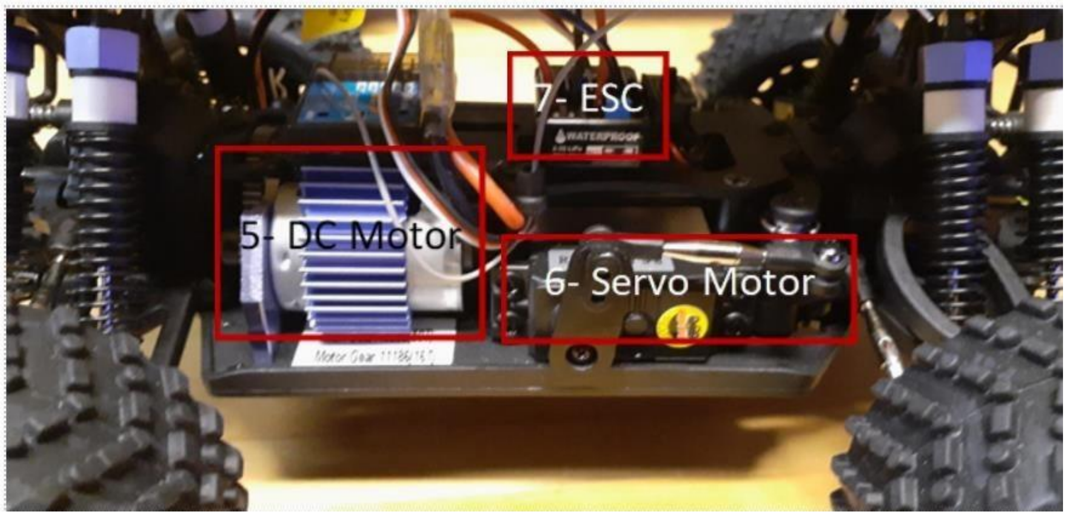
Final Project

In this project, you are going to implement an RC car's components by incorporating elements from the previous labs. You are also going to use a new board (i.e., PCA9695) for driving servo and DC motors. PCA9695 uses I2C to receive commands from Hi-Five board to generate PWM signal for the servo- and DC-motors. The final project weighs 15% of your total course grade.



The car prototype that you are going to use has seven main components:

1. Hi-five board
2. Pi board
3. Motor driver (PCA9695) 4- LIDAR
4. DC motor
5. Servo motor
6. Electronic Speed Controller (ESC)

Your goal in this project is to first use the Hi-five board to send I2C commands to PCA9695 to drive the servo motor (for steering) and DC motors (for moving forward and backwards) (Milestone 1). Then connect Pi to Hi-five board using UART (just like lab-9). This is to set up a connection between the two boards for sending steering commands from the Pi to the Hi-five board (Milestone 2). Lastly, you are going to control the car using a sequence of commands sending the steering commands from the Pi to the Hi-five board (using UART) and then to the motors (using PWM I2C controller) (Milestone 3).

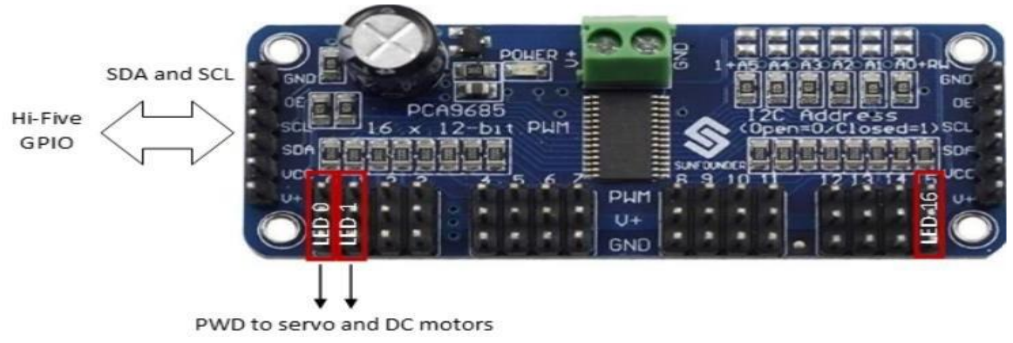
You should work on the final project in groups of four.

