INTRODUCTION

This application note demonstrates the use of a PIC17C756A microcontroller (MCU) in a brush-DC servomotor application. The PIC17CXXX family of microcontrollers makes an excellent choice for cost-effective embedded servomotor control applications. Some of the benefits of the PIC17CXXX MCU family include fast instruction cycle execution (up to 120 ns), an 8 x 8 hardware multiplier, and many useful hardware peripherals. The application hardware is shown in Figure 1.

SYSTEM OVERVIEW

A block diagram of the servomotor system is provided in Figure 2. The system is comprised of the following elements:

- PIC17C756A MCU
- RS-232 Interface
- Power Amplifier
- Brush-DC Motor & Rotary Encoder

The MCU is responsible for communications with the host system, measuring the motor position, calculating the compensation algorithm and motion profile, and producing the drive signal sent to the power amplifier.

HARDWARE DESCRIPTION

The design makes extensive use of the hardware peripherals available on the PIC17C756A. The peripherals used in this application are summarized in Table 1.

A complete schematic diagram for the application is given in Appendix A.
TABLE 1: PIC17C756A PERIPHERAL USAGE FOR DC SERVOMOTOR APPLICATION

<table>
<thead>
<tr>
<th>Peripheral</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMR0</td>
<td>Used as a counter to maintain the incremental up-count from the motor position encoder</td>
</tr>
<tr>
<td>TMR1</td>
<td>PWM1 time-base</td>
</tr>
<tr>
<td>TMR2</td>
<td>Servo update time-base</td>
</tr>
<tr>
<td>TMR3</td>
<td>Used as a counter to maintain the incremental down-count from the motor position encoder</td>
</tr>
<tr>
<td>PWM1</td>
<td>Generates drive signal for DC motor</td>
</tr>
<tr>
<td>USART1</td>
<td>Terminal communications</td>
</tr>
<tr>
<td>I/O</td>
<td>Encoder index signal, PWM amplifier enable, limit switch inputs</td>
</tr>
</tbody>
</table>

FIGURE 2: DC SERVOMOTOR BLOCK DIAGRAM
Motor Position Feedback

Referring to the schematic diagrams (Figure A-1 to Figure A-3), the outputs of the rotary encoder are connected to 2.7k pull-up resistors, filtered using RC networks, and buffered by Schmidt trigger inverters U5A - U5C. The outputs of the rotary encoder include two quadrature outputs and a third index output that is used to align the shaft of the motor to a known reference position. The conditioned index signal is connected to I/O pin RF0 of the MCU.

The conditioned quadrature outputs from the rotary encoder are connected to D flip-flops U6A and U6B. These D flip-flops decode the quadrature pulse train into up and down pulse outputs. A timing diagram indicating the operation of the decoder circuit is shown in Figure 3.

A simplified schematic diagram of the encoder interface is shown in Figure 4. The MCU accumulates the total distance traveled between servo updates based on the up and down pulse outputs from U6A and U6B. To accomplish this, Timer0 and Timer3 are configured as counters with external clock inputs. The output of D flip-flop U6A (up pulses) is connected to the Timer0 external clock input and the output of D flip-flop U6B (down pulses) is connected to the Timer3 external clock input. Each of these timer registers is 16 bits wide.

Three external logic inputs are provided at connector J4 on the motor driver PCB and are intended for mechanical limit switch sensing. These inputs could also be used to activate certain motor functions. The PWM Amplifier

Integrated circuit U1 is an H-bridge driver that uses DMOS output devices and can deliver up to 3A output current at supply voltages up to 52V. The device has an internal charge pump for driving the high-side transistors and dead-time circuitry to prevent cross-conduction of the output devices. Each side of the bridge may be driven independently and the inputs are TTL compatible. An enable input and automatic thermal shutdown are also provided. A transient voltage suppressor is connected across the motor terminals to prevent voltage spikes generated by the motor inductance from damaging the bridge.

The PWM1 output from the MCU is buffered through inverters U3A, U3B, and U3D and connected to both sides of the H-bridge driver IC. One side of the bridge is driven with an inverted PWM signal. By driving the bridge in this manner, the motor may be turned in either direction depending on the PWM duty cycle. A 50% PWM duty cycle will produce zero motor torque. A 100% duty cycle will produce maximum motor torque in the forward direction, while a 0% duty cycle will produce maximum motor torque in the opposite direction.

An enable signal from I/O pin RF4 of the MCU is connected to the bridge driver through inverter U3C. This signal turns the output of the PWM amplifier on or off.

---

**FIGURE 3: ENCODER TIMING**

Motor Reverses Direction Here

ENC. CH. A

ENC. CH. B

Up Count

Down Count
Servo Update Timing

The servo update calculations are performed in an interrupt service routine and are synchronized with the output of PWM1. This is desirable because the duty cycle is updated at multiples of the PWM period. The PWM1 output is connected to the TCLK12/RB4 pin and is used as a clock source for Timer2. Timer2 has an associated period register, PR2. When the value of Timer2 is equal to the value loaded in PR2, Timer2 is reset to 0 and an interrupt is generated. By adjusting the value in PR2, the servo update frequency may be adjusted to any ratio of the PWM1 output. At a device operating frequency of 33 MHz, the frequency of PWM1 is 32.2 kHz. A 3.9 kHz servo update frequency will be achieved with the value in PR2 set to 8.

RS-232 Transceiver

The TX and RX pins of USART1 are connected to a Dallas Semiconductor DS275 RS-232 transceiver. The chip was selected for its small size and because it is line-powered. The chip uses power from the receive input to generate the correct RS-232 voltage levels while transmitting. To save space, RS-232 connections are made through a RJ-11 connector on the MCU PCB.

Power Supply

Voltage regulator VR1 provides 5 volts to the MCU, RS-232 driver, interface logic, and the rotary encoder. The system is designed to operate at any supply voltage between 10 volts and 24 volts. The supply voltage is connected directly to the PWM amplifier.
SOURCE CODE

The source code is written in the C programming language for ease of implementation and was compiled using the MPLAB-C17™ compiler. A complete source code listing for the application has been provided in Appendix B.

