Homework 6: Circuit Design and Theory of Operation

Due: Thursday, February 24, at Classtime

Team Code Name: Fire Team Foxtrot **Group No. 1**

Team Member Completing This Homework: Andrew Penner

NOTE: This is the second in a series of four "design component" homework assignments, each of which is to be completed by one team member. The completed homework will count for 10% of the team member's individual grade. It should be a minimum of five printed pages.

Report Outline:

- **Introduction (brief description of design project)**
- **Theory of operation (circuit design narrative – describe function and operating mode of each major component, including rationale for choice of operating frequency, supply voltage, etc.)**
- **Documentation for circuit design**
  - **OrCAD schematic printed on 11x17 paper**
  - **OrCAD design rule check report**
  - **OrCAD bill of materials report**
- **List of References (include links to data sheets for all major components utilized)**

Evaluation:

Component/Criterion	Score	Multiplier	Points
Introduction & Theory of Operation	0 1 2 3 4 5 6 7 8 9 10	X 4	
Documentation for Circuit Design	0 1 2 3 4 5 6 7 8 9 10	X 4	
List of References	0 1 2 3 4 5 6 7 8 9 10	X 1	
Technical Writing Style	0 1 2 3 4 5 6 7 8 9 10	X 1	
		TOTAL	

Introduction

The Fully Integrated Fire Extinguishing roBOT (FIREbot) is a fully autonomous robot which detects, approaches, and extinguishes a small class A, B, or C flame on the ground. It carries a standard household fire extinguisher. Detection and pinpointing of flames is performed through an array of several types of sensors. A microcontroller running local software reads the sensors, makes decisions based upon their values, and drives several drive motors and servos to control the actions of the robot. An LCD display shows the current state of the robot and provides feedback to the user.

The robot is built on a small flat platform, which carries the motors, sensors, fire extinguisher, and electronics of the robot. Therefore, these components must be physically small and light, and must be capable of being mounted securely on the platform. It is powered by an onboard rechargeable battery, so the robot must consume a minimum of power and be driven at low voltages. The local microcontroller must read data from all the sensors, and be capable of driving all the outputs. At present, there is no plan to equip the microcontroller with external storage, so all code and data must be stored in onboard memory.

Theory of Operation

Power Supply

The choices in designing the robot's power supply were mainly driven by the power requirements of the motors (both DC motors and servos), the sensitivity of the analog sensors and the need to isolate the motors, the analog components and the digital circuits from each other.

The power supply block outputs four voltage rails: a 5V rail for analog sensors, a 5V rail for digital components, a 5V rail for the servos, and a 12V rail for analog components. The 5V rail for digital components is obviously necessary for supplying power to the microcontroller, a 16V8 PLD and other digital logic IC's. The reason for using three separate 5V rails is to isolate the noise caused by each type of component.

The 12V power rail is simply supplied directly by the battery. A p-channel power MOSFET [1] is used so the microcontroller can turn off the 12V rail to conserve battery power during sleep mode. This signal that controls the gate of the transistor is optically isolated from the microcontroller.

The 5V servo power rail and the 5V digital power rail are each supplied by circuits built around MAX746 switching power supply controllers. Each power supply uses an external n-channel power MOSFET [2] for switching. The transistors are directly controlled by the MAX746 controllers [3]. Both the digital and servo rails are designed to source 3A each. The input capacitors [4] to both switching power supply circuits are large so as to provide a stable 12V input. The output capacitor of the digital supply is a standard 470 microfarad electrolytic capacitor. The parallel output capacitors [4] of the servo supply are effectively an 880 microfarad capacitor with 0.025 ohm ESR. The servo supply was designed to allow no more than 25mV of output ripple when the rail is loaded at 3A. The 5V output of the servo switching power supply can be turned off if the microcontroller asserts a signal that is an input on the MAX746 controller. The 5V rail cannot be turned off. The power inductors [5], diodes, and other components in the MAX746-based circuits were chosen based on recommendations from the MAX746 datasheet [3].