Milestone 1

In this milestone you configure the PWM controller and use the Hi-five board to drive the servo and DC motor. Your milestone-1 source code (milestone1.tar.gz) is uploaded at the source code folder of the Canvas. Download and import into PlatformIO on VS code like you did for your previous labs).

You need to complete the 6 tasks highlighted in green color to finish milestone 1.

In order to accomplish this steering and motor control, the system will require stronger servos than previously used in the lab and subsequently needs an external power supply along with a dedicated servo driver. The PCA9685 is a 16 channel 12-bit PWM servo driver which uses the I2C serial communication protocol. In PCA9685 nomenclature, the output channels are called LED channels (because one of the main use-cases of the board is to drive LEDs). We use channel 0 and channel 1 (i.e., LED0 and LED1) for driving servo motor and DC motor, respectively.



You do not need to know the low-level operation of I2C protocol to finish this milestone. Instead, you are going to use ready-to-use libraries to communicate over the I2C interface. On the HiFive board, the I2C core is from a 3rd party provider called OpenCores. The framework used by HiFive, freedom-e-sdk (or "metal library"), includes an I2C library under the metal folder.

First, in the **c_cpp_properties.json** contained in the **.vscode** folder, confirm if your included path contains the following line:

```
[user specific info]/.platformio/packages/framework-freedom-e-sdk/freedom-metal"
```

This line adds the metal library to your include path – allowing you to easily include the metal library into your code by simply adding this line to the top of your code. (line 4 of milestone1/src/eecs388_i2c.c)

```
#include "metal/i2c.h"
```

We first briefly explain the metal/i2c library and then discuss the tasks that you need to do for this milestone.

Part 1: Setting up the I2C via the metal library

The metal library requires three key elements to function properly, a pointer to its instance and two u_int8 arrays, which will be used in the reading and writing data. While the length of the read array only needs to be 1, the length of the write array should be 5 (this will be explained later). The following code accomplishes this (lines 7-9 of milestone1/src/eecs388_i2c.c)

```
struct metal_i2c *i2c;
uint8_t bufWrite[5];
uint8_t bufRead[1];
```

The following line initializes the i2c device number 0 and get a handle of the device and assigns it to the metal_i2c pointer struct: (line 18 of milestone1/src/eecs388_i2c.c)

```
i2c = metal_i2c_get_device(0)
```

If `i2C == NULL`, then the connection to the I2C device, the PCA9685, was unsuccessful. (line 20 of milestone1/src/eecs388_i2c.c)

Finally, we need to initialize the I2C module in the HiFive board as the master with the following line. We are using a baud rate of 100000: (line 26 of milestone1/src/eecs388_i2c.c).

```
metal_i2c_init(i2c,I2C_BAUDRATE,METAL_I2C_MASTER);
metal_i2c_init(i2c,I2C_BAUDRATE,METAL_I2C_MASTER);
```

This concludes the I2C setup. From here, we will use the write and transfer methods to write/read PCA9685 registers. However, first, we must configure PCA9685 board with a few key configurations; otherwise, the driver will not work.

Part 2: Configuring the PCA9685

According to the datasheet found at http://wiki.sunfounder.cc/images/e/ea/PCA9685_datasheet.pdf, the base memory mapped address for a single PCA9685 is 0x40. For ease of use, we already defined these in your released eecs388_lib.h file: (lines 54-64 of milestone1/src/eecs388_lib.h)

```
//Setup for PCA9685
#define PCA9685_I2C_ADDRESS 0x40
#define PCA9685_MODE1 0x00 /**< Mode Register 1 */
#define PCA9685_LED0_ON_L 0x06 /**< LED0 on tick, low byte*/
#define PCA9685_PRESCALE 0xFE /**< Prescaler for PWM output frequency */

// MODE1 bits
#define MODE1_SLEEP 0x10 /**< Low power mode. Oscillator off */
#define MODE1_AI 0x20 /**< Auto-Increment enabled */
#define MODE1_EXTCLK 0x40 /**< Use EXTCLK pin clock */
#define MODE1_RESTART 0x80 /**< Restart enabled */
#define FREQUENCY_OSCILLATOR 25000000 /**< Int. osc. frequency in datasheet */
```

