Dyson School of Design Engineering

Imperial College London

DE2.3 Electronics 2

Lab Experiment 4: Motor & Interrupt

(webpage: http://www.ee.ic.ac.uk/pcheung/teaching/DE2_EE/)

Objectives

By the end of this experiment, you should have achieved the following:

- Learn how to drive the dc motors using the H-bridge driver chip
- Control motor speed with potentiometer via ADC
- Use hall effect sensors to detect speed of motor using polling and interrupt
- Use Bluefruit UART module to control the speed and direction of the motors

Before you start

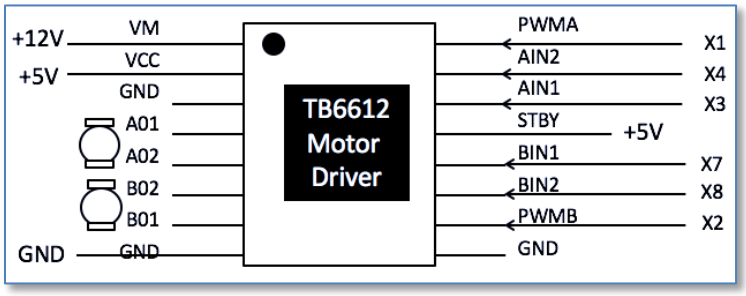
In this lab, you will be using the Pybench board, the motor assembly of the mini-segway that you will be using for the group project and a 11.1v lithium battery. There is no need to assemble the Pybench board to the motor assembly and do not install the wheels. You will put together the mini-Segway next week after the stabilizers are available.

Connect the ribbon cables between the Pybench board and the motors provided. Make sure that Pybench configuration switch is set at '11' (user mode). From now on, we will be using the Pybench board on its own without tethering it to Matlab.

Exercise 1: DC Motor and H-bridge

The goal of this exercise is to remind you how to drive a DC motor using the H-bridge chip TB6612. You have already used this chip last year with your DE1.3 Lab and Project. (Please refer to DE1.3 Lecture 16 slides 8 & 9, and DE1.3 Lab 4 Task 2 from last year.)

The task in hand is to use the potentiometer on Pybench to control the speed of the two DC motors using the H-bridge. The interface connection between the TB6612 and the Pyboard module is shown here. Unlike last year, you don't have to wire up the chip this year. All necessary connections have already been made for you on the Pybench board PCB.



IN1	IN2	Action
L	L	Stop
L	H	Counter Clockwise – controlled by PWM
H	L	Clockwise – controlled by PWM
H	H	Short brake

The direction of the motor is controlled according to the table shown here. The speed of the motor is determined by the duty cycle of the PWM signal. Since the DC motors are designed to operate at 12V, you will be using the lithium battery to power the motors. CONNECT THE LITHIUM BATTERY VIA THE YELLOW PLUG AND SOCKET ONLY. The toggle switch on Pybench turns the 12V supply ON and OFF to the rest of the system. Pybench was designed to take its power either from the PC via the USB cable (5V) or from the 12V battery, or from both! When Pybench is powered by the battery alone, a DC-to-DC converter provides the 5V necessary to drive the logic circuits.

Connect Pybench to your PC using a USB cable. Open a terminal window using putty.exe or, if you are using Mac, use Mac's terminal program. With your favourite editor, create a file: **lab4_ex1a.py** on the SD card containing the following MicroPython code. Change the **user.py** file on the SD card to run this **.py** file using the statement: **execfile('lab4_ex1a.py')** (instead of whatever you used in Lab 3 last week.) One of the two motors should now be turning. Change the speed of the motor. (How?)

```
import pyb
from pyb import Pin, Timer

# Define pins to control motor
A1 = Pin('X3', Pin.OUT_PP)      # Control direction of motor A
A2 = Pin('X4', Pin.OUT_PP)
PWMA = Pin('X1')                # Control speed of motor A

# Configure timer 2 to produce 1KHz clock for PWM control
tim = Timer(2, freq = 1000)
motorA = tim.channel (1, Timer.PWM, pin = PWMA)

def A_forward(value):
    A1.low()
    A2.high()
    motorA.pulse_width_percent(value)

A_forward(50)
```

Now modify this program to provide two more motor control functions: **A_back(value)** and **A_stop()**. Test that these functions are working.

