Homework 5: Theory of Operation and Hardware Design Narrative

Due: Friday, February 15, at NOON

Team Code Name: The Two Wheel Deal **Group No. 12**

Team Member Completing This Homework: Greg Eakins

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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 20% of the individual component of the team member's grade. The body of the report should be 3-5 pages, **not** including this cover page, references, attachments or appendices.

Evaluation:

SCORE	DESCRIPTION
10	***Excellent*** *– among the best papers submitted for this assignment. Very few corrections needed for version submitted in Final Report.*
9	***Very good*** *– all requirements aptly met. Minor additions/corrections needed for version submitted in Final Report.*
8	***Good*** *– all requirements considered and addressed. Several noteworthy additions/corrections needed for version submitted in Final Report.*
7	***Average*** *– all requirements basically met, but some revisions in content should be made for the version submitted in the Final Report.*
6	***Marginal*** *– all requirements met at a nominal level. Significant revisions in content should be made for the version submitted in the Final Report.*
*	***Below the passing threshold*** *– major revisions required to meet report requirements at a nominal level.* ***Revise and resubmit.***

* *Resubmissions are due within* ***one week*** *of the date of return, and will be awarded a score of "6" provided all report requirements have been met at a nominal level.*

Comments:

1.0 Introduction

Due to its duties as an upright balancing transportation device, The Two Wheel Deal requires a unique mixture of high sensitivity and high power circuitry in order to properly balance and transport a person. On the sensor side, it needs a precise sensor and microcontroller circuit to fine tune the demanded motor torque based on readings from multiple sensors and user inputs. On the power side, this vehicle needs high current motor controllers to bridge the gap between the microcontroller and the powerful DC motors on board, along with high capacity batteries to supply the required current.

2.0 Theory of Operation

Power Supply

All of the power for The Two Wheel Deal comes from a pair of 12V sealed lead acid wheel chair batteries wired in series to provide the circuit with 24V. The batteries are used to supply current primarily to the motor controllers, which direct the current through the NPC-T74 motors. The 24V from the batteries is stepped down to 12V using a linear voltage regulator. Though this is an inefficient means of regulating a large voltage difference, the simplicity of the circuit and the resilience to voltage ripple caused by the motor controllers far outweigh the additional current consumption which, when compared to the current consumption of the motors, is miniscule. The 12V from these regulators is used for powering the FET drivers on each motor controller. The voltage is again stepped down from 12V to 5V using a linear voltage regulator to ensure that the microcontroller and sensor circuit receive a stable voltage. The constancy of the 5V line is critical for the proper interaction of the sensors and the microcontroller. Fluctuations in the input voltage of the sensors will result in undesirable changes on the output of the sensors. The microcontroller, sensors, PLDs, LCD, and various other support devices are powered by the 5V regulator. All components outside of the motor controllers are 5V devices to simplify the power supply circuit, as well as eliminate any need for level translators or amplification hardware.

Microcontroller

The ATmega32 microcontroller interfaces to all of the major components of the vehicle. It runs off of an external crystal oscillator at the microcontroller’s maximum clock speed of 16 MHz to maximize the available computing power. It uses the ATD module to read an analog signal from the accelerometers, the gyroscopic angular rate sensor, the steering joystick, and the battery level meter. Based on the incoming data, it computes the duty cycle of two outgoing PWM signals that are used to command torque from the motors. At the same time, the microcontroller interfaces to an LCD screen to give the driver feedback on the state of the vehicle.

Sensors

A dual axis accelerometer and a single axis angular rate sensor are used to determine the angular position and angular velocity of the vehicle about its drive axis. Both sensors have analog outputs that are fed directly to the microcontroller's ATD channels. Both sensors have internal signal conditioning circuitry, reducing or eliminating the need for filtering circuitry. Physical orientation of each sensor is extremely important for obtaining the correct information on the vehicle's movements [1][2]. To facilitate proper mounting of the sensors without resorting to extraneous mounting of each sensor, the entire microcontroller and sensor PCB is mounted perpendicular to the ground along the centerline of the vehicle.

Battery level monitoring is performed by using a simple high resistance voltage divider connected directly to the battery. The 24V battery voltage is divided down to 5V to allow the ATD converters to read changes in the voltage of the battery. Knowing the state of the battery's charge will allow the controller to compensate for a low battery by increasing the duty cycle of the PWM signal going to the motor controllers, keeping the vehicle's performance constant over the life of the battery.

An infrared rider detection switch in the handlebar of the vehicle lets the system know when the rider has dismounted (either willingly or unwillingly). Logic in the software algorithm will insert a delay before any action is taken upon detecting a missing rider. This allows the rider to temporarily remove their hands from the handlebars if need be without the vehicle coming to an undesired halt.

Motor Controller

Each motor controller is controlled using a PWM signal from the microcontroller running at a frequency of approximately 2 kHz. Using this low frequency signal can cause an audible whine from the motors, but it increases the power handling of the circuit by reducing the losses generated by switching the FETs. The PWM signal is not fed directly to the MOSFETs, but instead it is fed to a FET driver that takes care of many of the important details of driving an H-bridge, such as applying the right voltages to the MOSFET gates and inserting a slight delay before switching from forward and reverse to prevent a circuit destroying shoot-through situation.

The FET controller controls a simple MOSFET H-bridge. Each leg of the bridge holds 3 MOSFETs rated at 100A continuously. This gives each one of The Two Wheel Deal's motor controllers a theoretical current capacity of about 300 amps, though given the passive cooling system, 150A is a more realistic value [3].