We will begin by writing a reset command to the mode1 register. The parameters of the write function are as follows:

```
/*! @brief Perform a I2C write.

* @param i2c The handle for the I2C device to perform the write operation.
* @param addr The I2C slave address for the write operation.
* @param len The number of bytes to transfer.
* @param buf The buffer to send over the I2C bus. Must be len bytes long.
* @param stop_bit Enable / Disable STOP condition.
* @return 0 if the write succeeds.

*/

inline int metal_i2c_write(struct metal_i2c *i2c, unsigned int addr,
                           unsigned int len, unsigned char buf[],
                           metal_i2c_stop_bit_t stop_bit) {

        return i2c->vtable->write(i2c, addr, len, buf, stop_bit);

}
```

We start by writing a reset command to the PCA9695, which looks like the following. The final parameter for writing is either METAL_I2C_STOP_DISABLE or METAL_I2C_STOP_ENABLE. It is a value defined that sets the stop condition in the I2C protocol. If you ever send a single write or read command to the PCA9685, you will use METAL_I2C_STOP_ENABLE as the final parameter. You should use METAL_I2C_STOP_DISABLE as the last parameter if you plan to do multiple sequential writes/reads. You should make sure that the final write/read has the stop condition as METAL_I2C_STOP_ENABLE. (lines 28-32 of milestone1/src/eecs388_i2c.c)

```
bufWrite[0] = PCA9685_MODE1;
bufWrite[1] = MODE1_RESTART;
success =
    metal_i2c_write(i2c,PCA9685_I2C_ADDRESS,2,bufWrite,METAL_I2C_STOP_DISABLE);//r
esets the register
```

We will now send several commands in order to configure the MODE1 register. For reference, the configuration is defined as follows:

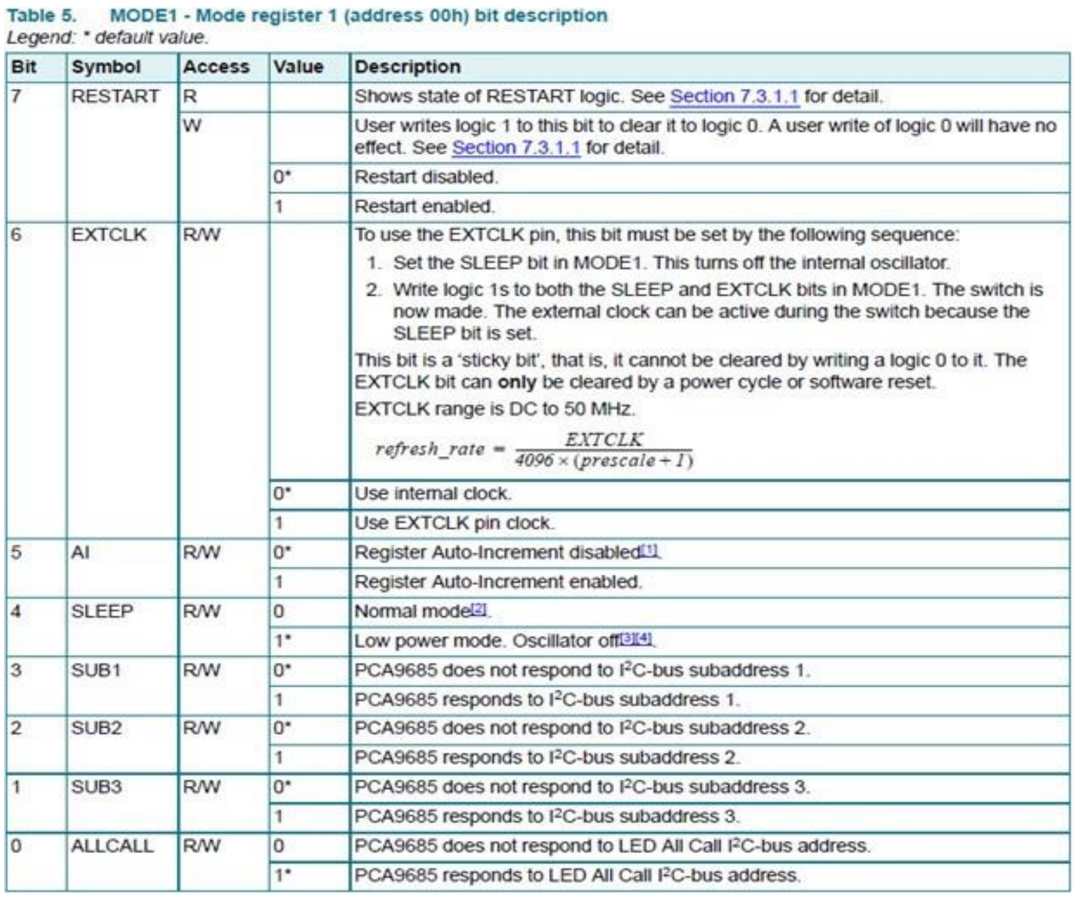


Table 5. MODE1 - Mode register 1 (address 00h) bit description

*Legend: * default value.*

Bit	Symbol	Access	Value	Description
7	RESTART	R		Shows state of RESTART logic. See Section 7.3.1.1 for detail.
		W		User writes logic 1 to this bit to clear it to logic 0. A user write of logic 0 will have no effect. See Section 7.3.1.1 for detail.
			0*	Restart disabled.
			1	Restart enabled.
6	EXTCLK	R/W		To use the EXTCLK pin, this bit must be set by the following sequence: 1. Set the SLEEP bit in MODE1. This turns off the internal oscillator. 2. Write logic 1s to both the SLEEP and EXTCLK bits in MODE1. The switch is now made. The external clock can be active during the switch because the SLEEP bit is set. This bit is a 'sticky bit', that is, it cannot be cleared by writing a logic 0 to it. The EXTCLK bit can **only** be cleared by a power cycle or software reset. EXTCLK range is DC to 50 MHz. $refresh\_rate = \frac{EXTCLK}{4096 \times (prescale + 1)}$
			0*	Use internal clock.
			1	Use EXTCLK pin clock.
5	AI	R/W	0*	Register Auto-Increment disabled[1].
			1	Register Auto-Increment enabled.
4	SLEEP	R/W	0	Normal mode[2].
			1*	Low power mode. Oscillator off[3][4].
3	SUB1	R/W	0*	PCA9685 does not respond to I^{2}C-bus subaddress 1.
			1	PCA9685 responds to I^{2}C-bus subaddress 1.
2	SUB2	R/W	0*	PCA9685 does not respond to I^{2}C-bus subaddress 2.
			1	PCA9685 responds to I^{2}C-bus subaddress 2.
1	SUB3	R/W	0*	PCA9685 does not respond to I^{2}C-bus subaddress 3.
			1	PCA9685 responds to I^{2}C-bus subaddress 3.
0	ALLCALL	R/W	0	PCA9685 does not respond to LED All Call I^{2}C-bus address.
			1*	PCA9685 responds to LED All Call I^{2}C-bus address.

The following commands will successfully configure the PCA9695. (lines 37-55 of milestone1/src/eecs388_i2c.c)

```
bufWrite[0] = PCA9685_MODE1;
success = metal_i2c_transfer(i2c,PCA9685_I2C_ADDRESS,bufWrite,1,bufRead,1);//initial read

oldMode = bufRead[0];
newMode = (oldMode & ~MODE1_RESTART) | MODE1_SLEEP;

bufWrite[0] = PCA9685_MODE1;
bufWrite[1] = newMode;

success = metal_i2c_write(i2c,PCA9685_I2C_ADDRESS,2,bufWrite,METAL_I2C_STOP_DISABLE);/

/sleep

bufWrite[0] = PCA9685_PRESCALE;
bufWrite[1] = 0x79;

success = metal_i2c_write(i2c,PCA9685_I2C_ADDRESS,2,bufWrite,METAL_I2C_STOP_DISABLE);/

/sets prescale
```

```
bufWrite[0] = PCA9685_MODE1;
bufWrite[1] = 0x01 | MODE1_AI | MODE1_RESTART;

success = metal_i2c_write(i2c,PCA9685_I2C_ADDRESS,2,bufWrite,METAL_I2C_STOP_DISABLE);//awake

delay(100);
```