The source code performs four basic functions:

- RS-232 communication
- Motor position measurement
- Compensator algorithm calculation
- Motion profile calculation

All functions, except the RS-232 communications are performed in an interrupt service routine.

RS-232 Communications

The DC motor software allows control of the motor operating mode and parameter changes via a remote terminal with a RS-232 link operating at 19.2 kbaud. All RS-232 communication takes place in the main program loop. The USART1 reception interrupt flag (RC1IF) is polled to detect when a character has been received. Each received character is stored in a buffer, echoed to the USART, and the buffer index is incremented. This continues until the buffer is full or a <CR> is received. After a <CR> is received, the buffer contents are checked for numerical or command data and a ‘READY>’ prompt is sent to the terminal. If the command is not recognized, an error message is sent out.

Servo Updates

The servo calculations are performed each time a Timer2 interrupt occurs. A flowchart of the servo interrupt service routine (ISR) is shown in Figure 5.

32-bit Operations

This application makes extensive use of 32-bit values. Since MPLAB-C17 does not provide direct support for 32-bit variable types, the 32-bit variables used in the program are declared as unions. The use of a union in the C programming language allows multiple variable types to share the same data space. A union with the name of ‘LONG’ has been declared in the source code. The union LONG consists of an array of four characters and an array of two integers. Therefore, any variables that are declared with this data type may be manipulated as four bytes or two integers. Additionally, the contents of the entire union may be copied to another location by simply assigning it to another union of the same type.

Position Updates

During each servo update period, the function UpdatePosition() is called. The count values in Timer0 and Timer3 are used to find the total motor distance traveled during the previous servo update period. The counters are never cleared to avoid the possibility of losing count information. Instead, the values of the Timer0 and Timer3 registers saved during the previous sample period are subtracted from the present values using two’s-complement signed arithmetic. This calculation provides the total number of up and down pulses accumulated during the servo update period. The use of two’s complement arithmetic accounts for a timer overflow that may have occurred since the last read. The down pulse count is then subtracted from the up pulse count, which provides a signed result indicating the total distance (and direction) traveled during the sample period. This value also represents the measured velocity of the motor in encoder counts per servo update period and is stored in the variable mvelocity.

The measured position of the motor is stored in the union mposition. The upper 24 bits of mposition holds the position of the motor in encoder counts. The lower eight bits of mposition represent fractional encoder counts. The value of mvelocity is added to mposition at each servo update period to find the new position of the motor. With 24 bits, the absolute position of the motor may be tracked through 33,554 shaft revolutions using a 500 CPR encoder. The size of mposition can be increased as necessary to track greater distances.
FIGURE 5: SERVO ISR FLOWCHART

START

UPDATE MOTOR
POSITION

VELOCITY
OR POSITION
MODE?

YES

UPDATE
MOTION
PROFILE

NO

CALCULATE
POSITION
ERROR

CALCULATE
PID ALGORITHM

UPDATE PWM
DUTY CYCLE

END
The theoretical maximum encoder bit rate is determined by the number of bits in the counter registers and the servo update rate. If the counter should overflow between servo update periods, motor position information will be lost. A 16-bit counter register, for example, would provide \(2^{16} - 1\) counts before an overflow occurred. Since two's complement arithmetic is used, the number of encoder counts during a given sample period must be limited to \(2^{15} - 1\) or 32767. The maximum encoder rate is determined by multiplying the servo sampling frequency by the maximum encoder counts per sample. For this design, the servo update frequency is 3.9 kHz, which gives a theoretical maximum encoder rate of 128 MHz. In practice, the encoder rate is limited by the external clock timing specifications for Timer0 and Timer3. The minimum external clock period for Timer0 and Timer3 is \(TCY + 40\text{ns}\). Therefore, the maximum encoder rate is 6.2 MHz for a device operating frequency of 33 MHz.

**PID Algorithm**

The MCU must calculate and provide the correct motor drive signal based on the received motion commands and position/velocity feedback data. A compensation algorithm is used to ensure that the feedback loop is stabilized. Many types of algorithms may be used including various implementations of digital filters, fuzzy-logic, and the PID (proportional, integral, derivative) algorithm. A PID algorithm is used in this application since it is widely used in industrial applications and is easy to implement.

Figure 6 shows a flowchart indicating the function of the PID algorithm as it is implemented here. During each iteration of the servo loop, a position error is calculated and is used as the input to the algorithm. To control the operation of the PID algorithm, each of the three terms has a gain constant that can be adjusted in real-time by the user. Each term of the PID algorithm is calculated using a 16 bit x 16 bit signed multiplication with the PID gain constants \(k_p\), \(k_i\), and \(k_d\) defined as 16-bit signed integers.

The union `position` holds the commanded motor position. The value of `mposition`, the measured motor position, is subtracted from `position` to find the present error in encoder counts. The least significant eight bits of these variables represent fractional encoder counts and are not used in the PID algorithm calculations. The `sub32()` function is used to subtract the values. The values to be subtracted are placed in `aarg` and `barg`. The result of the subtraction is available in `aarg` after the function has been called. The error calculation result in `aarg` is truncated to a signed 16-bit integer and stored in `u0`.

The multiplication routine is implemented as an inline assembly instruction in the C source code. The algorithm executes in 36 cycles and takes advantage of the 8 x 8 hardware multiplier on the MCU. To perform the multiplication, the signed 16-bit integers to be multiplied are loaded into `multplr` and `multcnd` variables and the function `mult()` is called. The 32-bit multiplication result is available in the union `aarg`. The `add32()` function is used to add the 32-bit terms of the PID algorithm.

The proportional term of the PID algorithm provides an output that is a function of the immediate position error, \(u_0\).

The integral term of the PID algorithm accumulates successive position errors calculated during each servo loop iteration and improves the low frequency open-loop gain of the servo system. The effect of the integral term is to reduce small steady-state position errors.

If the `stat.saturated` bit is set because the PWM output during the previous servo update period was saturated, the current position error is not be added to the integral value. This prevents a condition known as ‘integrator-windup’ that occurs when the integral term continues to accumulate error when the output is saturated. When the output is no longer saturated, the integral term ‘unwinds’ and causes abrupt motion as the accumulated error is reduced.

