temp: 38.02 C Freq: 40 Hz
NORMAL  Flow: 1537.44 Temp: 37.67 C Freq: 40 Hz
NORMAL  Flow: 1537.43 Temp: 38.37 C Freq: 40 Hz
NORMAL  Flow: 1537.43 Temp: 38.37 C Freq: 40 Hz
NORMAL  Flow: 1537.41 Temp: 39.40 C Freq: 40 Hz
NORMAL  Flow: 1537.42 Temp: 38.02 C Freq: 40 Hz
NORMAL  Flow: 1537.44 Temp: 38.02 C Freq: 40 Hz
NORMAL  Flow: 1537.42 Temp: 38.37 C Freq: 40 Hz
```

2. What is the calculated flow you see from your input?

As shown in the screenshot above, we get around 1537.43 gallons/second flow.

3. What is the range of temperatures you measured with your embedded system?

```
NORMAL  Flow: 1537.43 Temp: 38.37 C Freq: 40 Hz
NORMAL  Flow: 1537.43 Temp: 38.02 C Freq: 40 Hz
NORMAL  Flow: 1537.44 Temp: 37.67 C Freq: 40 Hz
NORMAL  Flow: 1537.43 Temp: 38.37 C Freq: 40 Hz
NORMAL  Flow: 1537.43 Temp: 38.37 C Freq: 40 Hz
NORMAL  Flow: 1537.41 Temp: 39.40 C Freq: 40 Hz
```

The minimum temperature reading is around **38.37** when the system is powered up.

```
NORMAL  Flow: 1537.41 Temp: 39.75 C Freq: 40 Hz
NORMAL  Flow: 1537.40 Temp: 40.09 C Freq: 40 Hz
NORMAL  Flow: 1537.39 Temp: 40.79 C Freq: 40 Hz
NORMAL  Flow: 1537.40 Temp: 40.09 C Freq: 40 Hz
NORMAL  Flow: 1537.39 Temp: 40.79 C Freq: 40 Hz
NORMAL  Flow: 1537.40 Temp: 39.75 C Freq: 40 Hz
NORMAL  Flow: 1537.39 Temp: 40.44 C Freq: 40 Hz
NORMAL  Flow: 1537.39 Temp: 40.79 C Freq: 40 Hz
NORMAL  Flow: 1537.39 Temp: 40.44 C Freq: 40 Hz
NORMAL  Flow: 1537.41 Temp: 39.75 C Freq: 40 Hz
```

After running the system for some time, the temperature varies between **39.75 C and 40.79 C, giving a variation range of 1.04 C.** The total temperature variation from system start is **2.42 C**.

4. How much time does the code spend in the main loop versus in Interrupt Service Routines?

For this benchmarking, we measure the time spent in main and ISR every 1000 SwTimerIsrCounter counts, equating to 100ms.

```
 *********** Select Mode ***********
 1] Hit NOR - Normal
 2] Hit QUI - Quiet
 3] Hit DEB - Debug
 4] Hit REG - Register: R0-R15
 5] Hit MEM - Memory: Data Section
 6] Hit STA - Stack: 16 words
 7] Hit V   - Version#

 ***********************************
 Enter Mode:
Time spent in main 1955 us 12336 count
Time spent in IRQ 839 us 5428 count
Time spent in main 98407 us 12336 count
Time spent in IRQ 2899 us 1429 count
Time spent in main 98893 us 12336 count
Time spent in IRQ 2907 us 1434 count
Time spent in main 98450 us 12336 count
Time spent in IRQ 2899 us 1429 count
Time spent in main 97144 us 12336 count
Time spent in IRQ 2871 us 1416 count
Time spent in main 98059 us 12336 count
Time spent in IRQ 2889 us 1425 count
```

In a 100ms period, the main takes around 98400 us and executes around 12336 times. With these values, we can calculate the time taken to execute a single iteration. The ISR takes 2900 us and executes around 1425 times.

For one iteration:

Time spent in main = 98400 us / 12336

= **7.98 us**

Time spent in ISR = 2900 us / 1425

= 2.04 us

5. Estimate the % of CPU cycles used for the main foreground process, assuming a 100-millisecond operating cycle.

STM32F401RE operates at 84MHz.

Single Cycle Time = 1 / (84 * 10^6) = **11.9ns**

Previously, we estimated that the main foreground spends around 98400 us for 100ms operating time.