The 5V analog power rail is supplied by an LM7805 linear regulator [6] using the 12V battery as the input voltage. This supply sources very little current, so an estimated maximum of 100mV output ripple can be achieved with only 220 microfarads of capacitance. The 5V output of the linear regulator can also be turned off with a power MOSFET [1] controlled by an optically isolated signal from the microcontroller.

The analog and digital grounds are connected only once in the design. They both connect to VBat- (the negative terminal of the battery) in the power supply block.

Universal Flame Detector Interface

The major component of the universal flame detector circuit is the UVTron ultraviolet flame detector [7]. The UVTron sensor is connected to a small, existing PCB which processes the signals from the sensor's anode and cathode and asserts a pulse on the output every second or so when it is detecting a flame. The open collector output of the UVTron's circuit board is used to clock a D-flip flop. The output of the D-flip flop is the output of this block and serves as an interrupt to the microcontroller. The microcontroller can clear the interrupt flag with a clear signal.

The 5V digital rail is used to supply all the components of this block, including the UVTron's associated circuit board. The only other device requiring power in this block is a standard 74HC74 D flip-flop.

Wide Angle Flame Detector Interface

The Wide Angle Flame Detectors block provides interface to the PD413-PI IR Photodiodes [8] that detect flames in a wide field of vision at long distance. The PD413-PI was chosen because it selectively reacts to a narrow band of IR which is primarily given off by flames. It draws a small current (up to a few microamps) proportional to the illuminance it detects in its spectral band. The current is amplified into a voltage which can be read by a microcontroller Analog-to-Digital pin.

The Wide Angle Flame Detectors block is physically separate from the main PCB, as it sits on a turntable controlled by a servo so that it can detect flames and provide angular position detection to the flames. This secondary PCB will be called the Turntable PCB, and to save cost, will be manufactured together with the primary PCB and then cut apart.

Because of the very small currents drawn by the PD413-PI and its sensitivity to noise, a special circuit had to be developed to amplify its signal to a large voltage and filter off noise. A current input inverting op-amp amplifier was used, along with a band pass filter. The op-amp was chosen to work off the single 5V rail provided, and to have leakage currents several orders of magnitude less than the currents drawn by the PD413-PI. A DC offset was added to drive the op-amp into its linear region. The band-pass filter passes between 1Hz and 1kHz, eliminating high-frequency noise as well as the DC offset and DC noise associated with ambient radiation detected by the PD413-PI.

Narrow Angle Flame Detector Interface

This sensor is a Raytec Compact CI active infrared temperature sensor [9] and requires 12V to operate. Its interface to the rest of the design is very simple, consisting of only a capacitor across its power and ground terminals and an analog output connected to an analog-to-digital converter on the microcontroller. Its output voltage is proportional to the surface temperature of the object it is pointed at.

Distance Sensor Interfaces

The Sharp GP2D120 active infrared proximity sensor [10] interface consists of four identical circuits; each individual circuit incorporates a single active infrared distance sensor. The composition of each of the parallel circuits is very simple – a decoupling capacitor and a bypass capacitor are used between the power and ground supplied to each sensor. The outputs from each distance sensor are connected to a separate analog-to-digital port on the microcontroller. An analog supply rail of 5 volts is used to power these circuits so as to isolate the analog sensors from the switching noise produced by digital components.

Push Buttons

This 3-way switch (which was originally intended to be 3 mutually exclusive locking push-buttons) provides the only user input to the robot. The center position indicates off and left or right positions select one of two operating modes. The capacitors effectively debounce the switch.

Microcontroller

The ATMega32 microcontroller [11] is interfaced to the rest of the design through very simple circuitry. To increase the number of logic signals the microcontroller can drive, an 8-bit serial shift register is connected to one microcontroller pin. The active low reset pin on the microcontroller is connected to a standard SPDT pushbutton switch circuit. Capacitors are used across the power and ground pins for both the digital and analog circuits. An 8 MHz oscillator is connected to the two oscillator pins of the microcontroller. The oscillator frequency of 8 MHz was chosen since the ATMega32 has a maximum clock frequency of 8 MHz and lowering the clock speed does not significantly reduce power consumption. The Capacitors C60 and C61 are recommended by the oscillator manufacturer. A JTAG interface is also necessary for programming the microcontroller. A table of all microcontroller pins their use in the design is included below.