The differential term of the PID algorithm is a function of the difference in error between the current servo update period and the previous one. The integral term improves the high frequency open-loop response of the servo system.

After the three terms of the PID algorithm are summed, the 32-bit result stored in `ypid` is saturated to 24 bits. The 16-bit signed integer `ypwm` is used to set the PWM duty cycle. The upper 16 bits of `ypid` are used to set the duty cycle, which effectively divides the output of the PID algorithm by 256. The range of the duty cycle is restricted so that the PWM duty cycle cannot be less than 1% or greater than 99%. This ensures that Timer2 will always receive a valid clock input for the servo update timing interrupt. If beyond the limits, `ypwm` is set to the maximum allowable positive or negative value and `stat.saturated` is set to ‘1’. An offset value of 512 must be added to `ypwm` before it is written to the PWM duty cycle registers. (For 10-bit PWM resolution, a value of ‘0’ written to the duty cycle registers provides a 0% duty cycle and a value of 1023 provides a 100% duty cycle.)
FIGURE 6: PID ALGORITHM FLOWCHART

START

CALCULATE PROPORTIONAL TERM (1)

SATURATION FLAG SET?

YES

NO

ADD ERROR TO INTEGRAL (2)

CALCULATE INTEGRAL TERM AND ADD TO YPID (3)

CALCULATE DIFFERENTIAL TERM AND ADD TO YPID (4)

IS OUTPUT SATURATED?

NO

YES

SET SATURATION FLAG

CLEAR SATURATION FLAG

UPDATE PWM DUTY CYCLE

END

(1) \( y_{pid} = kp \cdot u_0 \)
(2) \( \text{Integral} = \text{Integral} + u_0 \)
(3) \( y_{pid} = y_{pid} + \text{Integral} \cdot ki \)
(4) \( y_{pid} = y_{pid} + kd(u_0 - u_1) \)
Motion Profile

For optimum motion control, a method must be implemented that will control the motor acceleration and deceleration. Motion will be abrupt without the profile, causing excessive wear on the mechanical components and degrading the performance of the compensation algorithm.

For this application, a simple motion profile that generates trapezoidal (or triangular) moves has been implemented. The profile characteristics are adjusted by specifying a 16-bit velocity limit, vlim, and a 16-bit acceleration value, accel. The motion profile is used in Velocity Mode and Position Mode. If the motor is operating in one of these modes, the function UpdateTrajectory() is called each time ServoISR() is executed.

A specific motor velocity is established by adding an offset value to the commanded position at each servo update period. The 32-bit variable velact is used in the profile to hold the present commanded velocity of the motor. The lower 24 bits of velact and the least significant 8 bits of position, the commanded motor position, represent fractional encoder counts. The purpose of these additional bits is to increase the range of velocities that may be achieved. To achieve a particular motor velocity, the upper 16 bits of velact are added to position during each step of the profile. This allows the commanded motor velocity to vary between 1/256 counts/TS and 127 counts/TS. The actual velocity range of the motor is dependent on the servo update rate and the resolution of the encoder. With a 3.9 kHz servo update rate and a 500 CPR encoder, the range of commanded motor velocities is from 1.8 RPM to 59,436 RPM.

Motor acceleration/deceleration is accomplished in a manner similar to the motor velocity. The value of accel is added to or subtracted from velact at each servo update period.

A flowchart for the operation of the motion profile in Velocity Mode is shown in Figure 7. In Velocity Mode, data entered at the prompt is stored in the commanded velocity variable, velcom. After velcom is updated, the motor begins to accelerate or decelerate to the new commanded velocity. Acceleration continues until velact is equal to velcom or the velocity limit, vlim, has been exceeded. The value of velact is added to the commanded motor position, position. The motor will continue to run at the commanded velocity or the velocity limit until further velocity data is received. If the output is saturated (stat.saturated = ‘1’) during a particular servo update period, the commanded position is not changed.

A flowchart for the operation of the motion profile in Position Mode is shown in Figure 8. In Position Mode, a 16-bit relative movement distance is entered as encoder counts divided by 256. The total movement distance is divided by 2 and placed in phaseldist. A second variable, flatcount, is set to zero. The direction of the move is determined and stored in the stat.neg_move flag. The final move destination is calculated based on the present measured position and is stored in fposition. Finally, the stat.move_in_progress flag is set. Further position commands are ignored until the move has completed and this flag is cleared.

The motor begins to accelerate and the value of velact is subtracted from phaseldist at each servo update period to keep track of the distance traveled in the first half of the move. The value of velact is added or subtracted from the commanded motor position, position, depending on the state of the stat.neg_move flag. The motor stops accelerating when velact is greater than vlim. After the velocity limit has been reached, flatcount is incremented at each servo update period to keep track of the time spent in the flat portion of the move.

The first half of the move is completed when phaseldist becomes negative. At this time, the stat.phase flag is set to ‘1’. The variable flatcount is then decremented at each servo period. When flatcount = 0, the motor begins to decelerate. The move is complete when velact = 0. The previously calculated destination in fposition is written to the commanded motor position and the stat.move_in_progress flag is cleared at this time.
FIGURE 7: MOTION PROFILE FLOWCHART – VELOCITY MODE

START

YES IS OUTPUT SATURATED?

NO CURRENT VELOCITY LESS THAN COMMANDED VELOCITY?

YES ACCELERATE

CURRENT VELOCITY GREATER THAN COMMANDED VELOCITY?

NO CURRENT VELOCITY GREATER THAN VELOCITY LIMIT?

YES SET CURRENT VELOCITY LESS THAN COMMANDED VELOCITY

NO SET CURRENT VELOCITY GREATER THAN VELOCITY LIMIT

YES ADD CURRENT VELOCITY TO COMMANDED POSITION

END

DECELERATE

YES IS CURRENT VELOCITY GREATER THAN COMMANDED VELOCITY?

NO IS CURRENT VELOCITY LESS THAN COMMANDED VELOCITY?