Note that we use an on-chip timer circuit inside the microcontroller to generate a 1000Hz PWM signal to drive the motor. In order to understand how to programme this timer circuit in MicroPython, read, the following document page: https://docs.micropython.org/en/latest/library/pyb.Timer.html.

Write a new version of the program to drive BOTH motors (instead of just motor A). Note that you can use channel 2 of Timer 2 to control the second motor. (See MicroPython manual.)

Finally, create **lab4_ex1b.py** which uses the 5kΩ potentiometer to control the motors to go forward and backward at various speed, up to the maximum. The potentiometer is connected to pin 'X11'. To read the potentiometer voltage, you need the following MicroPython code:

```
pot = pyb.ADC(Pin('X11'))      # define potentiometer object as ADC conversion on X11
value = pot.read()              # value = 0 to 4095 for voltage 0v to 3.3v
```

Modify your program into **lab4_ex1c.py** to display the PWM duty cycle on the OLED display. This should be easy if you have kept a good logbook for Lab 4 last year. (Solution in Appendix A.)

Exercise 2 – Control motor speed via Bluetooth

You have used the BLE-UART module last year. Here you will use the mobile phone to control the motor speed. Please refer to DE1.3 Lab 4, tasks 7, 8 and 9.

Download the free Adafruit's BlueFruit mobile App for your phone. The Bluetooth board is connected to UART 6 as in last year. To use the BlueFruit module, you need to initialize the UART interface with this MicroPython code:

```
uart = UART(6)
uart.init(9600, bits=8, parity = None, stop = 2)
```

Check that your program is working properly.

```
# Use keypad U and D keys to control speed
DEADZONE = 5
speed = 0

while True:             # loop forever until CTRL-C
    while (uart.any()!=10):    # wait for 10 chars
        pass
    command = uart.read(10)
    if command[2]==ord('5'):
        if speed < 96:
            speed = speed + 5
            print(speed)
    elif command[2]==ord('6'):
        if speed > - 96:
            speed = speed - 5
            print(speed)
    if (speed >= DEADZONE):     # forward
        A_forward(speed)
        B_forward(speed)
    elif (speed <= -DEADZONE):
        A_back(abs(speed))
        B_back(abs(speed))
    else:
        A_stop()
        B_stop()
```

Exercise 3 – Detect the speed of the motor

Each motor is equipped with two hall effect sensors, which detect changes in magnetic field strength as shown in the photograph. The circular magnet has 13 pairs of N-S poles. The gear ratio of the motor is 1:30. This causes the hall effect sensors to produce 13 x 30 = 390 square pulses per revolution of the wheel. Since the two sensors are slightly offset from each other, the square waves from the two sensors are at different phase angles.

Appendix C is a summary of the hardware pins on the Pyboard, and how they are used to connect to the hardware modules and motors etc.

Connect your oscilloscope to pins Y4 and Y5 pins on the Pyboard using the jumper wires provided. Y4 and Y5 are connected to the hall effect sensors of motor A. Run the program lab4_ex1c to control the speed with the potentiometer and observe how Y4 and Y5 changes in both frequency and phase. Make sure that you understand the waveforms.

You can detect the speed of the motor by counting the number of positive transitions (low-to-high) on Y4 or Y5 in a time period of 100 msec, and divide the count value by 39 to obtain the number of revolutions of the wheel per second (rps).

You can also detect the direction of rotation of the motor by observing whether Y4 is LEADING Y5 in phase, or vice versa. However, since you are driving the motor with your own program, *you know* which direction the motor is turning. So, this is not so useful.

To count the pulses on pin Y4 for motor A and Y6 for motor B, you would need to define two Pin objects:

```
# Define pins for motor speed sensors
A_sense = Pin('Y4', Pin.PULL_NONE)  #  Pin.PULL_NONE = leave this as input pin
B_sense = Pin('Y6', Pin.PULL_NONE)
```

