BRADLEY UNIVERSITY (ECE Department)
ECE 120 - Intro to EE: Circuits & Digital Systems Laboratory
Lab #8: Robot Arm Position Control (4 weeks)

Topics: Design to product specifications, DC servo motor, pulse-width modulation (PWM), VHDL, Xilinx FPGA development board, combinational and sequential logic design, switch debouncing, generation of multiple clocks (counters) for system synchronization, digital system with multiple finite state machine processes, VHDL test bench code for simulation testing.

Pan-Tilt Introduction. The $35 pan-tilt unit shown below consists of two HS-422 servos. The HS-422 servo consists of a DC motor, set of gears, potentiometer for position feedback, and a controller board. The pan-tilt unit is commonly used in security devices where a small camera is mounted on the top base and the pan and tilt motions are controlled via computer (wired or wireless communication). Another common application is in the robotics area where the unit can be used in target tracking, sun seeking, and obstacle avoidance applications, or used in mapping terrain for autonomous vehicles. This pan-tilt unit was selected because the HS-422 is one of the most popular servos used in hobby robotics (RC cars, planes, etc.) as well as commercial camera applications. It is available from many sources for under $15.

Each HS-422 servo unit has three connections (+5V, ground, and a control signal). The control signal determines the position of the pan or tilt unit. The signal is required to be a PWM (pulse-width modulation) signal where the pulse width determines pan or tilt position. The frequency of the PWM is required to be 50 Hertz. The range of motion is approximately 180 degrees for the HS-422 servo but in the pan-tilt arrangement the motion will be limited to approximately 90 degrees.

Figure 1: Pan and Tilt Kit from Lynxmotion.

Robot Arm Mechanism Introduction. The pan-tilt unit used for the robot arm mechanism is shown in Fig. 2 below. Assembly and C-language software were designed to control the robot arm with our 80515 microcontroller development board (EMAC) and VHDL code for the Xilinx Spartan-3E FPGA board. This experiment was specifically designed for the Xilinx FPGA board for use in the ECE 120 freshman laboratory and Dr. Lu's EE568 VHDL Digital Systems course.

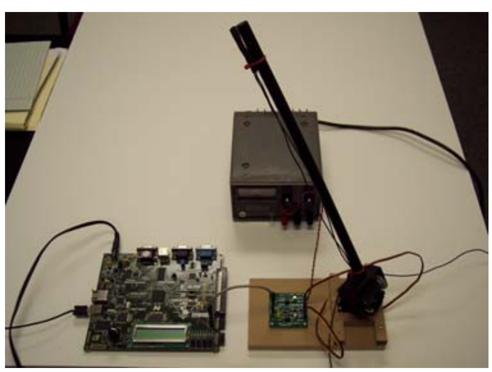

Figure 2. Robot Arm Mechanism.

Interface Board Introduction. Circuitry and PCB (printed circuit board) were designed to interface the Xilinx FPGA board with the pan-tilt unit. Opto-couplers (4N25) are used to isolate the FPGA electronics from the transistor driver circuit for the servo motors. A separate 5V supply is used for the two HS-422 servos. The board outline is shown below in Fig. 3 and the circuit in Fig. 4. The interface board has 4 connectors marked on the board as:

FPGA: 6 wires to Xilinx board: Pin 1: “D7", Pin 2: “C7", Pin 3: “F8", Pin 4: “E8", Pin 5: Gnd, Pin 6: 3.3V (not used)
Use the following for this experiment in your User Constraints File (*.ucf):

```
NET "pan_out" LOC = "D7" | IOSTANDARD = LVCMOS33 | SLEW = FAST | DRIVE = 8 ;
NET "tilt_out" LOC = "C7" | IOSTANDARD = LVCMOS33 | SLEW = FAST | DRIVE = 8 ;
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PAN: 3 wires (control, +5V, gnd) to Pan HS-422
TILT: 3 wires (control, +5V, gnd) to Tilt HS-422
POWER: 2 wires (+5V, gnd) to 5V power supply (test voltage before connecting to prevent damage).

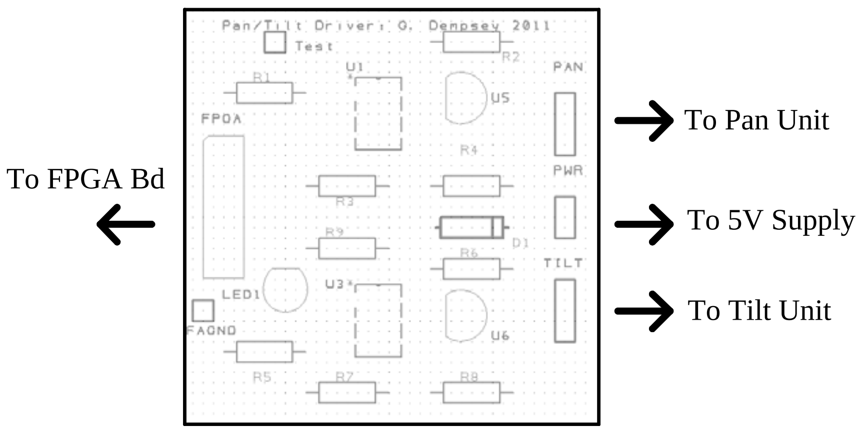


Figure 3. Interface PCB.

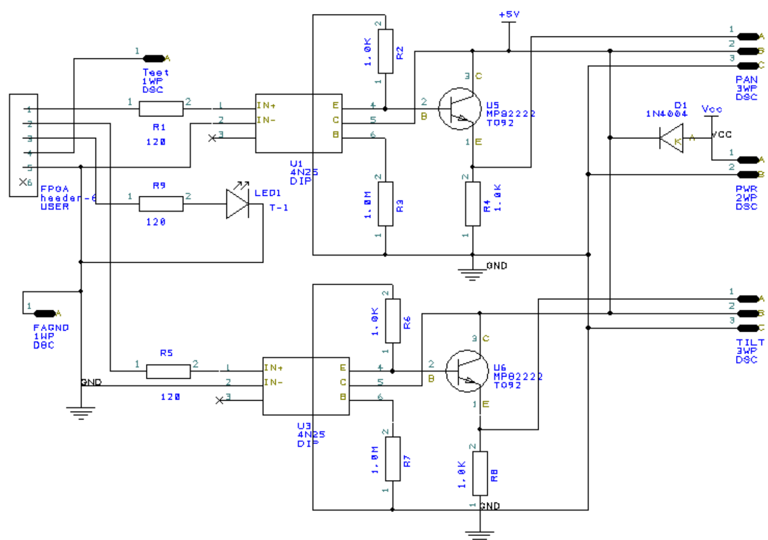


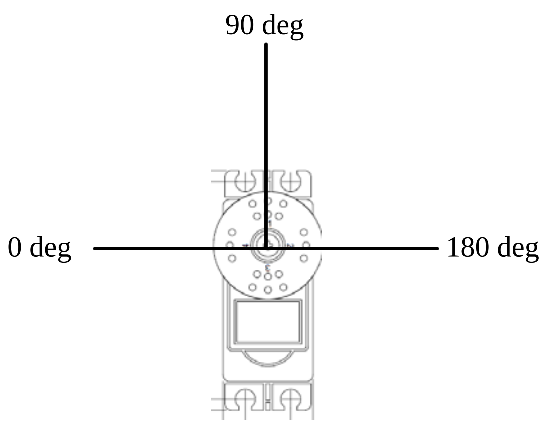
Figure 4. Interface Board Circuitry.

HS-422 Control Signal Format: As stated previously, a PWM signal is used to control the servo motor position. The PWM period is 20 milliseconds (50Hz) with a pulse width range (high period) from 1.05 to 1.95 milliseconds. A pulse width of 1.5 ms corresponds to the center or neutral position (90 degrees). See timing waveform and servo diagram below. A picture of the HS-422 servo from the Lynxmotion Web site is shown below.

Note 3 wires:
Red: +5V
Black: Ground
Yellow: Control Signal

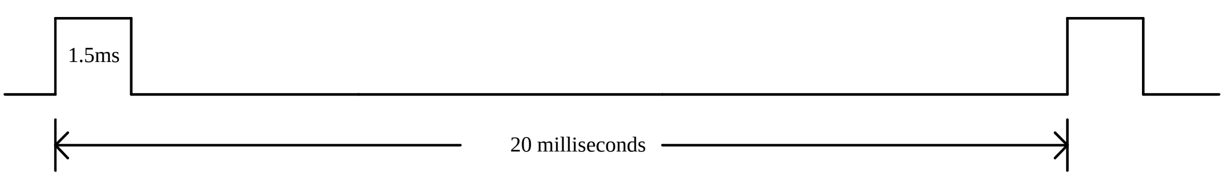
The 3-wire connector will be plugged in to interface board.

HS-422 Servo



The default (after reset) condition for the pan and tilt units will be 90 degrees. The robot arm will be pointing straight up. A 1.5ms pulse width is required for the servo for this 90 degree position. This is the neutral position for the HS-422. Note this must be a continuous (repeating) waveform. The position accuracy is much better near this "center" point than the minimum and maximum angles (0 and 180). With the servos mounted in the pan-tilt unit the angle range is limited to approximately 90 degrees (45 to 135 degrees).

Angle Definitions for Pan and Tilt Servos



Timing Diagram for 90 Degree Position

A pulse width of 1.05ms will position the servo to 45 degrees. A pulse width of 1.95ms will position the servo to 135 degrees. These are the minimum and maximum angles used in this experiment. The pulse-width variation will be in 30 microsecond steps for the pan and tilt sweep modes of operation which are defined in the next section of the document.

Pan and Tilt Sweep Operation: Consider the following applications.

1. Security application: It is desired to sweep a lightweight lipstick camera mounted at the end of the robot arm to check an area for security.
2. Autonomous vehicle: It is desired to sweep a photo-sensor mounted at the end of the robot arm to locate the maximum sunlight. The information would be used to position a solar panel for maximum charging of vehicle's battery.
3. Autonomous vehicle: Sweep terrain for obstacle avoidance.
4. Autonomous vehicle: It is desired to sweep a microphone mounted at the end of the robot arm to locate the maximum source of noise (target tracking). Other sensors that could be used: Infrared (image sensor), thermal or temperature sensors, sonar, and radar.

I. Tilt Sweep Mode: The different modes of operation will be selected by the 4 slide switches (discussed in the next section). For tilt sweep mode, the tilt position is reset to the minimum angle (45 degrees). The tilt angle is then incremented in 30 microsecond steps (3 degrees) every 100 milliseconds until the maximum angle is reached (135 degrees). The sweep time is equal to 3 seconds. Once the maximum position is reached (135 degrees), the tilt is reset back to the minimum angle (45 degrees). Then the cycle is repeated. Note that the robot arm is held at each position for 100 milliseconds.