YES SET CURRENT VELOCITY GREATER THAN VELOCITY LIMIT

NO SET CURRENT VELOCITY EQUAL TO VELOCITY LIMIT

YES SET CURRENT VELOCITY GREATER THAN VELOCITY LIMIT

NO SET CURRENT VELOCITY EQUAL TO VELOCITY LIMIT

YES SET CURRENT VELOCITY EQUAL TO COMMANDED VELOCITY

NO

NO

NO

NO

NO

NO
FIGURE 8: MOTION PROFILE FLOWCHART – POSITION MODE

START

IS OUTPUT SATURATED?

NO

IN PHASE 1 OF MOVE?

NO

HAS VELOCITY LIMIT BEEN REACHED?

YES

INCREMENT FLAT COUNT

ACCELERATE

DECELERATE

IS CURRENT VELOCITY LIMIT REACHED?

NO

IS FLAT COUNT 0?

YES

DECREMENT FLAT COUNT

SET POSITION COMMAND EQUAL TO CALCULATED FINAL POSITION

CLEAR MOVE IN PROGRESS FLAG

IS MOVE POSITIVE?

NO

ADD CURRENT VELOCITY TO COMMANDED POSITION

SUBTRACT CURRENT VELOCITY FROM PHASE 1 DISTANCE

IS PHASE 1 DISTANCE NEGATIVE?

NO

END

YES

SUBTRACT CURRENT VELOCITY TO COMMANDED POSITION

ADD CURRENT VELOCITY TO COMMANDED POSITION

IS MOVE POSITIVE?

NO

SUBTRACT CURRENT VELOCITY TO COMMANDED POSITION

ADD CURRENT VELOCITY TO COMMANDED POSITION

SET FLAG TO INDICATE PHASE 2

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USER INTERFACE

When power is first applied to the motor, the user will see a ‘READY>’ prompt appear on the terminal. At this time, the DC motor is ready to receive commands. A summary of all the commands is given in Table 2.

The software that controls the DC motor allows three basic modes of operation that are selectable from the remote terminal. These modes include Manual Mode, Velocity Mode, and Position Mode.

The default mode for the motor at power-up is Manual Mode. No position feedback is used in Manual Mode. The data entered at the prompt directly controls the PWM duty cycle delivered to the motor.

In Velocity Mode, the entry data specifies the signed motor velocity, which is given as encoder counts per sample period multiplied by 256. When new velocity data has been entered, the motor will accelerate or decelerate to the new velocity at a rate specified by the acceleration value. The motor will not accelerate if the velocity limit has been reached.

In Position Mode, the entry data specifies a signed 16-bit relative move distance. The movement distance, entered at the prompt, is given as encoder counts divided by 256. When a move distance is specified, a motion status flag is set and any additional move data are ignored until the current move is complete.

The profile of the move will be trapezoidal or triangular depending on the total move distance, the velocity limit, and the acceleration value. For a trapezoidal move, the motor will accelerate to the velocity limit and remain at that velocity until it is time for the motor to decelerate. If half of the move distance has been traveled before the motor reaches the velocity limit, the motor will begin to decelerate and the move will be triangular.

The motor operating parameters are displayed using the ‘R’ command. Any of the parameters may be modified by first entering the command to change the parameter, followed by a carriage return (<CR>). The parameter is then modified by entering the new value followed by a <CR>. The user can then verify that the parameter was changed by using the ‘R’ command again.

SUMMARY

The use of the PIC17C756A MCU in a DC servomotor application has many features that allow a cost-effective implementation with few external components. These include (2) 16-bit counters for position measurement, hardware PWM modules, and a hardware multiplier for high computational throughput.

ServoISR(), as written for this application, executes in 780 instruction cycles. For a servo update rate of 3.9kHz and a MCU clock frequency of 33 MHz, only 37% of the total MCU processing time is consumed. This provides additional time for performing unrelated tasks, computing more complicated compensator algorithms, or increasing the servo update rate.

TABLE 2: DC SERVO MOTOR COMMAND SUMMARY

<table>
<thead>
<tr>
<th>Command</th>
<th>Data Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>M &lt;CR&gt;</td>
<td>-500 ≤ data ≤ 500</td>
<td>Changes to the manual mode of operation. All subsequent data input is written directly to the PWM output.</td>
</tr>
<tr>
<td>V &lt;CR&gt;</td>
<td>-32768 ≤ data ≤ 32767</td>
<td>Changes to velocity mode. All subsequent data input is velocity in encoder counts per sample period multiplied by 256.</td>
</tr>
<tr>
<td>P &lt;CR&gt;</td>
<td>-32768 ≤ data ≤ 32767</td>
<td>Changes to position mode. All subsequent data input is a relative position move in encoder counts multiplied by 256.</td>
</tr>
<tr>
<td>W &lt;CR&gt;</td>
<td>-32768 ≤ data ≤ 32767</td>
<td>Changes the proportional gain factor of the PID algorithm. The command is followed by the data value.</td>
</tr>
<tr>
<td>L &lt;CR&gt;</td>
<td>-32768 ≤ data ≤ 32767</td>
<td>Changes the integral gain factor of the PID algorithm. The command is followed by the data value.</td>
</tr>
<tr>
<td>KP &lt;CR&gt; data &lt;CR&gt;</td>
<td>-32768 ≤ data ≤ 32767</td>
<td>Changes the proportional gain factor of the PID algorithm. The command is followed by the data value.</td>
</tr>
<tr>
<td>CI &lt;CR&gt; data &lt;CR&gt;</td>
<td>-32768 ≤ data ≤ 32767</td>
<td>Changes the integral gain factor of the PID algorithm. The command is followed by the data value.</td>
</tr>
<tr>
<td>KV &lt;CR&gt; data &lt;CR&gt;</td>
<td>-32768 ≤ data ≤ 32767</td>
<td>Changes the differential gain factor of the PID algorithm. The command is followed by the data value.</td>
</tr>
<tr>
<td>KA &lt;CR&gt; data &lt;CR&gt;</td>
<td>0 ≤ data ≤ 65535</td>
<td>Changes the velocity limit of the trajectory profile. The data value is encoder counts per sample period multiplied by 256. The command is followed by the data value.</td>
</tr>
<tr>
<td>KS &lt;CR&gt; data &lt;CR&gt;</td>
<td>0 ≤ data ≤ 65535</td>
<td>Changes the acceleration value for the trajectory profile. The command is followed by the data value.</td>
</tr>
</tbody>
</table>
APPENDIX A: SCHEMATICS

