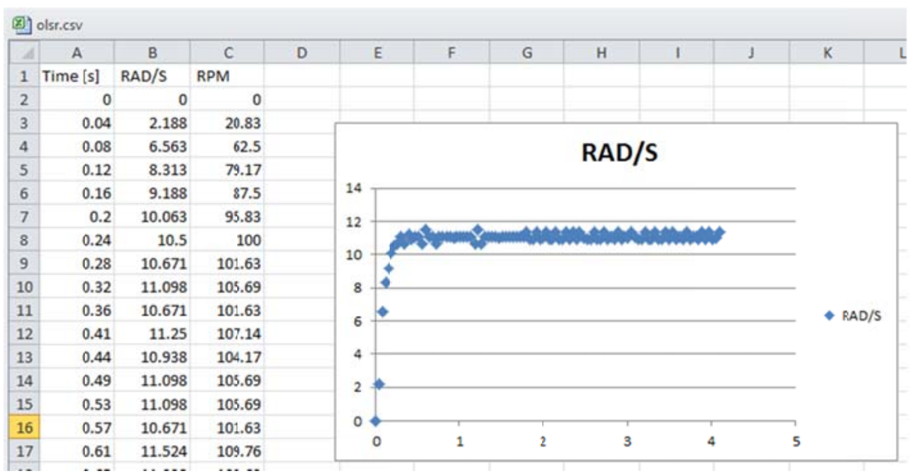
Hands-on Lab

Lego NXT – NXT Motor Open-Loop Step Response (OLSR)

In class, the theory underlying a DC motor was presented. Briefly, a DC motor can be modeled as a first order system. Here, a step input (i.e. a constant voltage) is applied to the motor. The motor's rotational speed gradually reaches a steady-state value as depicted in **Figure 1** below. This lab demonstrates this phenomenon. CountTick is used to set the sampling time, and to calculate the time between changes in the motor's angle. The resulting speed (rad/s and RPM) are computed and saved as a file. XLS scatter plot (Figure 1 graph) shows the motor's first-order response.



Time [s]	RAD/S	RPM
0	0	0
0.04	2.188	20.83
0.08	6.563	62.5
0.12	8.313	79.17
0.16	9.188	87.5
0.2	10.063	95.83
0.24	10.5	100
0.28	10.671	101.63
0.32	11.098	105.69
0.36	10.671	101.63
0.41	11.25	107.14
0.44	10.938	104.17
0.49	11.098	105.69
0.53	11.098	105.69
0.57	10.671	101.63
0.61	11.524	109.76

