CIWS-MWM Datalogger

Firmware Documentation

Firmware ver. 1.0.0

Project Organization

The CIWS-MWM Datalogger project is organized using the standard approach using header files and source files, applied to an Arduino IDE environment. For those unfamiliar, C/C++ code is separated into header files and source files. The following example aims to make it clear why this is the case.

Consider the following C code:

```
int main()
{
	int a = 2;
	int b = a * 4;
	printf(“The result is %d\n”, b);
	int c = b * 4;
	printf(“The result is %d\n”, c);
	return 0;
}
```

Obviously, this is a trivial example to illustrate how much more complex code is handled in this project. This code can be much more modular (and readable) by introducing a function:

```
int times4(int input)
{
	return input * 4;
}


int main()
{
	int a = 2;
	int b = times4(a);
	printf(“The result is %d\n”, b);
	int c = times4(b);
	printf(“The result is %d\n”, c);
	return 0;
}
```

The code is now more readable and modular, but now the `main()` function is at the bottom of the file (and it has to be, otherwise the function `times4()` would not be recognized in `main()`. Fortunately, programmers are good at finding ways around problems. The following code listing works just as well as the previous example:

```
int times4(int input);

int main()
{
      int a = 2;
      int b = times4(a);
      printf(“The result is %d\n”, b);
      int c = times4(b);
      printf(“The result is %d\n”, c);
      return 0;
}

int times4(int input)
{
      return input * 4;
}
```

Now, the `main()` function is much closer to the top of the file, making it easy to find the program's starting point. The `main()` function recognizes the `times4()` function because it's declared above `main()` using what's called a function prototype, while the rest of `times4()` is defined below `main()`. This works really well for a handful of functions, but defining every function in one file becomes a mess in a project like the CIWS-MWM firmware. To counter this, two new files are created: `times4.h` and `times4.cpp`. The function prototype goes in `times4.h`, and the function definition goes in `times4.cpp`, leaving the file containing `main()` nice and clean:

```
#include “times4.h”
int main()
{
      int a = 2;
      int b = times4(a);
      printf(“The result is %d\n”, b);
      int c = times4(b);
      printf(“The result is %d\n”, c);
      return 0;
}
```

Again, though this example seems trivial, it is a very good way to organize a large firmware project like CIWS-MWM. The aim of this section was to illustrate why the project is organized the way it is.

Main Loop: Firmware.ino

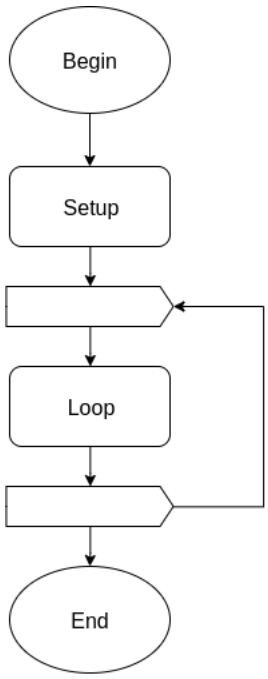
The file `Firmware.ino` is the program's starting point. All Arduino projects have a `.ino` file. Ours contains six functions:

- `void setup()`
- `void loop()`
- `void INT0_ISR()`
- `void INT1_ISR()`
- `void sdWriteError()`
- `byte numDigits()`
- `void storeNewRecord()`
- `byte bcdtobin(byte bcdValue, byte sourceReg)`

The functions `setup()` and `void()` in the `.ino` file are actually called in the following manner:

```
int main()
{
	setup();
	while(1)
	{
		loop();
	}
}
```

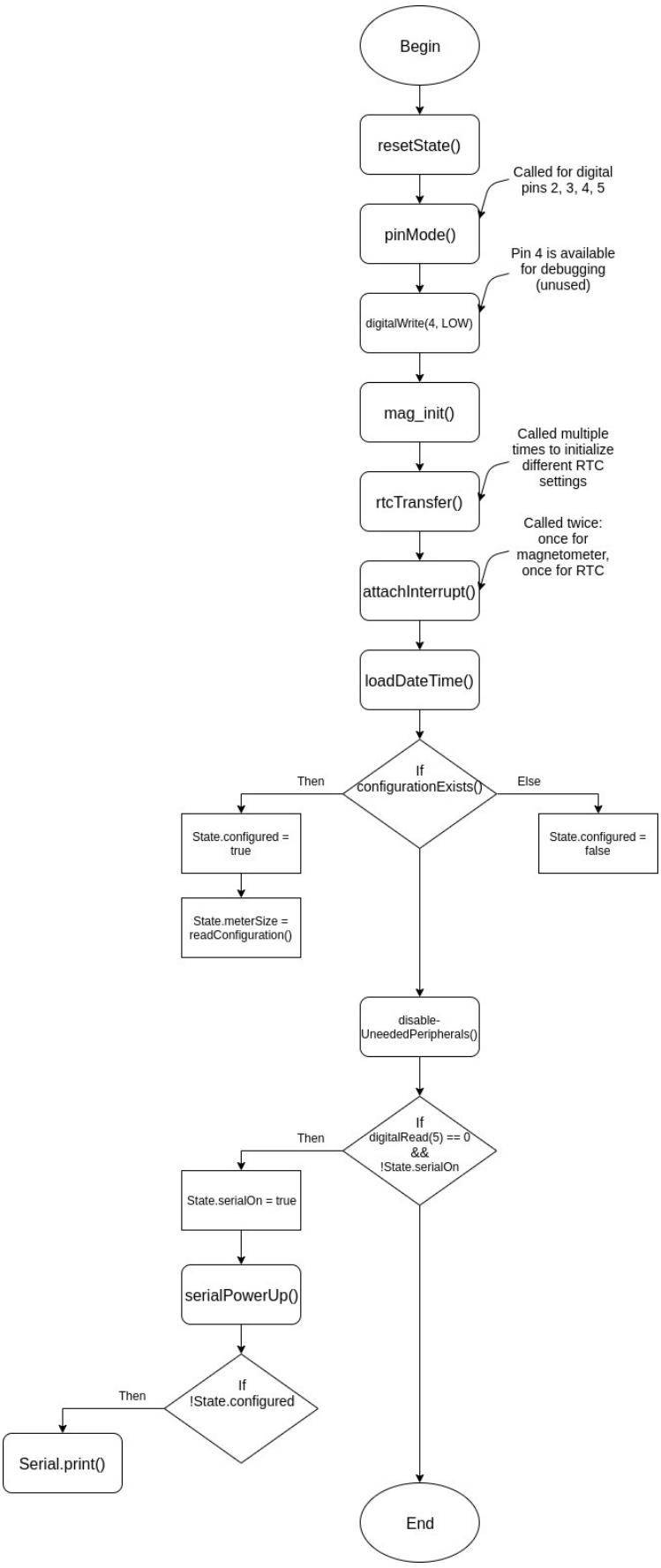
This way, `setup()` is called once, and `loop()` is called repeatedly until the microcontroller is reset. A flowchart of this process is shown here:



The `setup()` function does the following:

- Initializes the system state data structure
- Initializes GPIO Pins
- Initializes the magnetometer
- Initializes the real-time clock
- Sets up the magnetometer and real-time clock interrupt handlers
- Checks that the datalogger has valid configuration data
- Stops the clock for all unused peripherals
- Opens the serial interface if the serial activation button is pressed.

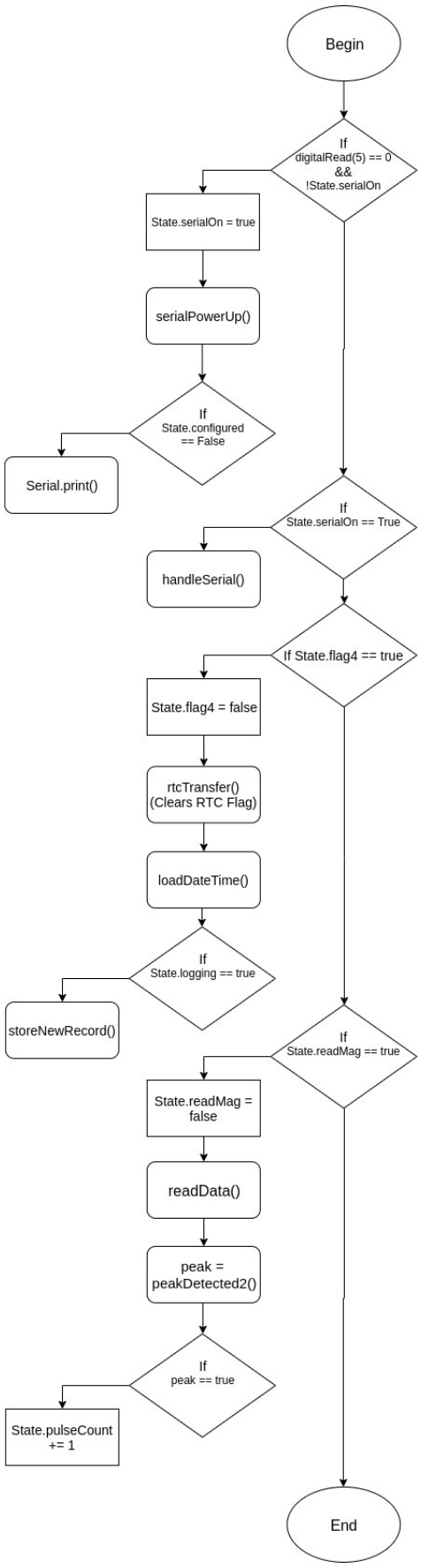
A flow chart of the `setup()` function is shown on the next page.


Begin
resetState()
pinMode()
Called for digital pins 2, 3, 4, 5
digitalWrite(4, LOW)
Pin 4 is available for debugging (unused)
mag_init()
rtcTransfer()
Called multiple times to initialize different RTC settings
attachInterrupt()
Called twice: once for magnetometer, once for RTC
loadDateTime()
If configurationExists()
Then
Else
State.configured = true
State.meterSize = readConfiguration()
State.configured = false
disable-UneededPeripherals()
If digitalRead(5) == 0 && !State.serialOn
Then
State.serialOn = true
serialPowerUp()
If !State.configured
Then
Serial.print()
End

The `loop()` function is the datalogger firmware's main loop, and performs the following actions:

1. Check if the serial activation button is pressed
2. Run the serial menu
3. Check if four seconds are up
4. Check if magnetometer data is ready
5. Process incoming data to count peaks

A flowchart of the `loop()` function is shown on the next page.