FIGURE A-1: SCHEMATIC 1
FIGURE A-2: SCHEMATIC 2

[Diagram of a schematic circuit with components labeled]

- U1: L6203
- C1: 0.1 uF
- C2: 0.01 uF
- C3: 0.01 uF
- C4: 0.1 uF
- C5: 100 uF, 22V
- C6: 0.1 uF
- R1: 2.5 W
- R7: 4.7 kΩ
- PWM
- POWER INPUT
- MOTOR CONNECTIONS
FIGURE A-3: SCHEMATIC 3

- **+5V**
- **R8** 2.7k
- **R9** 2.7k
- **R10** 2.7k
- **R11** 2.7k
- **R12** 2.7k
- **R13** 2.7k
- **R14** 2.7k
- **R15** 2.7k
- **R16** 2.7k
- **C7** 56pF
- **C8** 56pF
- **C10** 56pF
- **C11** 56pF
- **C12** 56pF
- **C13** 1μF

- **U5**: 74HC14
- **U6**: 74HC74
- **J3**: Rotary Encoder Connections
- **J4**: Limit Switch Inputs
- **J5**: +5V

- **EN**
- **PWM**
- **UP**
- **DWN**

- **CLR**
- **PRE**

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APPENDIX B: SOURCE CODE

// 17motor.c
// Written By: Steve Bowling, Microchip Technology
//
// This source code demonstrates the use of the PIC17C756A in a brush-DC servomotor application and is written for the MPLAB-C17 compiler. The following files should be included in the C17 project, which is compiled for the large memory model:

#include <p17c756.h>
#include <stdlib.h>
#include <usart16.h>
#include <string.h>
#include <timers16.h>
#include <captur16.h>
#include <pwm16.h>
#include <ctype.h>
#include <delays.h>
#include <mem.h>

#define F 1
#define W 0

const rom char start[] = "\r\n\r
17C756A DC Servomotor";
const rom char ready[] = "\n\rREADY>";
const rom char error[] = "\n\rERROR!";

char inpbuf[8]; // input buffer for ASCII commands
char data[9]; // buffer for ASCII conversions
char command; // holds the last parameter change

unsigned char
i, // index to ASCII buffer
udata, // received character from USART
mode, // determines servo mode
tempchar, // temp context saving for ISR
PRODHtemp, // 
PRODLtemp, // 
FSR0temp, // 
FSR1temp; // 

struct { // holds status bits for servo
unsigned phase; // first half/second half of profile
unsigned neg_move; // backwards relative move
unsigned move_in_progress; // servo output is saturated
unsigned bit4; //
unsigned bit5; //
unsigned bit6; //
unsigned bit7; //
} stat ;

int
unsigned int accel;  // acceleration parameter for motion profile

union LONG
{
unsigned int ui[2];
  int i[2];
  char b[4];
};

union LONG
aarg,  // Used for math calculations.
barg,  // Used to hold result of the PID calculations.
ypid, // Used to hold result of the PID calculations.
position, // Commanded position.
imposition, // Actual measured position.
fposition, // Final commanded position of motion profile.
poserror, // 32-bit position error calculated in the PID
mvelocity, // measured velocity
velact, // current commanded velocity
phase1dist, // total distance for first half of move.
flatcount; // Holds the number of sample periods for which the velocity limit was reached in the first half of the move.

void main(void);
  // Required for the main function
void InitPorts(void);
  // Initializes ports/peripherals
void InitVars(void);
  // Initializes variable used in program
void DoCommand(void);
  // Parses input buffer after a <CR> was received
void ServoISR(void);
  // Performs the error calculations and PID
void UpdatePosition(void);
  // Updates the measured motor position
void UpdateTrajectory(void);
  // Does the motion profile
void add32(void);
  // Performs a 32 bit addition
void sub32(void);
  // Performs a 32 bit subtraction
void mult(void);
  // Performs a 16 x 16 --> 32 multiplication
void ulitoa(unsigned int value1,
  unsigned int value0, char *string);  // Converts 32-bit value in two integers to an ASCII string in hexadecimal
char ntoh(unsigned int value);
  // format.

void main(void)
{
  InitVars();
  InitPorts();
  Install_PIV(ServoISR);
  // Servo_ISR is installed as the
Enable(); // int. handler.

putrsUSART1(start);
putrsUSART1(ready);

while(1) // This is the main program loop
{
    // that polls USART1 for received
    // characters.
    if(PIR1bits.RC1IF)
    {
        switch(udata = ReadUSART1())
        {
        case 0x0d:  DoCommand(); // got a <CR>, so process the string
            strset(inpbuf, 0); // clear the input buffer
            i = 0; // clear the input buffer index
            putrsUSART1(ready); // put a ready prompt on the screen
            break;
            
            default:    inpbuf[i] = udata; // put the received character in the
                        i++; // next buffer location and increment
                        if(i > 7) // the buffer index
                        {
                            putrsUSART1(ready); // if we got more than 7 chars before a
                            strset(inpbuf, 0); // <CR>, clear the input buffer and clear
                            i = 0; // the buffer index
                        }
                        else putcUSART1(udata); // otherwise, echo the received character
                        break;
        }
        //end switch(udata)
    }
    //end if(PIR1bits.RC1IF)
}
//end while(1)