The code segment to detect the speed of motor A is given here:

```
# Initialise variables
A_state = 0          # previous state of A sensor
A_speed = 0          # latest speed of motor A
A_count = 0          # positive transition count
tic = pyb.millis(); # keep time in millisecond

while True:              # loop forever until CTRL-C
    # detect rising edge on sensor A
    if (A_state == 0) and (A_sense.value()==1): # rising edge detected on A
        A_count += 1
    A_state = A_sense.value()   # read value on pin A_sense

    # Check to see if 100 msec has elapsed
    toc = pyb.millis()
    if ((toc-tic) >= 100):
        A_speed = A_count

        # drive motor - controlled by potentiometer (as before)
        .........

        A_count = 0          # reset transition count

    # Display new speed
        oled.draw_text(0,20,'Motor A:{:5.2f} rps'.format(A_speed/39))
        oled.display()
        tic = pyb.millis()
```

Note how I have implemented the equivalent of "tic" and "toc" from Matlab using Pyboard's pyb.millis() function. This function returns the internal real-time clock in millisecond. By keeping tic and toc variables, elapsed time can be calculated as (toc-tic).

Modify **lab4_ex1c.py** to a new program **lab4_ex3a.py**. Test the program to check the speed of motor A (in rev/sec). Note that the reported speed is very "noisy". Why?

Now add to following line just after the "while True:" statement:

```
while True:             # loop forever until CTRL-C
    # Do something that takes 1 msec
    pyb.delay(1)
    ......
```

You will see that the report speed is now completely incorrect. Why? (hint: pyb.delay(1) impose a delay of 1sec.)

Remove this spurious statement, and modify your program into **lab4_ex3b.py** so that you measure and display the speed of both motor A and motor B. The solution for **lab4_ex3b.py** is shown in Appendix B.

Explanation

The while loop is continuously looking for a low-to-high transition on motor A sensor signal on pin Y4. Within the loop, you also continuously check to see if 100msec has elapsed. If yes, you save the transition count (in A_speed) and reset the counter. The continual checking program loop is known as "**polling**". It is analogous to owning **a telephone that has NO ringer**. To see if anyone is calling, you need to "**poll**" the phone by picking it up and check to see if someone is one the line! This is a simple way to check, but it is extremely inefficient.

Exercise 4 – Speed measurement using interrupt

Instead of using **polling** as a method to check the status of the Y4 pin, you could install a "ringer" in the form of interrupts. **Interrupt** is a hardware feature on the microprocessor, which forces the processor to do something for you when an event occurs. For example, you can set up the Y4 pin in such a way that when a low-to-high transition occurs, a special function known as the "**interrupt service routine**" or **ISR** will be executed. The ISR runs the program code that deals with whatever the interrupt demands. When the ISR is completed, the processor returns to the original code and continues its execution. This is like having a ringer on your telephone. You may be in the middle of a meal and the phone rings. This interrupts you eating your meal and forces you to answer the phone. When you finish that, you return to your meal. This is far more efficient than you having to check if someone is calling you at regular intervals! AND you are will NOT miss a call.

You will now learn to program Pybench to work with interrupts. Modify your program **lab4_ex3a.py** to **lab4_ex4.py**, replacing the section after all the motor control functions (i.e. **B_forward**(value), **B_back**(value), **B_stop**( )) with the code segment shown on the next page.

This code is rather complicated. I will explain how this works on Friday at the tutorial. For now, I want you to focus on the following interesting points:

1. The while-loop is almost the same as that in **lab4_ex1c**, where the potentiometer is read, and its value is used to drive the motors. There is NO polling function: the sensor signal on Y4 is not used here. There is no checking of elapsed time either.
2. The loop assumes that the variable "A_speed" *magically* contains the number of transitions on Y4 and reports the rotational speed for motor A.
3. The magic is occurring in the "INTERRUPT" section immediately above.