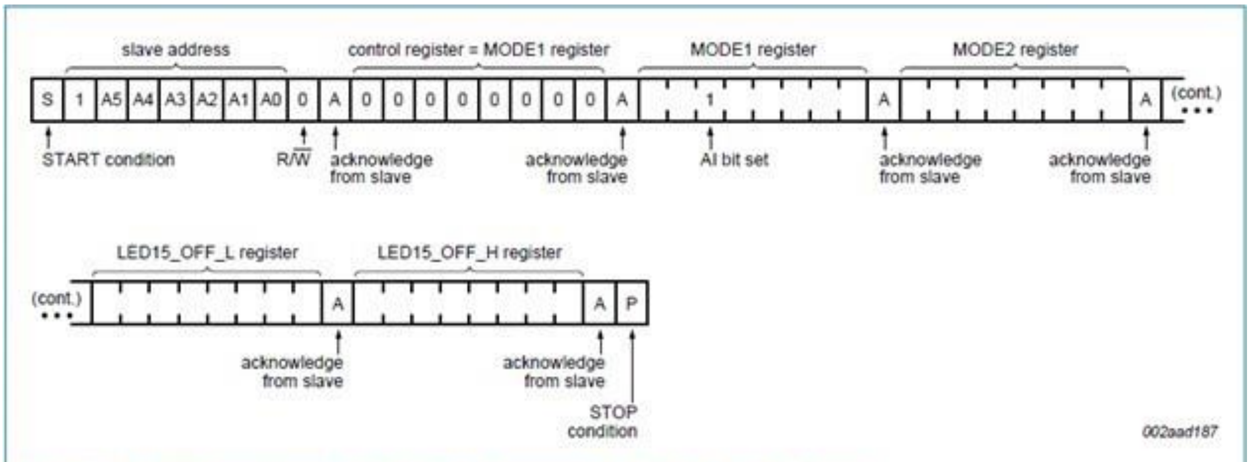


Fig 21. Write to all registers using the Auto-Increment feature; AI initially clear

Extra information: MODE1_AI stands for auto-increment. This means that each subsequent write from a defined starting address will automatically write to the next register. Writing under these conditions is shown below:

Part 3: Using the transfer method to control the PCA9695 (Servo control)