Number of cycles used by main = 98400us / 11.9ns

CPU cycles used in main = 8.269 * 10^6

Total CPU cycles in 100ms = 8.403 * 10^6

% of CPU cycles used for main =(8.269 * 10^6 / 8.403 * 10^6) = 98.4

6. Calculate the power consumption for your complete system (including proposed hardware additions) when in full run mode and again in low power mode.

We have considered the following components in our Project 1 Module 6 design.

Component	Voltage	Min current (Low Power Mode)	Max Current
STM32F401RE	3.3V	2.4 µA If we consider ADC running in the background and waking up the CPU after 1000 samples through DMA interrupt, add +1.6mA.	146uA/MHz @84MHz 12.26 mA ADC consumes an additional 1.6mA
16x2 LCD (with backlight)	5V	130mA (Typical)	
2 LEDs	1.9V	20mA (Typical)	
4-20 Current Loop (Texas XTR11x)	5V	200µA (Typical)	

Using the table above, we can calculate the power consumption in Low Power mode and Full running Mode.

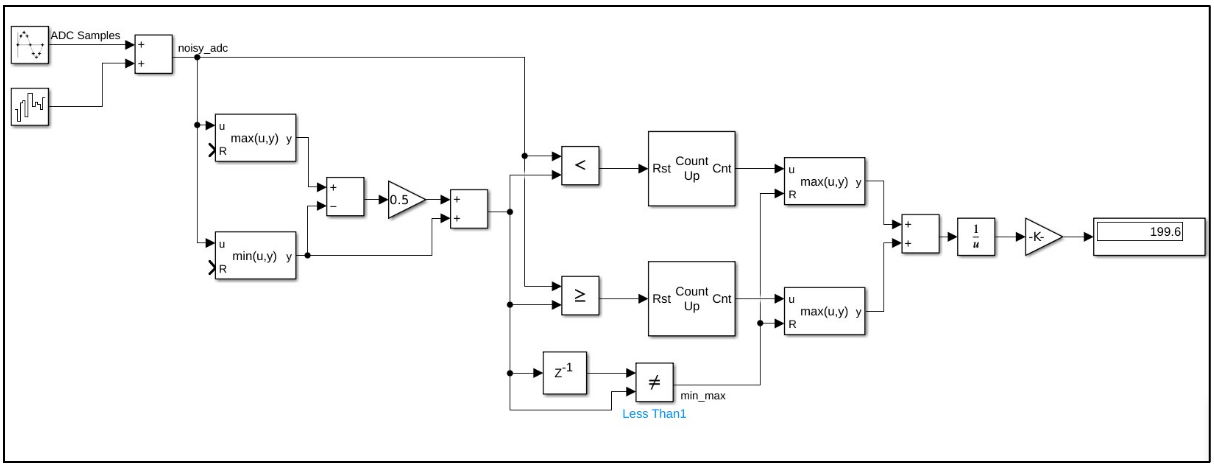
Component	Min Power	Max Power
STM32F401RE	7.92uW	45.74mW
16x2 LCD (with backlight)	OFF	650mW
2 LEDs	OFF	38mW
4-20 Current Loop (Texas XTR11x)	OFF	1mW
TOTAL	7.92uW	734.74mW

We have assumed that all the other peripherals are put to sleep, with that low power consumption of 7.92uW. When running at full speed and all the peripherals are enabled, the system consumes 734.74mW.

If we leave the essential peripheral ADC on for taking samples and then wake up the CPU after 1000 samples, then in low power mode, the system will consume 5.28mW.

If we keep the LCD on always and ADC takes samples, the system will consume 655.28mW with the CPU in a deep sleep.