Begin
If digitalRead(5) == 0 && !State.serialOn
State.serialOn = true
serialPowerUp()
If State.configured == False
Serial.print()
If State.serialOn == True
handleSerial()
If State.flag4 == true
State.flag4 = false
rtcTransfer() (Clears RTC Flag)
loadDateTime()
If State.logging == true
storeNewRecord()
If State.readMag == true
State.readMag = false
readData()
peak = peakDetected2()
If peak == true
State.pulseCount += 1
End

The functions `INT0_ISR()` and `INT1_ISR()` are both interrupt service routines. For those unfamiliar with interrupts, an interrupt service routine is a function executed when an event in hardware occurs. `INT0_ISR()` code executes when the voltage on digital pin 2 transitions from low to high, and `INT1_ISR()` code executes when the voltage on digital pin 3 transitions from high to low.

The voltage signal on digital pin 2 is controlled by the magnetometer. When the magnetometer has new data ready to report, it sets the voltage on pin 2 high, causing `INT0_ISR()` to execute.

The voltage signal on digital pin 3 is controlled by the real time clock. When four seconds have elapsed, the real time clock sets the voltage on pin 3 low, causing `INT1_ISR()` to execute.

Both interrupt service routines simply set a flag to true. The main loop checks these flags, and if they are set, responds accordingly. This is good practice; interrupt service routines need to be kept as short as possible.

The function `sdWriteError()` is used by `storeNewRecord()` to detect when an error occurs during a write to the SD card. This is accomplished by comparing the number of bytes that should have been written with the number of bytes that were actually written. The number of bytes written to the SD card is returned when data is written to the SD Card. It should be noted that this function catches some, but not all, of the SD card errors, and a solution will soon be developed.

The function `numDigits()` is used by `storeNewRecord()` to determine how many bytes will be written when a value is written to the SD card. This value is passed as an input to `sdWriteError()` for comparing the number of bytes that should have been written with the number of bytes that were actually written.

The function `storeNewRecord()` is primarily responsible for storing data records to the datalogger's SD Card by performing the following actions:

1. Gather date and time information
2. Activate the SPI module's clock
3. Open a file on the SD Card
4. Print the following fields separated by commas:
    i. Timestamp
    ii. Record Number
    iii. Pulse Count
5. Close the file
6. Increment the record number
7. Deactivate the SPI module's clock

The function `bcdtobin()` is responsible for converting the Binary Coded Decimal (BCD) data from the real-time clock into standard binary data, and takes a BCD value and a bitmask corresponding to

the real-time clock from which the BCD value came from. This conversion is accomplished by multiplying the top 4 bits by ten and adding that number to the bottom four bits.

System State: state.h and state.cpp

These files define two C/C++ structs, `State` and `SignalState`.

`State` keeps track of several important values:

- `byte pulseCount` – The number of pulses in the current sample period.
- `byte lastCount` – The number of pulses in the previous sample period.
- `unsigned int totalCount` – The number of pulses since logging started.
- `unsigned long recordNum` – The record number of the current sample period.
- `bool logging` – Boolean flag: True if the device is logging, false if it is not.
- `bool flag4` – Boolean flag: True if four seconds has passed, false if not.
- `bool serialOn` – Boolean flag: True if serial interface is active, false if it is not.
- `bool SDin` – Boolean flag: True if an SD card has been initialized, false if not.
- `bool readMag` – Boolean flag: True if magnetometer data is ready, false if it is not.
- `char meterSize` – Stores the meter resolution, used to compute water flow.
- `bool configured` – Boolean flag: True if valid configuration data exists in memory.
- `char filename[13]` – Stores the current filename.
- `bool rewrite` – True if an SD write error was detected, indicating a rewrite is required.

This `State` struct is initialized using the function `void resetState(volatile State_t* State)`. The pulse counts are initialized to zero, the record number is initialized to one, and the boolean flags are initialized to false.

`SignalState` keeps track of values used for processing the magnetometer signal. A few values are left over from an older signal processing algorithm. These are noted, and will be removed in a future release.

- `float x[2] = {0, 0};` – Input signal from the magnetometer.
- `float s = 0;` – From old algorithm.
- `float sf[2] = {0, 0};` – From old algorithm.
- `float a = 0.95;` – DC Removal filter pole.
- `float y[2] = {0, 0};` – Output signal from DC Removal filter.
- `float offset = -0.005;` – From old algorithm.
- `bool slopeWasPositive = false;` – From old algorithm.
- `bool slopeIsPositive = false;` – From old algorithm.
- `bool triggered = false;` – Boolean flag for software-based schmitt trigger.

The use of these values is detailed in the next section, **Peak Detection**.

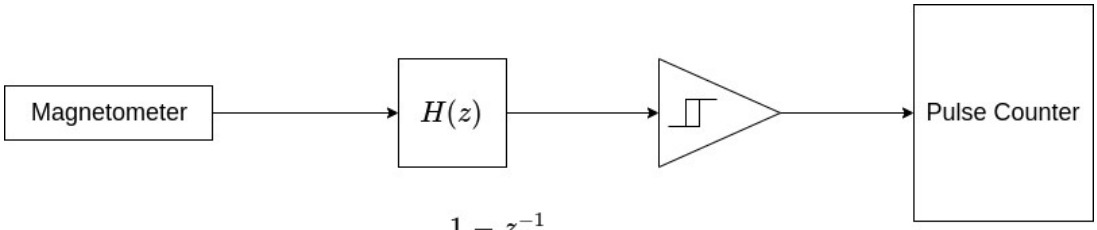
Peak Detection: detectPeaks.h and detectPeaks.cpp

These files define two functions:

1. `bool peakDetected(volatile SignalState_t* signalState)`
2. `bool peakDetected2(volatile SignalState_t* signalState)`

The function `peakDetected()` is deprecated, and will be entirely removed by the next version.