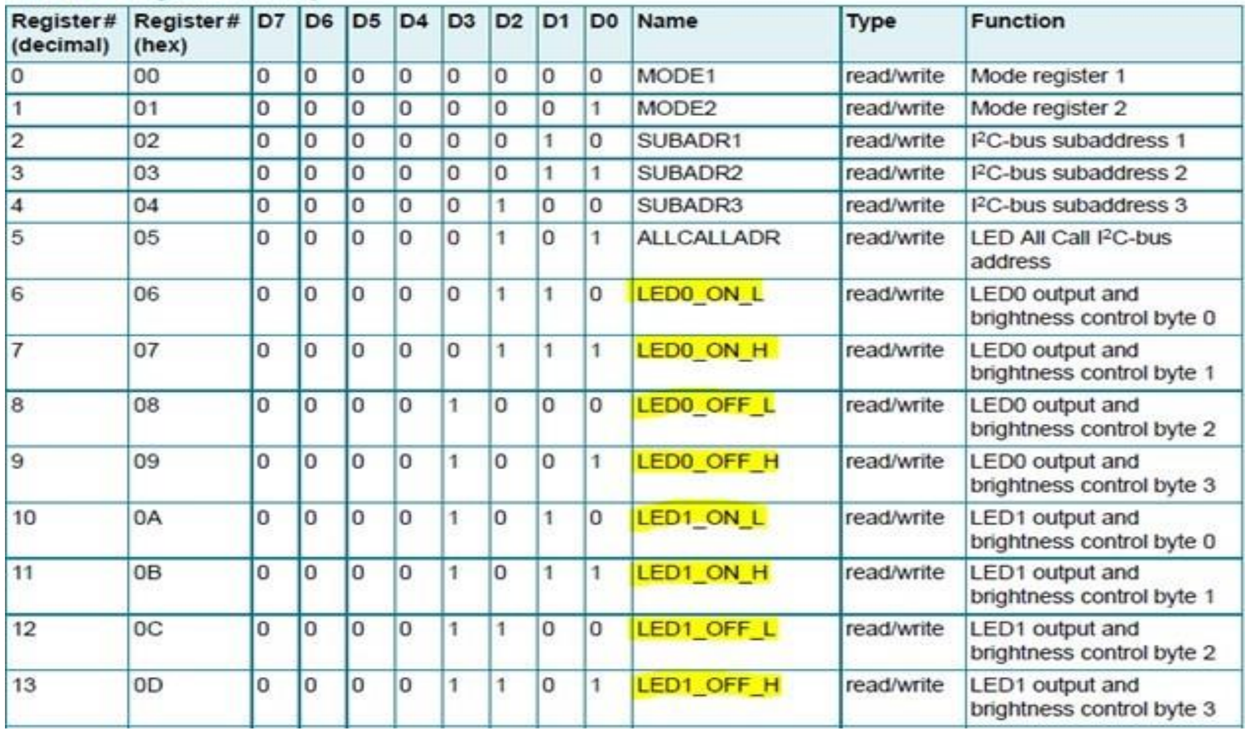
The transfer method in the I2C library allows us to send an arbitrary number of writes and reads with a single command; therefore, we specified our write array to have a length of 5. The parameters of transfer are shown below:

```
/*! @brief Performs back to back I2C write and read operations.
* @param i2c The handle for the I2C device to perform the transfer operation.
* @param addr The I2C slave address for the transfer operation.
* @param txbuf The data buffer to be transmitted over I2C bus.
* @param txlen The number of bytes to write over I2C.
* @param rxbuf The buffer to store data received over I2C bus.
* @param rxlen The number of bytes to read over I2C.
* @return 0 if the transfer succeeds.

*/

inline int metal_i2c_transfer(struct metal_i2c *i2c, unsigned int addr, unsigned char txbuf[], unsigned int txlen, unsigned char rxbuf[], unsigned int rxlen)
```

```
{
      return   i2c->vtable->transfer(i2c,   addr,   txbuf,   txlen,   rxbuf,   rxlen);
}
```

As we explained earlier, in PCA9685 nomenclature, the output PWM channels are called LEDs. We use only LED0 and LED1 to drive the servo and DC motors. Here are the register addresses that we will edit:

Table 4. Register summary



Register# (decimal)	Register# (hex)	D7	D6	D5	D4	D3	D2	D1	D0	Name	Type	Function
0	00	0	0	0	0	0	0	0	0	MODE1	read/write	Mode register 1
1	01	0	0	0	0	0	0	0	1	MODE2	read/write	Mode register 2
2	02	0	0	0	0	0	0	1	0	SUBADR1	read/write	I^2C-bus subaddress 1
3	03	0	0	0	0	0	0	1	1	SUBADR2	read/write	I^2C-bus subaddress 2
4	04	0	0	0	0	0	1	0	0	SUBADR3	read/write	I^2C-bus subaddress 3
5	05	0	0	0	0	0	1	0	1	ALLCALLADR	read/write	LED All Call I^2C-bus address
6	06	0	0	0	0	0	1	1	0	LED0_ON_L	read/write	LED0 output and brightness control byte 0
7	07	0	0	0	0	0	1	1	1	LED0_ON_H	read/write	LED0 output and brightness control byte 1
8	08	0	0	0	0	1	0	0	0	LED0_OFF_L	read/write	LED0 output and brightness control byte 2
9	09	0	0	0	0	1	0	0	1	LED0_OFF_H	read/write	LED0 output and brightness control byte 3
10	0A	0	0	0	0	1	0	1	0	LED1_ON_L	read/write	LED1 output and brightness control byte 0
11	0B	0	0	0	0	1	0	1	1	LED1_ON_H	read/write	LED1 output and brightness control byte 1
12	0C	0	0	0	0	1	1	0	0	LED1_OFF_L	read/write	LED1 output and brightness control byte 2
13	0D	0	0	0	0	1	1	0	1	LED1_OFF_H	read/write	LED1 output and brightness control byte 3