//end main

void DoCommand(void) // This routine parses the input buffer
{
    // after a <CR> was received.
    unsigned int num;

    if(isdigit(inpbuf[0]) || inpbuf[0] == '-') // Did we get a numerical input?
    {
        if(command) // Was numerical input preceded
        {
            // by a command to change a
            switch(command) // parameter?
            {
            case 'P':   kp = atoi(inpbuf); // proportional gain change
                        break;
            case 'I':   ki = atoi(inpbuf); // integral gain change
                        break;
            case 'D':   kd = atoi(inpbuf); // differential gain change
                        break;
            case 'A':   accel = atoui(inpbuf); // acceleration change
                        break;
            case 'V':   vlim = atoui(inpbuf); // velocity limit change
                        break;
            } // end switch(command)
        } // end if(command)
    } // end if(isdigit(inpbuf[0]) || inpbuf[0] == '-')
case 'S': PR2 = atoub(inpbuf);  // servo update timing change
    break;

default: break;
}
command = 0;
}
else if(mode == 0) ypwm = atoi(inpbuf);  // manual mode: write directly to PWM
else if(mode == 1) velcom = atoi(inpbuf);  // velocity mode: input data is velocity
else if(mode == 2)  // Input data is a relative movement
    // distance
{
    if(!stat.move_in_progress)  // Make sure no move is in progress.
        phase1dist.i[1] = atoi(inpbuf);  // Load the 16-bit relative movement
        // distance into the upper
        phase1dist.i[0] = 0;  // two bytes of phasdist variable
    fposition.i[0] = position.i[0];  // Final position is commanded position
    fposition.i[1] = position.i[1] + phase1dist.i[1];  // + relative move distance

        if((phasdist.b[3] & 0x80)  // If the relative move is negative,
            {  // and covert phasdist to a positive
            stat.neg_move = 1;  // set flag to indicate neg. move

            _asm  // value.
            comf phasdist+2,F // and covert phasdist to a positive
            clrf WREG,F
            incf phasdist+2,F
            addwfc phasdist+3,F
            _endasm
        }
else stat.neg_move = 0;  // Clear the flag for a positive move.

        _asm  // phasdist now holds the total
            // distance, so divide by 2
            rlcf phasdist+3,W
            rrcf phasdist+3,F
            rrcf phasdist+2,F
            rrcf phasdist+1,F
            rrcf phasdist+0,F
            _endasm

        flatcount.i[1] = 0;  // Clear flatcount
        flatcount.i[0] = 0;
        stat.phase = 0;  // Clear flag: first half of move.
        stat.move_in_progress = 1;
    }
else;
}
else switch(inpbuf[0])
{
    case 'K': if(inpbuf[1] == 'P') command = 'P';  // If this is a parameter change,
    if(inpbuf[1] == 'I') command = 'I';  // determine which parameter
    else
        else;
    
}
if (inpbuf[1] == 'D') command = 'D';
else
if (inpbuf[1] == 'A') command = 'A';
else
if (inpbuf[1] == 'V') command = 'V';
else
if (inpbuf[1] == 'S') command = 'S';
break;

case 'W':
if (PORTFbits.RF4 == 0)
{
    putsUSART1("\r\nPWM ON");
    SetDCPWM1(512);
}
else
{
    putsUSART1("\r\nPWM OFF");
}
PORTF = PORTF ^ 0x10;  // enables or disables PWM amplifier
break;

case 'R':
putsUSART1("  Kp = ");  // Send all parameters to host.
uitoa(kp, data);
putsUSART1(data);
putsUSART1("  Ki = ");
uitoa(ki, data);
putsUSART1(data);
putsUSART1("  Kd = ");
uitoa(kd, data);
putsUSART1(data);
putsUSART1("  Vlim = ");
uitoa(vlim, data);
putsUSART1(data);
putsUSART1("  Acc. = ");
uitoa(accel, data);
putsUSART1(data);
break;

case 'M':
putsUSART1(" Manual Mode");  // Put the servomotor in manual mode.
SetDCPWM1(512);
mode = 0;
break;

case 'V':
putsUSART1(" Velocity Mode");  // Put the servomotor in velocity mode.
velcom = 0;
SetDCPWM1(512);
position = mposition;
fposition = position;
mode = 1;
break;

case 'P':
putsUSART1(" Position Mode");  // Put the servomotor in position mode.
SetDCPWM1(512);
position = mposition;
fposition = position;
mode = 2;
break;

case 'L':
tempint0 = mposition.i[0];  // Send measured and commanded position
tempint2 = position.i[0];  // to host.
tempint1 = mposition.i[1];
tempint3 = position.i[1];
ulitoa(tempint3,tempint0,data);
putsUSART1(" Measured = ");
putsUSART1(data);
ulitoa(tempint3,tempint2,data);
putsUSART1(" Commanded = ");
putsUSART1(data);
break;

case 'Z':   if(!stat.move_in_progress) // Set measured position to 0.
{    if(mode) CloseTimer2(); // Disable interrupt generation.
position.i[1] = 0;
position.i[0] = 0;
mposition = position;
fposition = position;
WriteTimer0(0);
WriteTimer3(0);
mvelocity.i[1] = 0;
mvelocity.i[0] = 0;
UpCount = 0;
DownCount = 0;
if(mode) OpenTimer2(TIMER_INT_ON&T2_SOURCE_EXT); // Enable Timer2
}
putsUSART1(ready);
break;

default:    if(inpbuf[0] != '\0')
{    putsUSART1(error);
}
break;
}

 //---------------------------------------------------------------------
void ServoISR(void)
{
    PRODHtemp = PRODH; // Save context for necessary registers
    PRODLtemp = PRODL;
    FSR0temp = FSR0;
    FSR1temp = FSR1;
    UpdatePosition(); // Get new mposition, mvelocity values
    if(mode) // This portion of code not executed
{    UpdateTrajectory(); // in manual mode.
        aarg = position; // Do trajectory algorithm to get new
        barg = mposition; // commanded position.
        sub32(); // to get 32 bit position error.
        poserror.b[2] = aarg.b[3]; // LSByte holds fractional encoder counts,
poserror.b[0] = aarg.b[1];
        if (poserror.b[2] & 0x80) // If position error is negative.
        {    poserror.b[3] = 0xff; // Sign-extend to 32 bits.
        }}
if((poserror.i[1] != 0xffff) || (poserror.b[1] & 0x80))
{
    poserror.i[1] = 0xffff; // Limit error to 16-bit signed integer
    poserror.i[0] = 0x8000;
}
else;
}

else // If position error is positive.
{
    poserror.b[3] = 0x00;
    if((poserror.i[1] != 0x0000) || (poserror.b[1] & 0x80))
    {
        poserror.i[1] = 0x0000; // Limit error to 16-bit signed integer.
        poserror.i[0] = 0x7fff;
    }
    else;
}

u0 = poserror.i[0]; // Put position error in u0.