The function `peakDetected2()` is responsible for detecting peaks corresponding to water flow in the signal read by the magnetometer. Before going over the code, it is crucial to understand the filtering algorithm implemented by the code.



$$H(z) = \frac{1 - z^{-1}}{1 - \alpha z^{-1}}$$

Source:
https://www.embedded.com/design/configurable-systems/4007653/DSP-Tricks-DC-Removal

The function `peakDetected2()` implements the two middle blocks of the above diagram. The block *H(z)* removes the signal's DC offset. This centers the signal at zero, which permits a simple peak-detecting algorithm called a software schmitt trigger, the triangular block in the diagram.

The schmitt trigger watches for the signal to cross its high and low thresholds. When the signal crosses the high threshold, the schmitt trigger will count it as a peak, but will not count any other high-threshold crossing as a peak until the signal crosses the low threshold. This ensures that noise in the magnetometer's signal cannot be counted as extra peaks. This peak detection is implemented in the following way:

```
Begin:
    /** H(z) **/
    y[n] = a * y[n - 1] + x[n] - x[n - 1]
    /** Schmitt Trigger **/
    If triggered:
        If y[n] < -1:
            triggered is false
    If not triggered:
        If y[1] > 1:
            triggered is true
            return peak = true
End
```

A C/C++ struct called `SignalState` stores the current input sample (`x[n]`), the previous input sample (`x[n - 1]`), and the previous output sample (`y[n - 1]`). `SignalState` also holds `a` and `triggered`. Threshold values for the Schmitt Trigger are declared inside the function `peakDetected2()`. This information is all that is necessary to detect if a peak is occurring in the magnetometer's signal. `SignalState` is defined in the file `state.h`.

The value `a` is the pole of *H(z)*. For this filter, it is desirable for the pole to be close to, but not equal to, one. For any digital filter, a pole greater than or equal to one causes instability.

This function is only called once every time a data sample is collected from the magnetometer.

Magnetometer: magnetometer.h and magnetometer.cpp

The following functions are defined in `magnetometer.cpp` and `magnetometer.h`:

1. `bool mag_init()`
2. `void read_mag(int8_t* data)`
3. `void mag_transfer(int8_t* data, uint8_t reg, uint8_t numBytes, uint8_t RW)`
4. `readData(volatile SignalState_t* SignalState)`
5. `initializeData(volatile SignalState_t* SignalState)`

These functions are responsible for the initialization and reading of an LIS3MDL magnetometer. Above, they are listed in order of appearance, but in the following sections, they will be covered in order from low-level to high-level functionality.

The function `mag_transfer()` takes an array of data, a register number, the length of the array of data, and a read/write flag as input, and is responsible for writing data and reading data to and from the magnetometer. Most of the time, data will be read from the magnetometer, but data does get written to the magnetometer when initialized on startup. The data is read and written via an I^2C serial bus, and the Arduino IDE's Wire library is used for I^2C communication.

The function `mag_init()` does not take any input, and is responsible for initializing the magnetometer when the datalogger is started up. It utilizes the function `mag_transfer()` to write initialization data to the magnetometer. The following table lists the data written to each of the magnetometer's control registers, along with the behavior due to the data written.

Register	Data	Behavior
Control Register 1	0x32	- Temperature sensor disabled - X-Axis in Medium Performance Mode - Y-Axis in Medium Performance Mode - Output data rate ~560-570 Hz - Self-test disabled
Control Register 2	0x00 (Default)	- Output data scaled to $^{+}/_{-}$ 4 gauss
Control Register 3	0x00	- Low-power mode disabled - Sample: Continuous-conversion mode
Control Register 4	0x04	- Z-Axis in Medium Performance Mode
Control Register 5	0x80	- Set FAST READ

More data for these registers can be found in section 7 of the LIS3MDL datasheet. The key takeaway from this table is that the magnetometer is set to a high output data rate, medium performance mode for all axes, reads on a $^{+}/_{-}$ 4 gauss scale, and does what the datasheet refers to as FAST READ. FAST READ means that only the top half of the two-byte data sample are reported by the magnetometer. This is beneficial in part because most signal noise is contained in the lower half byte; however, the resulting signal is less smooth, so a signal consisting of two-byte data samples is being considered for a

future version. The combination of a fast output data rate and all axes set to medium performance mode results in an output data rate of about 570 Hz (measured experimentally).

The function `read_mag()` takes an array of data, which it will populate with data from the magnetometer by calling `mag_transfer(data, OUT_X_H, 3, MAG_READ);` This reads the data output of the X, Y, and Z axes of the magnetometer.

The function `readData()` takes a `SignalState` structure, described previously. The function calls `read_mag()` and stores the output byte from the x axis in the `SignalState` structure as a floating point number, allowing it to be processed by the functions in `detectPeaks.cpp`.

The function `initializeData()` actually does the same thing as the function `readData()`. They are likely to be merged in a future version.

Real Time Clock: RTC_PCF8523.h and RTC_PCF8523.cpp

The following functions are defined in `RTC_PCF8532.h` and `RTC_PCF8523.cpp`:

- `byte rtcTransfer(byte reg, byte flag, byte value)`
- `void registerDump()`
- `void loadDateTime(Date_t* Date)`
- `void setClockPeriod(uint8_t period)`

These files also define a list of hexadecimal addresses for the RTC's registers and a `Date` structure, which holds the current year, month, day, hour, minute, and second.