4. There are two **interrupt service routines**: 1) **isr_motorA(.)** and 2) **isr_speed_timer(.)**.
5. **isr_motorA(.)** increments "A_count" each time an interrupt occurs on the Y4 sensor signal.
6. **isr_speed_timer(.)** is called when Timer 4 period is over. Timer 4 is programmed to run at 10Hz, therefore a timer_4 interrupt occurs every 100msec. When this happens, the ISR saves the count value in "A_count" to "A_speed" and reset the counter.
7. A_count and A_speed are declared as global variable inside the ISRs (otherwise it is not visible in the ISRs).
8. The line: **micropython.alloc_emergency_exception_buf(100)** is required by MicroPython.

```
...
# Initialise variables
DEADZONE = 5
speed = 0
A_speed = 0
A_count = 0

#-------  Section to set up Interrupts ----------
def isr_motorA(dummy):  # motor sensor ISR - just count transitions
    global A_count
    A_count += 1

def isr_speed_timer(dummy):     # timer interrupt at 100msec intervals
    global A_count
    global A_speed
    A_speed = A_count           # remember count value
    A_count = 0                 # reset the count

# Create external interrupts for motorA Hall Effect Senor
import micropython
micropython.alloc_emergency_exception_buf(100)
from pyb import ExtInt

motorA_int = ExtInt ('Y4', ExtInt.IRQ_RISING, Pin.PULL_NONE,isr_motorA)

# Create timer interrupts at 100 msec intervals
speed_timer = pyb.Timer(4, freq=10)
speed_timer.callback(isr_speed_timer)

#-------  END of Interrupt Section  ----------

while True:             # loop forever until CTRL-C

    # drive motor - controlled by potentiometer
    speed = int((pot.read()-2048)*200/4096)
    if (speed >= DEADZONE):     # forward
        A_forward(speed)
        B_forward(speed)
    elif (speed <= -DEADZONE):
        A_back(abs(speed))
        B_back(abs(speed))
    else:
        A_stop()
        B_stop()

    # Display new speed
    oled.draw_text(0,20,'Motor A:{:5.2f} rps'.format(A_speed/39))
    oled.display()
```

Modify **lab4_ex4.py** so that you sense the speed of both motors and report them on the OLED display. (The full solution to **lab4_ex4.py** is available on the course webpage.)

Appendix A – Solution to Exercise 1c

```
'''    Marks the start of comment section
------------------------------------------------------
Name: Lab 5 Exercise 1c - Control motor using potentiometer
Creator:  Peter YK Cheung
Date:   28 Feb 2016
Revision:  1.0
------------------------------------------------------
Control motor using potentiometer with display drive speed
------------------------------------------------------
'''
import pyb
from pyb import Pin, Timer, ADC
from oled_938 import OLED_938   # Use OLED display driver

# Define pins to control motor
A1 = Pin('X3', Pin.OUT_PP)      # Control direction of motor A
A2 = Pin('X4', Pin.OUT_PP)
PWMA = Pin('X1')                # Control speed of motor A
B1 = Pin('X7', Pin.OUT_PP)      # Control direction of motor B
B2 = Pin('X8', Pin.OUT_PP)
PWMB = Pin('X2')                # Control speed of motor B

# Configure timer 2 to produce 1KHz clock for PWM control
tim = Timer(2, freq = 1000)
motorA = tim.channel (1, Timer.PWM, pin = PWMA)
motorB = tim.channel (2, Timer.PWM, pin = PWMB)

# Define 5k Potentiometer
pot = pyb.ADC(Pin('X11'))

# I2C connected to Y9, Y10 (I2C bus 2) and Y11 is reset low active
oled = OLED_938(pinout={'sda': 'Y10', 'scl': 'Y9', 'res': 'Y8'}, height=64,
                    external_vcc=False, i2c_devid=61)
oled.poweron()
oled.init_display()
oled.draw_text(0,0, 'Lab 5 - Exercise 1c')
oled.display()

def A_forward(value):
    A1.low()
    A2.high()
    motorA.pulse_width_percent(value)

def A_back(value):
    A2.low()
    A1.high()
    motorA.pulse_width_percent(value)

def A_stop():
    A1.high()
    A2.high()
```

```
def B_forward(value):
    B2.low()
    B1.high()
    motorB.pulse_width_percent(value)

def B_back(value):
    B1.low()
    B2.high()
    motorB.pulse_width_percent(value)

def B_stop():
    B1.high()
    B2.high()

# Use 5k potentiometer to control motor speed
DEADZONE = 5
speed = 0

while True:              # loop forever until CTRL-C
    speed = int((pot.read()-2048)*200/4096)
    oled.draw_text(0,40,'Motor Drive:{:5d}%'.format(speed))
    oled.display()
    if (speed >= DEADZONE):     # forward
        A_forward(speed)
        B_forward(speed)
    elif (speed <= -DEADZONE):
        A_back(abs(speed))
        B_back(abs(speed))
    else:
        A_stop()
        B_stop()
```