multcnd = u0; // Calculate proportional term

multiplr = kp; // of PID

mult();

ypid = aarg;

if(!stat.saturated) integral +=u0; // Bypass integration if saturated.

multcnd = integral; // Calculate integral term of PID

multiplr = ki;

mult();

barg = ypid; // Add integral term.

ypid = u0 - u1; // Calculate differential term of PID

multiplr = kd;

mult();

barg = ypid; // Add differential term

add32();

ypid = aarg;

if((ypid.b[3] & 0x80) // If PID result is negative
{
    if((ypid.b[3] < 0xff) || (ypid.b[2] & 0x80))
    {
        ypid.i[1] = 0xff80; // Limit result to 24-bit value
        ypid.i[0] = 0x0000;
    }
    else;
}
else // If PID result is positive
{
    if((ypid.b[3] || (ypid.b[2] > 0x7f))
    {
        ypid.i[1] = 0x007f; // Limit result to 24-bit value
        ypid.i[0] = 0xffff;
    }
    else;
}

ypid.b[0] = ypid.b[1]; // Shift PID result right to get

ypid.b[1] = ypid.b[2]; // upper 16 bits of 24-bit result in

ypwm = ypid.i[0]; // ypid.i[0]
ui = u0; // Save current error in ui
} // end if(mode)
stat.saturated = 0; // Clear saturation flag

if(ypwm > 500)
{
    ypm = 500;
    stat.saturated = 1;
}
else if(ypwm < -500)
{
    ypm = -500;
    stat.saturated = 1;
}
SetDCPWM1((unsigned int)(ypm + 512)); // Write new duty cycle value
PRODH = PRODHtemp; // Restore context.
PRODL = PRODLtemp;
FSR0 = FSR0temp;
FSR1 = FSR1temp;
PIR1bits.TMR2IF = 0; // Clear flag that generated interrupt.

// The relative distance travelled during the sample period is found using
// the following formula:
//
// mvelocity = (Timer0 - prev. Timer0) - (Timer3 - prev. Timer3)
//
// This is done so the timers do not have to be cleared each sample period
// and potentially cause counts to be lost.
//
void UpdatePosition(void)
{
    mvelocity.i[0] = DnCount; // Add previous Timer3 value
    mvelocity.i[0] -= UpCount; // Subtract previous Timer0 value
    UpCount = ReadTimer0(); // get new values from Timer0
    DnCount = ReadTimer3(); // and Timer3
    mvelocity.i[0] += UpCount; // Add current Timer0 value
    mvelocity.i[0] -= DnCount; // Subtract current Timer3 value
    mvelocity.b[2] = mvelocity.b[1]; // Shift result left: Lsbyte is
    mvelocity.b[1] = mvelocity.b[0]; // fractional
    mvelocity.b[0] = 0;
    if (mvelocity.b[2] & 0x80) // Sign-extend result
        mvelocity.b[3] = 0xff;
    else
        mvelocity.b[3] = 0;
    aarg = mposition; // Add velocity to measured position
    barg = mvelocity;
    add32();
    mposition = aarg;
}
void UpdateTrajectory(void)
{
    if(mode == 1) // If servomotor is in velocity mode.
    {
        if(!stat.saturated) // Don't update profile if saturated.
        {
            if(velact.i[1] < velcom) // If current velocity is less than
                // commanded velocity.
            {
                aarg = velact;
                barg.i[0] = accel;
                barg.i[1] = 0;
                add32();
                velact = aarg;
                if(velact.i[1] > velcom) // Don't exceed commanded velocity
                    velact.i[1] = velcom;
                if(velact.i[1] > vlim) // Don't exceed velocity limit parameter
                    velact.i[1] = vlim;
            }
        }
        else if(velact.i[1] > velcom) // If current velocity exceeds commanded
            // velocity
        {
            aarg = velact;
            barg.i[0] = accel;
            barg.i[1] = 0;
            sub32();
            velact = aarg;
            if(velact.i[1] < velcom) // Don't exceed commanded velocity
                velact.i[1] = velcom;
            if(velact.i[1] < -vlim) // Don't exceed velocity limit parameter
                velact.i[1] = -vlim;
        }
        else; // If the motor is stopped.
        aarg = position; // Add current commanded velocity to
        barg.i[0] = velact.i[1]; // the commanded position
        if(velact.b[3] & 0x80) // Don't exceed commanded velocity.
            barg.i[1] = 0xffff;
        else barg.i[1] = 0;
        add32();
        position = aarg;
    }
    else if(mode == 2) // If we're in position mode.
    {
        if(!stat.saturated) // Don't update profile if output is
            // saturated
        {
            if(!stat.phase) // If we're in the first half of the move.
            {
                if(velact.i[1] < vlim) // If we're still below the velocity limit
                    // for the move
                {
                    aarg = velact;
                    barg.i[0] = accel;
                    barg.i[1] = 0;
                    add32();
                    velact = aarg;
                }
                else // If we're at the velocity limit,
                {
                    _asm
                    clrf WREG,F // increment flatcount to keep track of
                    // time spent in flat portion of
                    // trajectory.
                }
            }
        }
    }
}
infc flatcount+0,F
addwfc flatcount+1,F
addwfc flatcount+2,F
addwfc flatcount+3,F
_endasm
}

aarg = phaseldist;

// go ahead and subtract the current
barg.i[1] = 0;
// velocity from the move distance to keep
barg.i[0] = velact.i[1];
// track of the number of encoder counts
sub32();
// travelled during this sample period.
phaseldist = aarg;

aarg = position;