The function `rtcTransfer()` is responsible for transferring data to the RTC, and takes an eight-bit register number, a read/write flag, and an eight-bit value to write. This function utilizes the Arduino IDE's Wire library for I^2C communication with the RTC.

The function `registerDump()` prints the data in each register to a serial terminal, and is used to verify the contents of each RTC register.

The function `loadDateTime()` reads all of the RTC's date and time registers, and stores the resulting data in a `Date_t` structure. This function is called every four seconds.

The function `setClockPeriod()` writes the input clock period to the RTC Timer A Register. This value is set to 4 seconds by default in `rtcTransfer()`.

The RTC is initialized in Firmware.ino using the following calls to `rtcTransfer()`:

```
rtcTransfer(reg_Tmr_CLKOUT_ctrl, WRITE, 0x3A);
rtcTransfer(reg_Tmr_A_freq_ctrl, WRITE, 0x02);
rtcTransfer(reg_Tmr_A_reg, WRITE, 0x04);
rtcTransfer(reg_Control_2, WRITE, 0x02);
rtcTransfer(reg_Control_3, WRITE, 0x80);
```

These calls are likely to be combined into a single function in a future release. Below is a table detailing what each register configuration does:

Register	Data	Behavior
Timer CLOCKOUT Control	0x3A	- Disable 1-second clock output - Configure Timer A as countdown timer. - Disable Timer B
Timer A Frequency Control	0x02	- Use a 1 Hz source clock for Timer A countdown.
Timer A Register	0x04	- Set Timer A to countdown from 4 (4-second timer).
Control Register 2	0x02	- Clears any interrupt flags - Enables Timer A Countdown Interrupt - Disables all other interrupts in Control Register 2
Control Register 3	0x80	- Enables battery switch-over function in standard mode - Clears any interrupt flags - Disables interrupts in Control Register 3

Configuration Data: configuration.h and configuration.cpp

The ATmega328p microcontroller used for this datalogger has a small chunk of Electrically Erasable Programmable Read-Only Memory, or EEPROM, in which datalogger configuration data is stored. 15 bytes of EEPROM are used, laid out in the following organization:

Address	Data
0x00	Site Number (100’s Place)
0x01	Site Number (10’s Place)
0x02	Site Number (1’s Place)
0x03	Meter Size
0x04	Datalogger ID (100’s Place)
0x05	Datalogger ID (10’s Place)
0x06	Datalogger ID (1’s Place)
0x07	File Number (1000’s Place)
0x08	File Number (100’s Place)
0x09	File Number (10’s Place)
0x0A	File Number (1’s Place)
0x0B	Meter Conversion Factor (1's Place)
0x0C	Meter Conversion Factor (10's Place)
0x0D	Meter Conversion Factor (100's Place)
0x0E	Meter Conversion Factor (1000's Place)
0x0F	Checksum 0
0x10	Checksum 1
0x11	Checksum 2
0x12	Checksum 3

Three functions are used in relation to this configuration data:

- `bool configurationExists();`
- `uint8_t readConfiguration(uint8_t segment);`
- `void writeConfiguration(uint8_t segment, char data);`

The function `configurationExists()` checks the EEPROM for valid configuration data by reading the checksum bytes in addresses 0xB – 0xE using the `readConfiguration()` function. It then calculates two different values: Checksum 0 + Checksum 1 and Checksum 2 + Checksum 3. If they both equal 0xFF, then the configuration data is considered present and valid.

The function `readConfiguration()` first waits for completion of any EEPROM writes in progress. It then loads a read address into the EEPROM Address Register (EEAR) and initiates an EEPROM Read

operation. It then returns the data in EEDR, the register in which data read from the EEPROM is stored.

The function `writeConfiguration()` takes both an address and a data byte. It first waits for completion of any EEPROM writes in progress. It loads a read address into the EEAR, loads data into the EEDR, enables EEPROM writes, and starts an EEPROM write.

Power Reduction: powerSleep.h and powerSleep.cpp

The MWM Datalogger is a battery-powered logger, and as such, it is crucial that energy is saved in every possible part of the device to prolong the possible logging period. This is done in part with the functions listed here:

- `void enterSleep();`
- `void disableUnneededPeripherals();`
- `void twiPowerUp();`
- `void twiPowerDown();`
- `void serialPowerUp();`
- `void serialPowerDown();`
- `void SDPowerUp();`
- `void SDPowerDown();`

If you've been examining the source code, you've no doubt encountered these functions. That's because most peripherals are powered down on start-up, and are only powered on when needed. These functions make use of functions from `<avr/sleep.h>` and `<avr/power.h>`. These libraries are available through the Arduino IDE, or by installing `avr-libc`. Power-up and power-down are accomplished by activating and deactivating the clock, respectively. When a peripheral receives no clock signal, it does nothing, and is effectively powered off.