Microcontroller Pin Name	**Intended Use For Pin**	**Signal Connected to Pin**	**Description of Signal Function**
PB0/XCK/T0	I/O pin	nUVTron_CLR	Clears the UVTron's device interrupt flag
PB1/T1	I/O pin	LCD_STROBE	LCD shift register strobe
PB2/INT2/AIN0	I/O pin	LCD_E	LCD enable
PB3/OC0/AIN	PWM Output	RMotor_PWM	Controls the right drive motor
PB4/SS	I/O pin	LCD_RS	LCD control signal
PB5/MOSI	I/O pin	LCD_RW	LCD control signal
PB6/MISO	I/O pin	LCD_CLK	LCD clock signal
PB7/SCK	I/O pin	LCD_SHIFT	LCD serial shift enable
RESET	Active low async. Reset	Reset Pushbutton	Reset Pushbutton
VCC	Power	+5V_Digital	5V digital supply rail
GND	Ground	D_GND	Digital ground plane
XTAL2	Oscillator pin	Oscillator	8MHz oscillator
XTAL1	Oscillator pin	Oscillator	
PD0/RXD	SCI Receive	Debug_RX	Serial debug receive line
PD1/TXD	SCI Transmit	Debug_TX	Serial debug transmit line
PD2/INT0	Interrupt	UVTron_IRQ	Device interrupt flag
PD3/INT1	I/O pin	Push_button_1	Input from switch
PD4/OC1B	Timer output compare	Trigger_Position_PWM	Servo driver
PD5/OC1A	Timer output compare	Sensor_Platform_Position_PWM	Servo driver
PD6/ICP1	I/O pin	Push_button_2	Input from switch
PD7/OC2	PWM output	LMotor_PWM	DC motor driver
PC0/SCL	I/O pin	nLowBatt	Low battery signal from MAX746
PC1/SDA	I/O pin	Out_Shift_STR	I/O shift reg. control
PC2/TCK	JTAG TCK signal	JTAG_TCK	JTAG Programming Interface
PC3/TMS	JTAG TMS signal	JTAG_TMS	
PC4/TDO	JTAG TDO signal	JTAG_TDO	
PC5/TDI	JTAG TDI signal	JTAG_TDI	
PC6/TOSC1	I/O pin	Out_Shift_CLK	I/O shift reg. clock
PC7/TOSC2	I/O pin	Out_Shift_D	I/O shift reg. input
AVCC	Power	+5V_Analog	5V analog supply rail
GND	Ground	D_GND	Digital ground plane
AREF	Ground	A_GND	Analog ground plane
PA7/ACD7	A-to-D input	IR1_Wide	IR photodiode circuit voltage output
PA6/ACD6	A-to-D input	IR2_Wide	
PA5/ACD5	A-to-D input	Temp_Narrow	IR temp. sensor voltage output
PA4/ACD4		No Connect	
PA3/ACD3	A-to-D input	Distance_Out4	IR distance sensor voltage output
PA2/ACD2	A-to-D input	Distance_Out3	
PA1/ACD1	A-to-D input	Distance_Out2	
PA0/ACD0	A-to-D input	Distance_Out1	

Table 1: Microcontroller Pin Descriptions

Motor Drivers

The Motor Drive block responds to signals from the microcontroller to drive the two power motors of the FIREbot. The power motors are Lynxmotion Planetary Gearmotors, which are DC brush motors with integrated gearboxes. The motors run on 12V DC and have a stall current of 750mA each. Pulse Width Modulation is used to control the speed of each motor, and there is no motor feedback, as the robot responds solely to its distance and flame detection sensors.

The inputs to the Motor Drive block are 8 digital signals from the Microcontroller, 4 to control each motor. The signals are the control signals Forward, Reverse, and Brake (which are mutually exclusive), and a Pulse Width Modulation signal PWM. The CPU asserts one of Forward, Reverse, or Brake (or none of these) to indicate the intended mode of operation of the motor, and PWM indicates the speed of the motor in Forward or Reverse Mode.