II. Pan Sweep Mode: The pan sweep mode is identical to the tilt sweep mode operation.

III. Pan and Tilt Dual Sweep Mode: On initiation of the dual sweep mode, the pan and tilt positions are reset to the minimum angles (45 degrees). The pan sweep is then started: swept from 45 to 135 and then reset back to 45 degrees. After this pan cycle, the tilt position is incremented to the next position (50 degrees). This process is continued until the final sweep is for a tilt position of 135 degrees. The total time for the process is 90 seconds. The process is then started back at the minimum tilt and pan positions (45 degrees).

IV. Advanced Modes for Extra Credit: The symmetrical sweep pattern discussed above is efficient for hardware implementation but is not the best algorithm to minimize power, i.e., power supply current. For example, when the robot arm pan and tilt positions are near 90 degrees, very little arm movement occurs with the algorithm presented in Section III. Power and process time can be decreased when the arm is near the 90 degree positions. Extra credit will depend on the total reduction of process time from 90 seconds. The arm should still be held at each position for 100ms.

The photo-cell used in the light-seeking robot lab is mounted on the end of the robot arm. A light detection circuit to sense maximum light could be used to sound an alarm (buzzer used in Lab #4). This additional circuitry would be considered for extra credit points.

V. Prelabs: The deliverables for Weeks 1-3 Prelabs/Post-Labs and the Final Product Grading are shown in a separate document.

FPGA Switch and Led Setup and other System Requirements:

I. 4 Slide Switches: 0= down, 1= up, Switch 0 is LSB

Switch Positions	Pan Mode	Tilt Mode	
0000	NC (no change)	NC	
0001	90	90	
0010	NC	tilt control*	
0011	pan control*	NC (no change)	
0100	pan max	NC	
0101	pan min	NC	
0110	NC	tilt max	
0111	NC	tilt min	
1000	pan sweep	NC	
1001	NC	tilt sweep	
1010	pan sweep	tilt sweep	**Note: dual sweep mode**
1011	advanced modes		
1100	advanced modes		
1101	advanced modes		
1110	advanced modes		
1111	advanced modes		

***** pan or tilt controlled via rotary push-button switch (**extra credit**)
slide switches debounced appropriately
NC state: arm maintains last position

Reset: Push-button switch BTN_SOUTH (K17) debounced appropriately

Manual Pan or Tilt Positioning: Rotary Push-Button Switch ROT_A (K18) and ROT_B (G18)

II. LED Status: 0= off, 1= on, LED 0 is LSB

LED 0 -3 correspond to the slide switch positions (see table above, 0 = off, 1= on)
LED 4: toggled every 20ms
LED 5: toggled every 100ms
LED 6: can be used for diagnostics by user (student)
LED 7: off when reset, on otherwise

Spartan-3E FPGA LEDs: The FPGA board has eight individual surface-mount LEDs located above the slide switches. The LEDs are labeled LED7 through LED0. LED7 is the left-most LED, LED0 the right-most LED. Each LED has one side connected to ground and the other side connected to a pin on the FPGA via a 390ohm current limiting resistor. The LED is turned on by driving the associated FPGA control signal High (3.3V).

III. Required clocks: derived from 50MHz (20ns) clock
30 us timing: used for PWM timing for pan and tilt control signals
20 ms timing: used for PWM period
100ms timing: used for pan and tilt sweep modes

IV. I/O Pin Connections:

```
NET "clk" PERIOD = 20.0ns HIGH 50%;
NET "clk" LOC = C9;

NET "BTN_SOUTH" LOC = "K17" | IOSTANDARD = LVTTL | PULLDOWN ;

NET "pan_out" LOC = "D7" | IOSTANDARD = LVCMOS33 | SLEW = FAST | DRIVE = 8 ;
NET "tilt_out" LOC = "C7" | IOSTANDARD = LVCMOS33 | SLEW = FAST | DRIVE = 8 ;

NET "sw1" LOC = L13;
NET "sw2" LOC = L14;
NET "sw3" LOC = H18;
NET "sw4" LOC = N17;

NET "LED7" LOC = "F9" | IOSTANDARD = LVTTL | SLEW = SLOW | DRIVE = 8 ;
NET "LED6" LOC = "E9" | IOSTANDARD = LVTTL | SLEW = SLOW | DRIVE = 8 ;
NET "LED5" LOC = "D11" | IOSTANDARD = LVTTL | SLEW = SLOW | DRIVE = 8 ;
NET "LED4" LOC = "C11" | IOSTANDARD = LVTTL | SLEW = SLOW | DRIVE = 8 ;
NET "LED3" LOC = "F11" | IOSTANDARD = LVTTL | SLEW = SLOW | DRIVE = 8 ;
NET "LED2" LOC = "E11" | IOSTANDARD = LVTTL | SLEW = SLOW | DRIVE = 8 ;
NET "LED1" LOC = "E12" | IOSTANDARD = LVTTL | SLEW = SLOW | DRIVE = 8 ;
NET "LED0" LOC = "F12" | IOSTANDARD = LVTTL | SLEW = SLOW | DRIVE = 8 ;
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