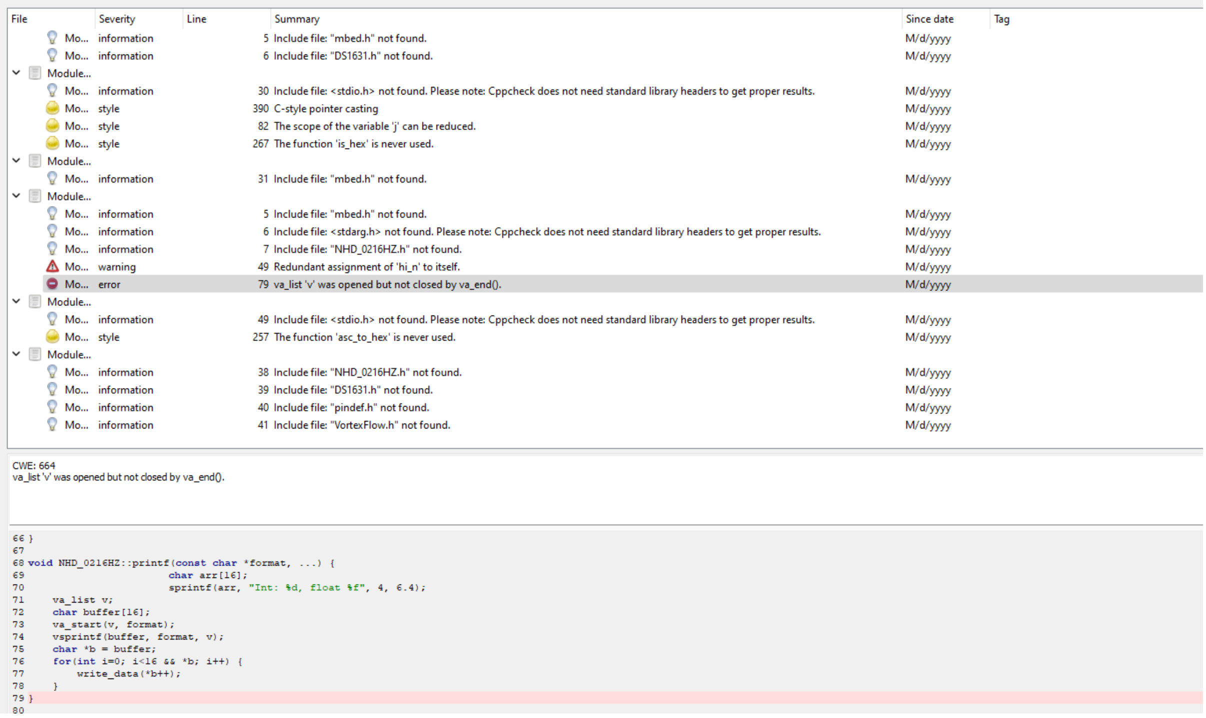
Simulink Model for Frequency Detection



We developed the above model for frequency detection. The model first tries to predict the mean amplitude value by taking the maximum and minimum amplitudes. The mean amplitude adjusts to an accurate value as more samples are obtained. After obtaining the mean amplitude, the model counts the maximum number of samples above and below the average amplitude value. These values are added together to get the sample count for a period. Since we know the sample time as 100us, we can calculate the frequency by taking the reciprocal.

CPPCheck

After running the CPPCheck, we get one error and one warning.



File	Severity	Line	Summary	Since date	Tag
Mo...	information	5	Include file: "mbed.h" not found.	M/d/yyyy	
Mo...	information	6	Include file: "DS1631.h" not found.	M/d/yyyy	
Module...					
Mo...	information	30	Include file: <stdio.h> not found. Please note: Cppcheck does not need standard library headers to get proper results.	M/d/yyyy	
Mo...	style	390	C-style pointer casting	M/d/yyyy	
Mo...	style	82	The scope of the variable 'j' can be reduced.	M/d/yyyy	
Mo...	style	267	The function 'is_hex' is never used.	M/d/yyyy	
Module...					
Mo...	information	31	Include file: "mbed.h" not found.	M/d/yyyy	
Module...					
Mo...	information	5	Include file: "mbed.h" not found.	M/d/yyyy	
Mo...	information	6	Include file: <stdarg.h> not found. Please note: Cppcheck does not need standard library headers to get proper results.	M/d/yyyy	
Mo...	information	7	Include file: "NHD_0216HZ.h" not found.	M/d/yyyy	
Mo...	warning	49	Redundant assignment of 'hi_n' to itself.	M/d/yyyy	
Mo...	error	79	va_list 'v' was opened but not closed by va_end().	M/d/yyyy	
Module...					
Mo...	information	49	Include file: <stdio.h> not found. Please note: Cppcheck does not need standard library headers to get proper results.	M/d/yyyy	
Mo...	style	257	The function 'asc_to_hex' is never used.	M/d/yyyy	
Module...					
Mo...	information	38	Include file: "NHD_0216HZ.h" not found.	M/d/yyyy	
Mo...	information	39	Include file: "DS1631.h" not found.	M/d/yyyy	
Mo...	information	40	Include file: "pindef.h" not found.	M/d/yyyy	
Mo...	information	41	Include file: "VortexFlow.h" not found.	M/d/yyyy	

CWE: 664
va_list 'v' was opened but not closed by va_end().