The outputs of the Motor Drive block are the analog drive voltages that connect directly to the positive and negative terminals of the power motors.

The Motor Drive block is implemented in 3 parts: the glue logic, H-bridges, and snubbers. The glue logic converts the signals from the microcontroller to the signals to control the gates of the H-bridges. It is implemented as simple logic burned into a PLD. The H-bridges selectively couple the motor terminals to the +12V and Ground rails, and isolate the analog motor drive voltages from the Digital circuitry. Finally, the snubber snubs inductive kickback from the motors.

Extinguisher Trigger Servo & Sensor Platform Servo Drivers

The Extinguisher Trigger and Sensor Platform Drive blocks are identical, since they both control very similar servos. They are quite simple, consisting only of optical isolation for the Pulse Width Modulation signals and decoupling capacitors for the power. Since the servos may cause noise on their power rail, they have a dedicated 5V rail.

Siren Interface

The Siren block interfaces a 12V siren to a pin of the microcontroller. The input is the Siren_Activate signal from the microcontroller, and the output is the positive and negative terminals of the siren. The Siren_Activate signal is optically isolated, and controls the gate of a FET to switch the positive terminal of the siren. An LED is also activated, so that the siren can be removed if it gets too obnoxious during testing.

20x4 Character LCD Interface

The LCD [12] interface is based on a 74HC74 8-bit serial shift register whose input is driven by a microcontroller port pin. The microcontroller loads a byte into the register serially. When the LCD_STROBE signal is asserted by the microcontroller, the byte of data appears on the output of the shift register IC. This shift register reduces the number of port pins required to send data to the LCD from eight to one. Other LCD control signals are driven directly by microcontroller port pins. A potentiometer controls the contrast of the LCD.

Debug Port Interface

The Debug Port block provides an RS-232 interface through which an external PC can connect to the FIREbot. It is primarily for debug information, although it may also be used to send simple commands to the robot.

The Debut Port’s TX and RX signals are connected directly to the microcontroller. The outputs are the pins of a DB9 serial connector. The TX and RX signals are optically isolated from the analog circuitry, and then level-shifted to the +/-12V logic levels on the RS-232. This task is performed by a MAX201 RS-232 Level Shifter IC [13], which is powered by +5V and +12V, and inverts the +12V to get -12V. Only the TX, RX and SGND signals of the DB9 are used, the others are tied to ground or terminated appropriately.

List of Refrences / Datasheet Links

[1] http://www.irf.com/product-info/datasheets/data/irf9z34n.pdf

[2] http://rocky.digikey.com/WebLib/InternationalRectifier/Web%20Data/IRFZ20.pdf

[3] http://pdfserv.maxim-ic.com/en/ds/MAX746.pdf

[4] http://rocky.digikey.com/WebLib/Epcos/Web%20Data/B45197,%20B45198.pdf

[5] http://www.jwmiller.com/pdf2/PM2120.pdf

[6] http://rocky.digikey.com/WebLib/Fairchild/Web%20Data/LM7805_MC78xx_MC78xxA.pdf

[7] http://www.acroname.com/robotics/parts/R66-R2868.pdf

[8] http://rocky.digikey.com/WebLib/Sharp/Web%20Data/pd413pi.pdf

[9] http://www.raytek-northamerica.com/admin/file_handler/2ae6092f570efab9e577de9b6820919c/1013704784/CI_DS_2-1302_Rev_C_LREZ.pdf

[10] http://rocky.digikey.com/WebLib/Sharp/Web%20Data/gp2d120.pdf

[11] http://rocky.digikey.com/WebLib/Atmel/Web%20Data/ATmega32(L)%20Preliminary%20Complete.pdf

[12] http://www.crystalfontz.com/products/2004a/CFAH2004ANYAJP.pdf

[13] http://rocky.digikey.com/WebLib/Maxim/Web%20Data/MAX200,1,2,3,4,5,6,7,8,9,11,13.pdf