Figure 1: Open-Loop Step Response of a LEGO NXT motor

Step 1: Write save, and compile **`motorOlsr1_0a.nxc`**

Note: The program is long only because it is filled with comments. Moreover, the code leverages the concepts learned in file handling (e.g. `x^2File1.0.nxc`) and timers (e.g. `stopWatch1_0a.nxc`).

```
// File: displaySquareAndSquareRoot3_0.nxc

// FILE: mtrOlsr1_0a.nxc - Works!
// AUTH: P.Oh
// DATE: 03/13/23 15:58
// DESC: OLSR of NXT motor (Port A) with data written to file olsr.csv
//       with 40 msec sampling time
// VERS: 1_0a: ME 425/625 Release version
// REFS: nxtMotorOlsr1_0.nxc; x^2File1.0.nxc, rotate0_1a.nxc, mtrSpeed0_2a5.nxc
//       mtrOlsr0_1a.nxc
// NOTE: Uses MotorRotationCount which reports encoder count in degrees
//            and program calculates difference over delta tic counts

#define MOTOR OUT_A // set constant MOTOR for Port A
#define FULL_SPEED 75 // 75 percent of possible motor speed
#define DEG2RPM 166.667 // deg/msec to RPM
#define RPM2RADPERSEC 0.105; // RPM to rad/sec

task main() {
  // Declare variable ---------------------------------------------------
  // Motor related variables
  long degPrev, degCurr, degDelta;   // motor's degrees previous,current, delta
  float motorRpm;                    // motor speed [RPM]
  string strMotorRpm;                // string form of motorRpm
  float motorRadPerSec;              // motor speed [rad/s]
  string strMotorRadPerSec;          // string form of motorRadPerSec

  // File related variables
  unsigned int result;                // flag returned when handling files
  byte fileHandle;                    // handle to the data file
  short bytesWritten;                 // number of bytes written to the file
  string fileName, fileHeader, text;  // name, header and text to write to file

  // Timing related variables
  long ticPrev, ticCurr, ticDelta;    // previous, current and delta ticks
  long ticWait, ticEnd;               // ticks to wait and to end
  long msSamplingTime;                // sampling time in [msec]
  float secElapsed;                   // seconds elapsed in [sec]
  string strSecElapsed;               // string form of secElapsed

  // Button related variables
  bool orangeButtonPushed, rightArrowButtonPushed;

  // Initialize variables -------------------------------------------------
  secElapsed = 0.0; // set elapsed time to zero
  degPrev = 0; // motor initially motionless so set angle to zero
  msSamplingTime = 40; // [msec] sampling time

  // Algorithm starts here ---------------------------------------------------
  // (1) Set up the file
  fileName = "olsr.csv" ;         // <---- file name you want data saved to
  result=CreateFile(fileName, 2048, fileHandle);
  // (1A) Check if filename already exists, and overwrite it
  while (result==LDR_FILEEXISTS) {
      CloseFile(fileHandle);
      DeleteFile(fileName);
      // result=CreateFile(fileName, 1024, fileHandle);
      result=CreateFile(fileName, 2048, fileHandle);
  } // end while
  // (1B) write column header to file
  fileHeader = "Time [s], RAD/S, RPM" ; // <---- column header in your CSV file
  WriteLnString(fileHandle, fileHeader, bytesWritten);
```

```
  // (2) Process that generates data
  // Prompt user to begin step input
  TextOut (0, LCD_LINE1, "-> starts" );
  do { // wait until user hits right button
   rightArrowButtonPushed = ButtonPressed(BTNRIGHT, FALSE);
  } while(!rightArrowButtonPushed);

  // Begin step response
  TextOut (0, LCD_LINE1, "Orange Btn quits" );
  strSecElapsed = FormatNum("%5.3f" , secElapsed);
  // (2A) read current motor angle [deg] and poll timer before applying power
  degPrev = MotorRotationCount(MOTOR);
  // Command motor to move i.e. step input
  ticPrev = CurrentTick(); // poll timer 1st time <<<<<<<<<<<<<<<<<<<<<<<<<<<
  OnFwd(MOTOR, FULL_SPEED); // turn on motor at FULL_SPEED value

  do {
   // (2B) poll timer a 2nd time, measure elapsed time in [msec], read
   // motor's rotational angle [deg] and compute rotational speed [RPM]
   ticCurr = CurrentTick(); // poll timer a 2nd time <<<<<<<<<<<<<<<<<<<<<<<<<
   // Read change in motor angle
   degCurr = MotorRotationCount(MOTOR); // get relative position [deg]
   degDelta = degCurr - degPrev;

   // Measure elapsed time and hence motor RPM
   ticDelta = ticCurr - ticPrev; // time [msec] elapsed between angle reads
   motorRpm = (degDelta * DEG2RPM) / ticDelta; // deg/ms * DEG2RPM yields RPM
   strMotorRpm = FormatNum("%5.2f" , motorRpm);

   // Display motor actual speed and elapsed time
   TextOut(0, LCD_LINE4, FormatNum("RPM = %5.2f" , motorRpm));
   TextOut(0, LCD_LINE6, FormatNum("Time = %5.3f s" , secElapsed));

   // (2C) compute rotational speed [rad/s].  Form string versions of the data
   // and write to file
   motorRadPerSec = motorRpm * RPM2RADPERSEC; // RPM * RPM2RADPERSEC gives rad/s
   strMotorRadPerSec = FormatNum("%5.3f" , motorRadPerSec);
   secElapsed = secElapsed + (ticDelta/1000.0); // [sec]
   strSecElapsed = FormatNum("%1.2f" , secElapsed);
   text=StrCat(strSecElapsed, "," , strMotorRadPerSec, "," , strMotorRpm);
   WriteLnString(fileHandle, text, bytesWritten);

   // (2D) call the current values the previous ones before looping back
   ticPrev = ticCurr; // assign 2nd polled tick value to 1st polled tick value
   degPrev = degCurr; // assign current rot'n count as previous rot'n count

   // (2E) compute how much time to do nothing until sampling cycle is completed
   // EG: suppose the current loop iteration took 35 msec.  Suppose the defined
   // sampling time is 40 msec.  Thus, we should wait for 5 msec before looping
   // back.
   ticEnd = CurrentTick(); // <<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
   ticWait = msSamplingTime - (ticEnd - ticCurr);
   Wait(ticWait);

   // Check if user wants to quit
   orangeButtonPushed = ButtonPressed(BTNCENTER, FALSE);
  } while( !orangeButtonPushed );

  // Orange button pressed, so command 0 speed to motor and quit
       ClearScreen();
       TextOut(0, LCD_LINE2, "Quitting", false);
       // Stop motor
  OnFwd(MOTOR, 0);
  CloseFile(fileHandle);
  PlaySound(SOUND_LOW_BEEP);  // Beep to signal quitting
       Wait(SEC_2);
  StopAllTasks();
}  // end of main
```