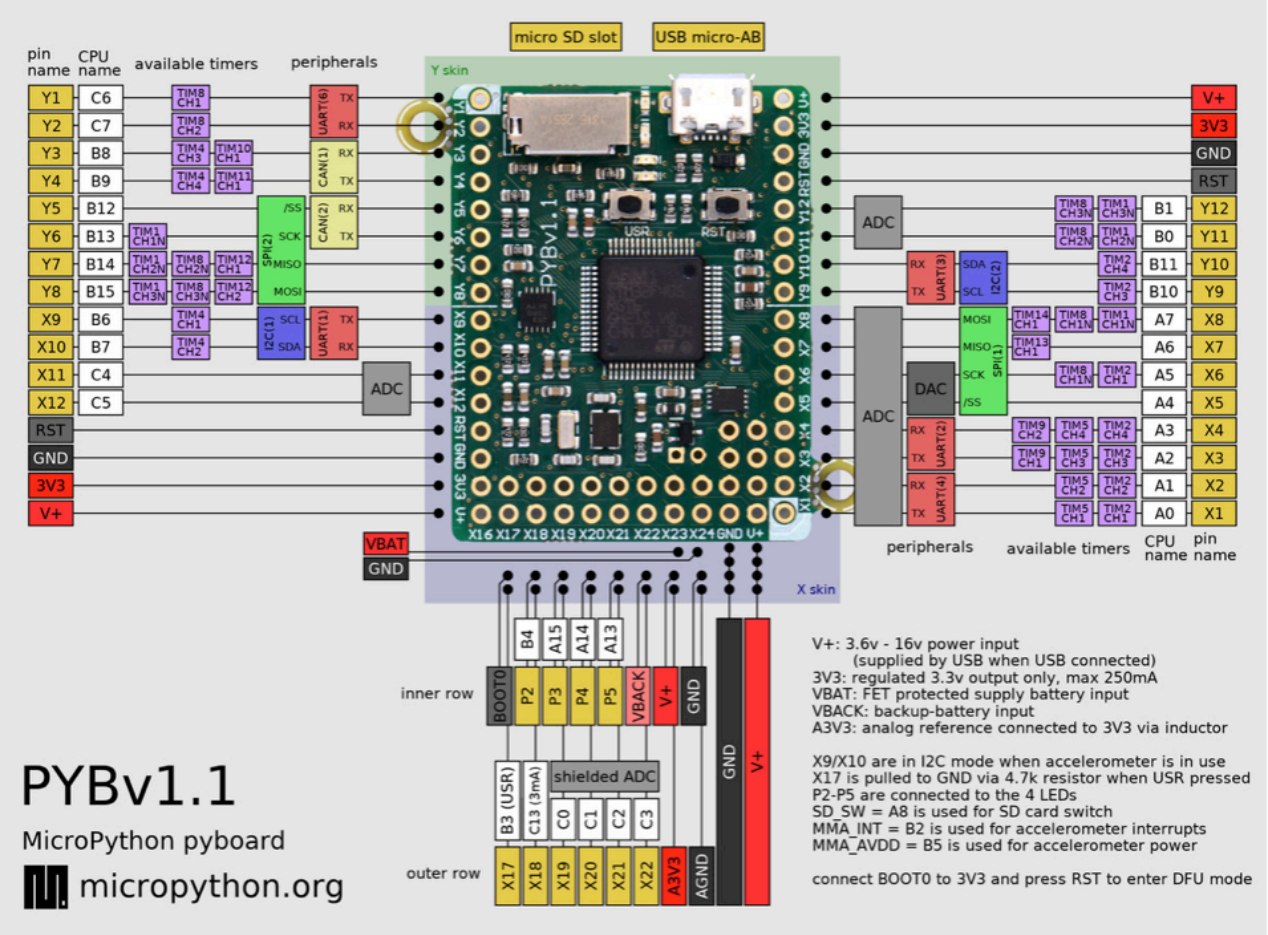
Appendix B: Solution to Exercise 3b

```
'''    Marks the start of comment section
-----------------------------------------------------
Name: Lab 5 Exercise 3b - Detect speed of motor by polling
Creator:  Peter YK Cheung
Date:   28 Feb 2016
Revision:  1.0
-----------------------------------------------------
This fails because OLED display is slow and transitions
are missed in the polling loop
-----------------------------------------------------
'''
import pyb
from pyb import Pin, Timer, ADC
from oled_938 import OLED_938   # Use OLED display driver

# Define pins to control motor
A1 = Pin('X3', Pin.OUT_PP)      # Control direction of motor A
A2 = Pin('X4', Pin.OUT_PP)
PWMA = Pin('X1')                # Control speed of motor A
B1 = Pin('X7', Pin.OUT_PP)      # Control direction of motor B
B2 = Pin('X8', Pin.OUT_PP)
PWMB = Pin('X2')                # Control speed of motor B

# Configure timer 2 to produce 1KHz clock for PWM control
tim = Timer(2, freq = 1000)
motorA = tim.channel (1, Timer.PWM, pin = PWMA)
motorB = tim.channel (2, Timer.PWM, pin = PWMB)

# Define 5k Potentiometer
pot = pyb.ADC(Pin('X11'))

# I2C connected to Y9, Y10 (I2C bus 2) and Y11 is reset low active
oled = OLED_938(pinout={'sda': 'Y10', 'scl': 'Y9', 'res': 'Y8'}, height=64,
                external_vcc=False, i2c_devid=61)
oled.poweron()
oled.init_display()
oled.draw_text(0,0, 'Lab 5 - Exercise 3a')
oled.display()

# Define pins for motor speed sensors
A_sense = Pin('Y4', Pin.PULL_NONE)  #  Pin.PULL_NONE = leave this as input pin
B_sense = Pin('Y6', Pin.PULL_NONE)

def A_forward(value):
    A1.low()
    A2.high()
    motorA.pulse_width_percent(value)

def A_back(value):
    A2.low()
    A1.high()
    motorA.pulse_width_percent(value)

def A_stop():
    A1.high()
    A2.high()
```

```
def B_forward(value):
    B2.low()
    B1.high()
    motorB.pulse_width_percent(value)