The function `enterSleep()` puts the microcontroller into a standby mode in which very little power is consumed. The mode `SLEEP_MODE_STANDBY` is selected, sleep is enabled, and the microcontroller is put to sleep. The program is halted at this point. On wake-up, sleep is disabled and the function returns control. ***Use of this function causes data samples to be recorded incorrectly, and as such is unused. This function will be put in use again once the error is corrected.***

The function `disableUnneededPeripherals()` is called on startup in `Firmware.ino`. This function first disables the ADC by writing 0x00 to the ADCSRA register. Once this is done, this function calls the following functions from `<avr/power.h>`:

```
power_adc_disable();
power_timer0_disable();
power_timer1_disable();
power_timer2_disable();
power_twi_disable();
power_usart0_disable();
power_spi_disable();
```

This deactivates the clock to all of the above peripherals.

All of these peripherals are turned on again when needed using the corresponding `PowerUp()` function:

- I^2C bus: `twiPowerUp()`

- Serial Port: `serialPowerUp()`
- SD Interface (SPI): `SDPowerUp()`

Each `PowerUp()` function is similar:

I²C Bus:

```
void twiPowerUp(){
  power_twi_enable();  // From <avr/power.h>
  _delay_us(1);        // Pause execution for peripheral to start
  Wire.begin();        // Initialize Arduino's Wire library
  _delay_us(1);        // Pause execution for peripheral to start
  return;
}
```

Serial Port:

```
void serialPowerUp(){
  power_usart0_enable();    // From <avr/power.h>
  _delay_ms(10);            // Pause execution for peripheral to start
  Serial.begin(9600);       // Initialize Arduino's Serial library
  _delay_ms(10);            // Pause execution for peripheral to start
  Serial.print(F(">> Logger: Logger ready.\n>> User:   "));
  return;
}
```

SD Interface (SPI):

```
void SDPowerUp(){
  power_spi_enable();       // From <avr/power.h>
  return;
}
```

All of these peripherals are turned off again when needed using the corresponding `PowerDown()` function:

- I²C bus: `twiPowerDown()`
- Serial Port: `serialPowerDown()`
- SD Interface (SPI): `SDPowerDown()`

All of the `PowerDown()` functions simply call their respective `power_xxx_disable()` function from the `<avr/power.h>` library (as seen in `disableUnneededPeripherals()`).

Serial User Interface: handleSerial.h and handleSerial.cpp

Before going over the functions defined by these two files, It's useful to understand how the firmware processes user input generally. Recall from the main loop that the function `handleSerial()` is called once per loop, assuming the interface is active. The `handleSerial()` function is the central piece to the entire interface, and calls the other functions defined in these two files based on the user input.

There are a lot of functions, so hold on tight. All of these functions are used in relation to interaction between the user and the datalogger:

- `void handleSerial(volatile State_t* State, Date_t* Date, volatile SignalState_t* SignalState);`
- `void setConfiguration(volatile State_t* State);`
- `void cleanSD(volatile State_t* State);`
- `void viewDateTime(Date_t* Date);`
- `void exitSerial(volatile State_t* State, Date_t* Date);`
- `void ejectSD(volatile State_t* State);`
- `void printHelp();`
- `void initSD(volatile State_t* State);`
- `void listFiles(void);`
- `void startLogging(volatile State_t* State, volatile SignalState_t* SignalState, volatile Date_t* Date);`
- `void stopLogging(volatile State_t* State);`
- `void updateDateTime(Date_t* Date);`
- `void RTC_Doctor();`
- `void clockPeriod();`
- `char getInput();`
- `char getNestedInput();`
- `void printWater(State_t* State);`
- `void printConfig(State_t* State);`
- `void createHeader(State_t* State);`
- `void nameFile(State_t* State, Date_t* Date);`
- `void incrementFileNumber(void);`

The `handleSerial()` function is passed the `State`, `Date`, and `SignalState` structures. These structs may or may not be used in the next function call, but each one has the potential of being used. This function checks for user input from the serial interface (remember, this function is called once per loop, whether the user inputs data or not). If it's there, `handleSerial()` calls the function `getInput()`, which will be described later. For now, it is enough to know that it retrieves input that the user types.

Next, `handleSerial()` calls another function based on what input it received. A table on the next page details what functions get called for what input is received:

User Input	Function Call	Notes
g	`setConfiguration(State);`	Edit datalogger configuration data.
c	`cleanSD(State);`	Delete files from an SD card.
d	`viewDateTime(Date);`	Display the current date/time.
e	`exitSerial(State, Date);`	Deactivate the serial interface.
E	`ejectSD(State);`	Tells the program that the SD card is not in use.
h	`printHelp();`	Print a list of commands.
i	`initSD(State);`	Initialize the SD card.
l	`listFiles();`	List files on the SD card.
p	`printConfig(State);`	Display the datalogger's configuration data.
R	`RTC_Doctor();`	Debug the Real Time Clock.
s	`startLogging(State, SignalState, Date);`	Initiate logging session.
S	`stopLogging(State);`	Terminate a logging session.
t	`clockPeriod();`	Adjust the time interval between SD writes.
u	`updateDateTime(Date);`	Edit the current date/time.
w	`printWater(State);`	Display current water use (if logging session is active).

The datalogger expects single-character commands. If the user enters a string of characters, then each one is executed simultaneously. If any entered character is not listed in the list above, then the datalogger will report that the command is an unknown command.

The function `getInput()` calls the function `Serial.read()` to pull user input from the serial interface. It then prints the input to the terminal, so the user can see what he/she typed (unless the user typed a newline character).

Some of the functions that get called require their own input. This case is handled with the `getNestedInput()` function. This function is actually quite similar to `handleSerial()`. It loops until the user inputs a newline character. Each time it loops, the function checks for available serial data. If it's there, it calls `getInput()`. It can be thought of as a nested `handleSerial()` for individual functions.