Program: `motorOlsr1_0a.nxc`

Step 2: Construct a mount for your LEGO NXT motor. Connect the motor to Port A on the Brick. Execute `motorOlsr1_0a.nxc`. This will immediately have the NXT motor (that's connected to Port A) move at 75% power. Count 3 to 5 seconds, and then press the Orange button. This will stop the motor and quit the program.

Step 3: Refer to Concept 1 in the Lab entitled **labBricxxFileHandling-102822a.pdf**. Recall, one can use BrixCC's Tools- NXT Explorer to see the files in one's Brick. Click and drag the file olsr.csv to your laptop. Use Excel to open the file and create a scatter plot (like the one shown above in Figure 1).

Code Explanation: The cyan highlight of Step (1) is very similar to the code in `x^2File1_0.nxc`. This section creates a file named `olsr.csv` and writes a comma separated header for 3 columns of your data: `Time [s]`, `RAD/S`, and `RPM`. Recall, Excel reads CSV files and will automatically put any data in these columns for easy plotting.

Step (2A) reads the motor's current angle [deg], polls the timer with a `CountTick`, and then applies power to the NXT motor. Step (2B) begins the do-while loop. Here, one polls the timer and reads the current motor angle. Step (2C) uses that information to compute the motor's rotational speed and writes the data to the file.

Highlighted in green is Step (2E). This is important to ensure the desired sampling rate. In other words, one wants to sense, compute, and write data at <u>specific</u> times (i.e. at the sampling rate). The comments give an example to rationalize the need for Step (2E). Here's another example. One observes the program has two TextOut statements. These display the `motorRpm` and `secElapsed` on the Brick. Displaying info is a time-consuming process for any micro-controller. For the NXT, such displays can take 2-5 milliseconds to execute. Also, the `do-while` loop has a single `WriteLnString` function. This also consumes time, but varies. Some microprocessors collect data to write into RAM and then flushes it to memory (e.g. EEPROM) when it's filled. Other microprocessors write data directly to memory. Some microprocessors do a combination. The net effect is that Step (2E) employs a Wait statement to ensure the do-while loop time matches the prescribed sampling time.

Exercise 1: In NxC create programs for the following:

1-1 Repeat **`motorOlsr1_0a.nxc`** but using (1) a 25% and (2) 50% power level. Compare the resulting open-loop step response plots with the 75% power level. What are the rise times for the 3 different plots? Why are they different or the same?