def B_back(value):
    B1.low()
    B2.high()
    motorB.pulse_width_percent(value)

def B_stop():
    B1.high()
    B2.high()
```

```
# Initialise variables
DEADZONE = 5
speed = 0
A_state = 0
B_state = 0
A_speed = 0
B_speed = 0
A_count = 0
B_count = 0
tic = pyb.millis();

while True:             # loop forever until CTRL-C
    # detect rising edge on sensor A
    if (A_state == 0) and (A_sense.value()==1): # rising edge detected on A
        A_count += 1
    if (B_state == 0) and (B_sense.value()==1): # rising edge detected on B
        B_count += 1
    A_state = A_sense.value()
    B_state = B_sense.value()

    # Check to see if 100 msec has elapsed
    toc = pyb.millis()
    if ((toc-tic) >= 100):
        A_speed = A_count
        B_speed = B_count

        # drive motor - controlled by potentiometer
        speed = int((pot.read()-2048)*200/4096)
        if (speed >= DEADZONE):     # forward
            A_forward(speed)
            B_forward(speed)
        elif (speed <= -DEADZONE):
            A_back(abs(speed))
            B_back(abs(speed))
        else:
            A_stop()
            B_stop()

        A_count = 0
        B_count = 0

        # Display new speed
        oled.draw_text(0,20,'Motor A:{:5.2f} rps'.format(A_speed/39))
        oled.draw_text(0,30,'Motor B:{:5.2f} rps'.format(B_speed/39))
        oled.display()
        tic = pyb.millis()
```

Appendix C – Pin Assignment on Pybench



Pin Assignments for Pybench

PIN	FUNCTION
X1	Motor PWM_A/Servo 1
X2	Motor PWM_B/Servo 2
X3	Motor control AIN1/Servo 3
X4	Motor control AIN2/Servo 4
X5	Analogue OUTPUT
X6	SW0
X7	Motor control BIN1
X8	Motor control BIN2
X9	IMU-I2C SCL
X10	IMU-I2C SDA
X11	POT5K
X12	Analogue INPUT

PIN	FUNCTION
Y1	BLE-UART Tx
Y2	BLE-UAR Rx
Y3	SW1
Y4	Motor sensor A_A
Y5	Motor sensor A_B
Y6	Motor sensor B_A
Y7	Motor sensor B_B
Y8	OLED-i2C RST
Y9	OLED-I2C SCL
Y10	OLED-I2C SDA
Y11	Microphone amplifier
Y12	Unused