The function `setConfiguration()` takes a `State` struct as an input and prompts the user to enter configuration data for the datalogger's site number, ID number, meter resolution, and file number. It also displays the current configuration setting for the user's convenience. Pseudo code for this function is listed here:

```
Begin:
      Let user know the datalogger is configuring
      Prompt user for 3-digit site number and display current site number
      Get user input and store as the new 3-digit site number

      Prompt user for 3-digit ID number and display current ID number
      Get user input and store as the new 3-digit ID number

      Prompt user for new meter resolution (x.xxx format)
      Get user input and store the new meter resolution

      Prompt user for 4-digit file number and display current file number
      Get user input and store as the new 4-digit file number

      Write configuration checksums

      Call printConfig(State) (Prints configuration for user's convenience)
End
```

The function `cleanSD()` takes a `State` struct as an input, and allows the user to delete certain files on an SD card. This is accomplished using the SD library for Arduino. The pseudo code for this function is listed below:

```
Begin:
      If the State.SDin flag is false
            Tell the user that the SD card is not initialized
            Exit this function
      If the State.logging flag is false
            Call listFiles() (Prints all files on the SD Card)
            Prompt the user for a file to remove
            Get user input
            Warn the user that the file will permanently delete the file
            Ask the user whether or not to continue
            Get user input
            If yes
                  Call SDPowerUp()
                  Call SD.begin()
                  Call SD.remove(filename)
                  Call SDPowerDown()
            Call listFiles()
      Else
            Tell the user that files can't be deleted while logging
End
```

The function `viewDateTime()` prints the date and time to the terminal, and takes a `Date` struct as an input. The pseudo code is listed below:

```
Begin:
      Copy data from the Date struct
      Print Month
      Print Day
      Print Year
      Print Hour
      If Minute < 10
            Print 0
      Print Minute
End
```

The function `exitSerial()` sets a flag in the `State` struct which tells the rest of the system that the serial interface is not active. It also calls `serialPowerDown()` from `powerSleep.h`, which helps extend the device's battery life. The pseudo code is listed below:

```
Begin:
      Call viewDateTime(Date)
      Tell the user he/she is exiting the interface
      Set serialOn flag in State false
      Pause execution for one second (allows time for messages to finish)
      Call serialPowerDown()
End
```

The function `ejectSD()` sets a flag in the `State` struct which tells the rest of the system that the SD card is "ejected", or not initialized, possibly not even in the system. The pseudo code is listed below:

```
Begin:
      If the State.logging flag is true
            Tell the user the SD Card cannot be ejected while logging
            Exit this function
      If the State.SDin flag is false
            Tell the user the SD Card is already ejected
            Exit this function
      Set the State.SDin flag false
      Tell the user the SD Card may be removed
End
```

The function `printHelp()` prints a list of commands to the terminal for the user's reference. The printing, as always, is done with the Arduino IDE's `Serial.print()` function. The pseudo code is listed below:

```
Begin:
      Print list of commands (using Serial.print())
End
```

The function `initSD()` takes a `State` struct as an input, and is responsible for initializing the Arduino SD library and letting the rest of the system know that the SD card is initialized. The pseudo code is listed below:

```
Begin:
      Call SDPowerUp()
      If SD.begin() returns successful
            Set State.SDin flag True
            Tell the user the SD Card is ready for use
      Else
            Set State.SDin flag False
            Tell the user the SD Card could not be initialized.
      Call SDPowerDown()
End
```

The function listFiles() uses Arduino's SD library to display all of the files available on the SD Card for the user's convenience. The pseudo code is listed below:

```
Begin:
      Call SDPowerUp()
      Open the root partition of the SD card
      Rewind directory (starts listing files at beginning of card)
      Print top of table (File name, file size)
      While there's still files
            Open the next file
            Print the file name
            Print the file size
            Close the file
      Call SDPowerDown()
End
```

The function `RTC_Doctor()` is designed for easy resetting of the real time clock. This feature was included as we developed the proper settings for the real time clock, and if we got something wrong, we could check RTC registers and even write data to them.

The function `startLogging()` takes `State`, `SignalState`, and `Date` structs as inputs, and is responsible for initiating a logging session. It Generates a new filename (that does not already exist on the SD card), sets the system state flags and values, writes a header for the data file, initializes data for the peak detection algorithm, and enables the magnetometer interrupt, so the datalogger will respond when the sensor signals that data is ready. The pseudo code is listed below:

```
Begin:
      If State.SDin flag is True
            If State.logging flag is True
                  Tell user the device is already logging
            Else
                  Call nameFile(State, Date) (Generates a new file name)
                  Call SDPowerUp()
                  Loop While the current filename matches a file on the SD Card
                        Call incrementFileNumber()
                        Call nameFile(State, Date)
                  End Loop
                  Print file name for user's convenience
                  Set State.logging flag to True
                  Set State.recordNum = 1
                  Set State.pulseCount = 0
                  Set State.lastCount = 0
                  Set State.totalCount = 0
                  Call createHeader(State) (Writes a header to the data file)
                  Call initializeData(SignalState)
                  Enable magnetometer sensor interrupt
                  Tell user that the logging session has started
      Else
            Tell user the logging session couldn't start without an SD card
End
```