// Add the current velocity to the
// commanded position.
if(stat.neg_move) sub32();
else add32();
position = aarg;

if(phaseldist.b[3] & 0x80) // If phase1dist has gone negative, the
  stat.phase = 1;
// first half of the move has completed
)
else // If we're in the second half of the
  // move.
{
if((flatcount.i[1] || flatcount.i[0])
{
_asm
  clrF WREG,F
  decF flatcount+0,F
  subwfb flatcount+1,F
  subwfb flatcount+2,F
  subwfb flatcount+3,F
  _endasm

} else
if(velact.i[1]) // If velact is not 0, decelerate.
{
aarg = velact;
barg.i[0] = accel;
barg.i[1] = 0;
sub32();
velact = aarg;
} else // flatcount is 0, velact is 0, so move is
  // over. Set commanded position equal to
  // the final position calculated at the
  // the beginning of the move.
{
position = fposition;
stat.move_in_progress = 0;
}

aarg = position;
// Add current velocity to commanded
// position.

barg.i[1] = 0;
barg.i[0] = velact.i[1];
if(stat.neg_move) sub32();
else add32();
position = aarg;

} // END if(!stat.saturated)
}
// END if(mode == 2)
else;
}
//*****************************************************************************

void add32(void) //
{
    _asm
        MOVFP barg+0,WREG
        ADDWF aarg+0,F
        MOVFP barg+1,WREG
        ADDWFC aarg+1,F
        MOVFP barg+2,WREG
        ADDWFC aarg+2,F
        MOVFP barg+3,WREG
        ADDWFC aarg+3,F
    _endasm
}

//*****************************************************************************

void sub32(void) //
{
    _asm
        MOVFP barg+0,WREG
        SUBWF aarg+0,F
        MOVFP barg+1,WREG
        SUBWFB aarg+1,F
        MOVFP barg+2,WREG
        SUBWFB aarg+2,F
        MOVFP barg+3,WREG
        SUBWFB aarg+3,F
    _endasm
}

//*****************************************************************************

void mult(void) // Multiplies 16-bit values in multplr
{
    _asm // and multend.
        movfp multcnd+0,WREG
        mulwf multpir+0
        movpf PRODH,aarg+1
        movpf PRODL,aarg+0
        movfp multcnd+1,WREG
        mulwf multpir+1
        movpf PRODH,aarg+3
        movpf PRODL,aarg+2
        movfp multcnd+0,WREG
        mulwf multpir+1
        movfp PRODL,WREG
        addwf aarg+1,F
        movfp PRODH,WREG
        addwfc aarg+2,F
        clr f
        addwfc aarg+3,F
        movfp multcnd+1,WREG
        mulwf multpir+0
}
void ulitoa(unsigned int value1, unsigned int value0, char *string)
{
    unsigned int temp; // Converts 32-bit value stored in two
    // integers to an ASCII string in
    // hexadecimal format.
    temp = value1;
    *string = ntoh(temp >> 12);
    string++;
    temp = value1 & 0xf00;
    *string = ntoh(temp >> 8);
    string++;
    temp = value1 & 0x0f0;
    *string = ntoh(temp >> 4);
    string++;
    temp = value1 & 0x0f;
    *string = ntoh(temp);
    string++;
    temp = value0;
    *string = ntoh(temp >> 12);
    string++;
    temp = value0 & 0xf00;
    *string = ntoh(temp >> 8);
    string++;
    temp = value0 & 0x0f0;
    *string = ntoh(temp >> 4);
    string++;
    temp = value0 & 0x0f;
    *string = ntoh(temp);
    string++;
    *string = 0;
    return;
}
char ntoh(unsigned int value) // Converts hexadecimal value to ASCII
{ // value.
    char hexval;
    if(value < 10) hexval = value + '0';
    else if(value < 16) hexval = value - 10 + 'A';
    return hexval;
}

void InitVars(void)
{
    i = 0;
    kp = 2000;
    ki = 15;
    kd = 6000;
    vlim = 4096;
    velcom = 0;
    velact.i[1] = 0;
    velact.i[0] = 0;
    accel = 65535;
    integral = 0;
    mvelocity.i[1] = 0;
    mvelocity.i[0] = 0;
    UpCount = 0;
    DnCount = 0;
    position = mposition;
    fposition = position;
    stat.move_in_progress = 0;
    stat.neg_move = 0;
    stat.phase = 1;
    mode = 0;
    ypwm = 0;
    strset(inpbuf,'\0');
}

void InitPorts(void)
{
    ADCON1 = 0x0E; // ensure port F is configured for digital IO.
    PORTF = 0x00; // ensure port F is 0 before setting data direction.
    DDRF = 0x0f; // RF<7:4> outputs, RF<3:0> inputs
    PORTFbits.RF4 = 0; // ensure pwm amplifier is disabled!!!

    // Up/Down Register Setup
    WriteTimer0(0);
    WriteTimer3(0);
    OpenTimer0(TIMER_INT_OFF&T0_EDGE_FALL&T0_SOURCE_EXT&T0_PS_1_1);
    OpenTimer3(TIMER_INT_OFF&T3_SOURCE_EXT);
}

//---------------------------------------------------------------------
// AN718

} // AN718

} // AN718

//---------------------------------------------------------------------
TCON2bits.CA1 = 1;

// PWM Setup ------------------------------------
OpenTimer1(TIMER_INT_OFF&T1_SOURCE_INT&T1_T2_8BIT);// set up timer1 for PWM timebase
OpenPWM1(0xff); // start up PWM1
SetDCPWM1(512); // set the initial PWM duty cycle
// to ~50%
PR2 = 0x08; // Set Timer2 overflow period to 8
// for 3.9 kHz update at 33 MHz
OpenTimer2(TIMER_INT_ON&T2_SOURCE_EXT); // Enable Timer2

// USART1 Setup -------------------------------
OpenUSART1(USART_TX_INT_OFF&USART_RX_INT_OFF&USART_ASYNCH_MODE&
USART_EIGHT_BIT&USART_CONT_RX, 26); // open the serial port
// 19.2 kbaud @ 33 Mhz

}
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