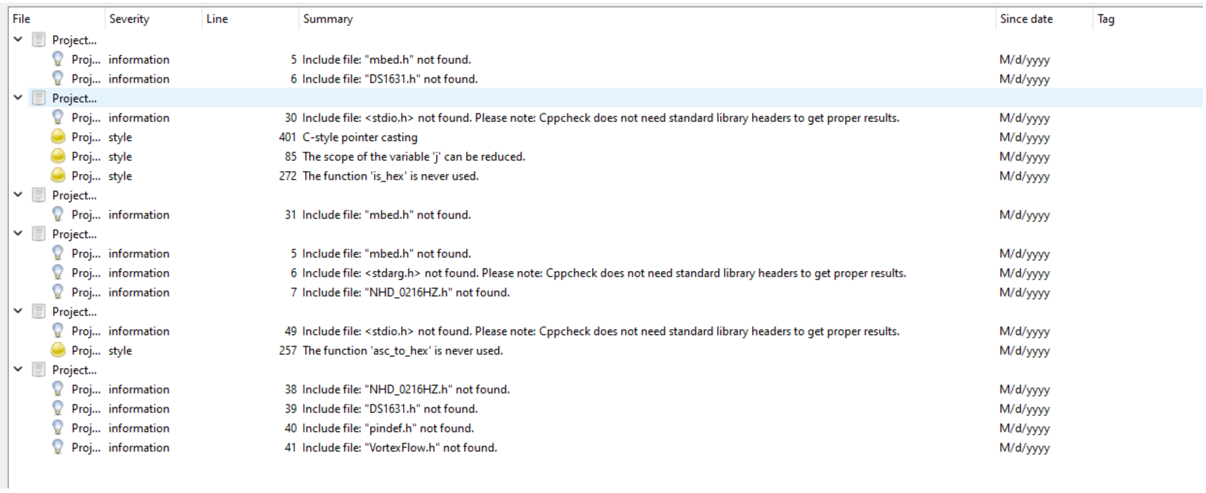
```
}

void NHD_0216HZ::printf(const char *format, ...) {
                    char arr[16];
                    sprintf(arr, "Int: %d, float %f", 4, 6.4);
    va_list v;
    char buffer[16];
    va_start(v, format);
    vsprintf(buffer, format, v);
    char *b = buffer;
    for(int i=0; i<16 && *b; i++) {
        write_data(*b++);
    }
}
```

- The error appears because va_start does not end with va_end. Since va_start uses dynamic allocation, we must hanlde this by adding va_end.
- The warning appears because there is a redundant assigning of the same value to the same variable twice. This can be resolved by taking the additional assignment.

Apart from this, we didn't notice any major warnings or errors.

After resolving the issues:



File	Severity	Line	Summary	Since date	Tag
Project...					
Proj...	information	5	Include file: "mbed.h" not found.	M/d/yyyy	
Proj...	information	6	Include file: "DS1631.h" not found.	M/d/yyyy	
Project...					
Proj...	information	30	Include file: <stdio.h> not found. Please note: Cppcheck does not need standard library headers to get proper results.	M/d/yyyy	
Proj...	style	401	C-style pointer casting	M/d/yyyy	
Proj...	style	85	The scope of the variable 'j' can be reduced.	M/d/yyyy	
Proj...	style	272	The function 'is_hex' is never used.	M/d/yyyy	
Project...					
Proj...	information	31	Include file: "mbed.h" not found.	M/d/yyyy	
Project...					
Proj...	information	5	Include file: "mbed.h" not found.	M/d/yyyy	
Proj...	information	6	Include file: <stdarg.h> not found. Please note: Cppcheck does not need standard library headers to get proper results.	M/d/yyyy	
Proj...	information	7	Include file: "NHD_0216HZ.h" not found.	M/d/yyyy	
Project...					
Proj...	information	49	Include file: <stdio.h> not found. Please note: Cppcheck does not need standard library headers to get proper results.	M/d/yyyy	
Proj...	style	257	The function 'asc_to_hex' is never used.	M/d/yyyy	
Project...					
Proj...	information	38	Include file: "NHD_0216HZ.h" not found.	M/d/yyyy	
Proj...	information	39	Include file: "DS1631.h" not found.	M/d/yyyy	
Proj...	information	40	Include file: "pindef.h" not found.	M/d/yyyy	
Proj...	information	41	Include file: "VortexFlow.h" not found.	M/d/yyyy	