The function `stopLogging()` takes the `State` struct as an input. It sets a flag to stop the logging session, disables the magnetometer sensor interrupt, and increments the file number for the next logging session. Note that the file number checking implemented in the function `startLogging()` is a preventative measure, it should never have to execute the loop code. The pseudo code is listed below:

```
Begin:
      If State.logging flag is True
            Set State.logging flag False
            Disable Magnetometer Sensor interrupt
            Tell user that the logging session has ended
            Call incrementFileNumber()
      Else
            Tell user that the device is not logging.
End
```

The function `clockPeriod()` adjusts the RTC timer period, which correspondingly adjusts the time interval between SD writes during a data logging session. The pseudo code is listed below:

```
Begin:
      Prompt user for a new 3-digit time period in seconds
      Receive 100's place (with call to getNestedInput())
      Receive 10's place (with call to getNestedInput())
      Receive 1's place (with call to getNested Input())
      Convert these decimal places to a single value period
      Call setClockPeriod(period); (See RTC_PCF8523.h)
End
```

The function `updateDateTime()` takes the `Date` struct as an input. The function prompts the user for date and time information, and uploads that information to the RTC. The pseudo code is listed below:

```
Begin:
      Tell user the device is updating the date and time
      Prompt user for a new month in MM format
      Receive 10's place (with call to getNestedInput())
      Receive 1's place (with call to getNestedInput())
      Prompt user for a new day in DD format
      Receive 10's place (with call to getNestedInput())
      Receive 1's place (with call to getNestedInput())
      Prompt user for a new year in YY format
      Receive 10's place (with call to getNestedInput())
      Receive 1's place (with call to getNestedInput())
      Prompt user for a new hour in HH format
      Receive 10's place (with call to getNestedInput())
      Receive 1's place (with call to getNestedInput())
      Prompt user for a new minute in MM format
      Receive 10's place (with call to getNestedInput())
      Receive 1's place (with call to getNestedInput())
      Convert month digits to Binary Coded Decimal
      Convert day digits to Binary Coded Decimal
      Convert year digits to Binary Coded Decimal
      Convert hour digits to Binary Coded Decimal
      Convert minute digits to Binary Coded Decimal
      Upload new month to RTC (call to rtcTransfer)
      Upload new day to RTC (call to rtcTransfer)
      Upload new year to RTC (call to rtcTransfer)
      Upload new minute to RTC (call to rtcTransfer)
      Upload 0x00 (new second) to RTC (call to rtcTransfer)
      call loadDateTime(Date) (Copies new date and time from RTC)
      call viewDateTime(Date) (Prints Date and Time for user)
      Tell user the date and time have been reset.
End
```

The function `getInput()`, as discussed previously, receives input from the user for the top level of the `handleSerial()` function. The user input is returned as the function's output. The pseudo code is listed below:

```
Begin:
      Read input from user with call to Serial.read()
      If input is not a newline
            Print the input (so user can see what was typed)
End
```

The function `getNestedInput()`, as discussed previously, is very similar to the function `getInput()`. The difference is that `getNestedInput()` loops until it has received input from the user, while `getInput()` is only designed to check once per iteration of `handleSerial()`. As such, `getNestedInput()` is used by functions called from `handleSerial()` which also need user input. The pseudo code is listed below:

```
Begin:
      Set finished to False
      Loop while finished is False
            input = getInput()
            If input is not a newline
                  finished is True
      End Loop
End
```

The function `printWater()` takes the `State` struct as an input, and prints water flow data for the user to see. The pseudo code is listed below:

```
Begin:
      Tell the user that the data is from the previous sample
      Copy State.lastCount to pulses
      Copy State.totalCount to totalPulses
      If State.meterSize is 1
            Set convFactor = 0.033
      Else If State.meterSize is 5
            Set convFactor = 0.0087
      Else
            Set convFactor = 0
      Total Flow = pulses * convFactor
      Total Flow Since Start = totalPulses * convFactor
      Average Flowrate = Total Flow * 60 / 4
      Print pulses
      If convFactor is not 0
            Print Total Flow
            Print Average Flowrate
            Print totalPulses
            Print Total Flow Since Start
      Else
            Tell user the meter configuration is invalid.
End
```

The function `printConfig()` takes the `State` struct as an input. It reads the configuration data in the datalogger's EEPROM and prints it to the terminal. The pseudo code is listed below:

```
Begin:
      Read and Print the 3-digit Site Number
      Read and Print the 3-digit ID Number
      Read and Print the 4-digit File Number
      Read and Print the x.xxx Meter Resolution
End
```

The function `createHeader()` takes the `State` struct as an input. It is responsible for writing a header to the current data file:

```
Site #: xxx
Datalogger ID #: xxx
Meter Resolution: x.xxx
Time,Record,Pulses
```

The pseudo code is listed below:

```
Begin:
      Call SDPowerUp()
      Open the logging session's file
      Write the 3-digit Site Number
      Write the 3-digit ID Number
      Write the x.xxx meter resolution
      Print "Time,Record,Pulses\n"
      Close the file
      Call SDPowerDown()
End
```

The function `nameFile()` takes a both the `State` and `Date` structures as inputs, and names a file based on the site number and file number stored in the datalogger's EEPROM in the following format, where 's' denotes a site number digit and 'f' denotes a file number digit:

`sss_ffff.csv`

The function `incrementFileNumber()` reads the file number digits from the datalogger's EEPROM, sums them together, adds one, and rewrites them back to the EEPROM.

Table of Functions and Structs (Lexicographical Order)

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