Task 1: The breakup function

When looking at the register summary, note that each LEDn has 4 components, ON_L, ON_H, OFF_L, and OFF_H. This is because 4096 is a 12-bit number, so it must be broken up to fit into two 8-bit numbers, as I2C writes a byte at a time. L refers to the lower 8 bits, and H refers to the higher 8 bits. Your task will be to define a function that takes an integer and breaks it down into the high 8-bits and low 8-bits, assigning the references high and low to these values. (Implement void breakup function in milestone1/src/eecs388_i2c.c)

```
void breakup(int bigNum, uint8_t* low, uint8_t* high){

//Put task 1 code here

}

Example usage:

uint8_t = variable1
```

```
uint8_t = variable2

breakup(2000,&variable1,&variable2);

//Variable1 -> low 8 bits of 2000

//Variable2 -> high 8 bits of 2000
```

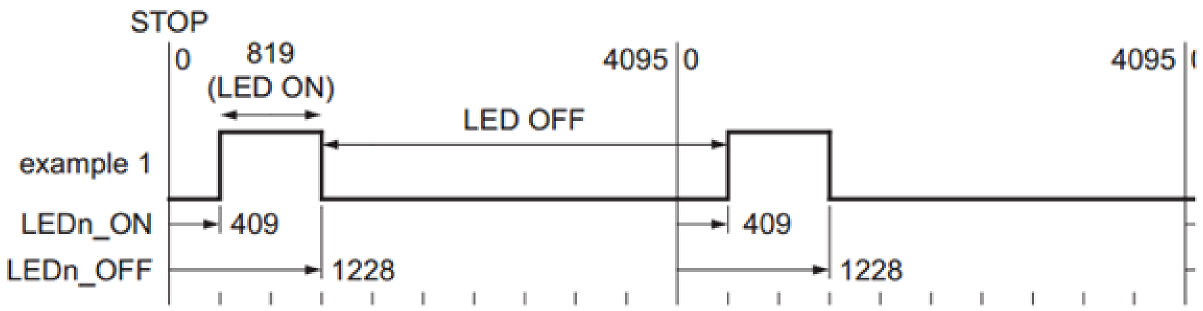
Task 2: The Steering Function

Before we define your second task, you need some information about the servo motors on the car. Controlling the servo and motor Electronic Speed Controller (ESC) with PWM is very similar to how we did so in the actuator Lab. However, in this case, we will be converting values ranging from 0 to 20 ms to 0 to 4095 cycles.

We provide getServoCycle function that converts an angle between -45 to 45 to a servo duty cycle (lines 149-163 in milestone1/src/eecs388_lib.c). You need to write the return cycle into LED1_OFF_L and LED1_OFF_H to change the angle of the tires.

```
//A function used to quickly map [-45,45] to [155,355]

int map(int angle,int lowIn, int highIn, int lowOut, int highOut{

        int mapped = lowOut + (((float)highOut-lowOut)/((float)highIn-lowIn))*(angle-
        lowIn);
        return mapped;

}

//only provide an angle ranging from -45 to 45

//Sending values outside this range will cause

//unexpected behavior

int getServoCycle(int angle){

        int cycle_value;

        cycle_value = map(angle, -45, 45, SERVOMIN, SERVOMAX);

        return cycle_value;

}
```

Extra information: The PWM relationship can be viewed below. Note that we will set LEDn_ON time to zero for this project to simplify the calculation of LEDn_OFF; however, you can set LEDn_ON to a positive value and offset LEDn_Off cycles accordingly. The servos duty cycle rangesm from 150/4095 to 600/4095 cycles; however, due to the constraints of the system, this range is closer to 155/4095 to 355/4095 cycles. The getServoCycle function will account for this constraint.



Your task: use the getServoCycle, breakup, and transfer functions to implement the following steering function to control the steering of the car. You need to alter the PWM of the servo motor. Angle is between the range -45 to 45.