Even though the FET drivers help prevent shoot-through by inserting a slight delay before changing directions [4], special circuitry has been added to the H-bridges to compensate for the large MOSFETs used in this design. The large gate capacitances (on the order of a few µF) cause a sizable delay in the turn-off time of each FET, and if the opposing set of FETs turn on before the first set turns off, shoot through will occur. Resistors have been added in series with the gate of each transistor to slow down the turn on time, and a Schottky diode wired in parallel with the resistor aid in speeding up the turn off time of each FET by pulling the charge off of the transistor's gate.

Each motor controller requires that the incoming PWM signal be switched between two separate pins to switch the motor controller between forward and reverse. Since the microcontroller only has enough PWM channels to supply 1 PWM signal to each motor controller, additional logic must be added to allow for a single PWM signal to command both forward and reverse. Though this logic can be implemented using a few discreet logic gates, a single PLD is used to simplify this circuit and allow for future expansion.

The rapid switching of high current inductive loads makes the motor controller an electrically chaotic part of the circuit. To provide a measure of safety to the microcontroller and logic circuits, the motor controller circuits are separated from the microcontroller circuit by running each PWM signal through an optical isolator.

Human Interface

An LCD screen is used to provide the user with vehicle information such as approximate vehicle speed and battery life. The microcontroller interfaces to the LCD screen directly using a parallel interface. Steering of the vehicle is implemented by reading the voltage output from a variable resistance joystick circuit. This value is sent directly to an ATD channel on the microcontroller.

3.0 Hardware Design Narrative

The PWM module of the ATmega32 is used to send a torque demand to the motors. The microcontroller has only two 16-bit PWM outputs, and both will be utilized. These outputs correspond to pins OC1A and OC1B. General I/O pins PD0 and PD1 have been chosen to control the direction of the motors primarily due to their close proximity to the PWM output pins.

The ATD module is used extensively for reading the values coming from the sensors. All of the sensors have a 0-5V output range, so they can be directly connected to the ATD pins. The dual axis accelerometer's two outputs uses ATD pins PA1 and PA2, the output of the angular rate sensor uses PA3, the 2.5V reference voltage of the angular rate sensor uses PA4, the steering joystick uses PA5, and the battery level circuit is connected to PA0.

The LCD screen will take up the most I/O pins. While the parallel interface of the LCD could be using the SPI and a shift register to save microcontroller pins, a high number of free I/O pins make this an unnecessary addition to the circuit. The LCD screen requires 10 pins to operate. The 8 data bits will use pins PC0-PC7. These pins are controlled internally by a single data register. Putting all of the LCD data pins together simplifies the software algorithm for writing data to the LCD. The screen needs a register select (RS) and a clock signal (E) as well, and these are assigned to pins PA7 and PD7 respectively. Placing these signals in close proximity simplifies the physical routing on the PCB.

The signals from the passenger detection sensors will be reduced to a single signal by using a PLD. That signal will be read by pin PA6 on the microcontroller. A summary of the microcontroller pin assignments can be found in Table 3.1.

Signal	Pin Name	Pin Number
PWM Motor Controller Torque Demand	OC1A, OC1B	19, 18
Motor Controller Direction Control	PD0, PD1	14, 15
2-axis Accelerometer	PA1, PA2	39, 38
Angular Rate Sensor	PA3,PA4	37,36
Steering Joystick	PA5	35
Battery Level Monitor	PA0	40
LCD Data	PC0-PC7	22-29
LCD Register Select (RS)	PA7	33
LCD Clock (E)	PD7	21
Passenger Detection	PA6	34

Table 3.1 – Summary of Microcontroller Pin Usage

4.0 Summary

The Two Wheel Deal's circuitry has been carefully designed around creating a circuit that is both sensitive enough to properly detect and react to small changes in the vehicle's dynamics, yet powerful enough to move a person. The lead acid batteries supply ample current to the motors, while the linear voltage regulators provide a stable power supply to the voltage sensitive digital components. A microcontroller sits at the center of the design, interfacing directly to all of the sensors and user inputs while interfacing through isolation circuits to the motor controllers to prevent damage to the delicate circuitry surrounding the microcontroller. The end result is simple yet effective realization of a circuit that performs all of the calculations, sensing, and power delivery required for The Two Wheel Deal.

List of References

[1] Analog Devices, "Analog Devices ADXL103/ADXL203 Data Sheet", [Online Document], [cited 9 February 2008], http://www.analog.com/UploadedFiles/Data_Sheets/ADXL103_203.pdf

[2] Melexis, "MLX90609-E2 Angular Rate Sensor Data Sheet", [Online Document], [cited 9 February 2008], http://www.melexis.com/prodfiles/0005095_MLX90609E2_web_datasheet.pdf

[3] Fairchild Semiconductor, "HRF3205 Power MOSFET Data Sheet", [Online Document], [cited 9 February 2008], http://www.fairchildsemi.com/ds/HR/HRF3205.pdf

[4] Intersil, "HIP4081A 80V High Frequency H-Bridge Driver", [Online Document], [cited 9 February 2008], http://www.intersil.com/data/an/an9405.pdf

[5] Atmel, "ATmega32 Datasheet", [Online Document], [cited 9 February 2008], http://www.atmel.com/dyn/resources/prod_documents/doc2503.pdf

Appendix A: System Block Diagram