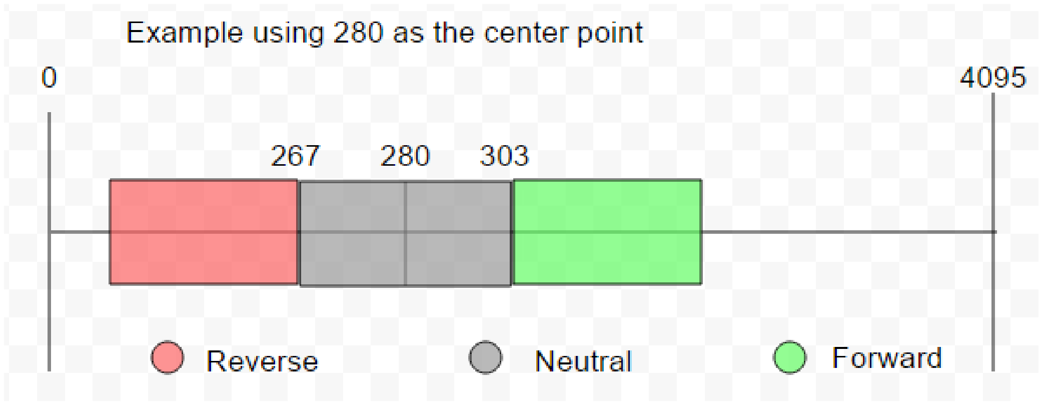
```
void steering(int angle){

/*

	Write Task 2 code here

*/

}
```

Example usage: steering(0); -> driving angle forward

Part 4: Using the transfer method to control the PCA9695 (Motor control)

Controlling the motor is like controlling the servo with one difference: the motor is connected to an ESC, which has its own rules for usage. ESC must be configured before it moves the motor. This process is relatively simple; you must write an arbitrary PWM in cycles for the ESC to calibrate around. This is accompanied by a beep (Second beep after turning on the switch within the car) signaling calibration being completed. From this arbitrary point, there is a dead band of plus or minus 23 cycle lengths, sending a PWM outside this dead band will make the motor drive forward or backward, respectively. This relationship is illustrated below:

Be Advised: these RC cars are designed to drive at very high speeds. Keep the values around 313 and 265 and be sure the robot is propped up so it cannot suddenly drive away!



Task 3: Calibrating and defining the stop function

Implement the following function to stop the wheels from moving. The function also can be used to calibrate ESC when first called with a 2 second delay. This will be accomplished by setting the LED0_OFF to 280

```
void stopMotor(){

/*
      Write             Task             3             code             here
*/
}
```

`Example Use: stopMotor(); -> sets LED0_Off to 280`

Task 4: Drive Forward function

Implement the following function to make the wheels drive forward. Further details are provided below regarding the parameters and results.

```
void driveForward(uint8_t speedFlag){

/*
      Write             Task             4             code             here
*/
}
```

The given speedFlag will alter the motor speed as follows:

speedFlag = 1 -> value to breakup = 313

speedFlag = 2 -> value to breakup = 315 (optional)

speedFlag = 3 -> value to breakup = 317 (optional)

Example Use: driveForward(3); -> sets LED0_Off to 317

Task 5: Drive Reverse Function

Implement the following function to make the wheels drive in reverse. Further details are provided below regarding the parameters and results.

```
void driveReverse(uint8_t speedFlag){

/*

Write Task 5 code here

*/

}
```

The given speedFlag will alter the motor speed as follows:

speedFlag = 1 -> value to breakup = 267

speedFlag = 2 -> value to breakup = 265 (optional)

speedFlag = 3 -> value to breakup = 263 (optional)

Example Use: driveReverse(2); -> sets LED0_Off to 265

Part 5: Putting it all together

Task 6: Fully controlling the PCA9685

Using all your implemented functions, perform the following sequence of actions:

1. Calibrate the motors
2. Set the steering heading to 0 degrees (wait for 2 seconds)
3. Drive Forward (wait for 2 seconds)
4. Change the steering heading to 20 degrees (wait for 2 seconds)
5. Stop the car (wait for 2 seconds)
6. Drive in reverse (wait for 2 seconds)
7. Set steering heading to 0 degrees (wait for 2 seconds)
8. Stop the motors