Homework 3: Design Constraint Analysis and Component Selection Rationale

Due: Friday, February 1, at NOON

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

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NOTE: This is the first in a series of four "professional 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

The Two Wheel Deal will be a compact, maneuverable, self-balancing personal transportation vehicle meant to revolutionize the way that short distance travel is conducted. Most of its design constraints are derived from the fact that it will be used as a mode of transportation to replace walking. It must be small enough to travel most places that pedestrians travel, it must be powerful enough to move a normal sized person while having enough extra power to maintain balance at normal speeds, and it must be light enough to pick up if necessary. The design of this vehicle is based heavily on the Segway PT, a commercial product built by Segway LLC. As such, many of the design constraints are based on the attributes of the production model.

2.0 Design Constraint Analysis

The most essential group of design considerations in this project involves the control system that is used to keep the vehicle upright. This means choosing sufficiently powerful motors, sensors with an appropriate measurement range, and a microcontroller capable of crunching through a precise control algorithm while interfacing to all of the vehicle's devices. The success of this project hinges on choosing all of these components appropriately.

The human interface and safety system is important for ensuring a safe and comfortable experience on the vehicle. An LCD display for displaying vital information, an easy to use steering mechanism, rider detection sensors, and battery level monitoring are among a few of the important components that must be considered in this design. Appropriate selection of these devices should allow for easy control of the vehicle and a reasonable degree of safety.

2.1 Computation Requirements

The control algorithm will be the primary responsibility of the microcontroller. This will involve reading the outputs of the accelerometers, angular rate sensor, and the steering angle sensor, then computing the required torque for each wheel and updating the PWM duty cycle. The target update rate is 100 Hz, which would be equivalent to that of the Segway [1]. The algorithm might need to use floating point arithmetic, which will require a decent amount of processing power.

The microprocessor will need to do some filtering on the sensor inputs, as the pulse width modulated motors and the potentially rough terrain will cause some noisy input signals.
The last computational responsibility of the microcontroller will be the output to the LCD screen. Every character on the screen will have to be regularly refreshed to provide meaningful data to the user.

2.2 Interface Requirements

The microcontroller will first need to interface to the motor controllers using a PWM signal. This interface will be optically isolated to prevent current spikes and noise from destroying the microcontroller or its pins. The microcontroller will also interface directly to the accelerometers and the angular rate sensor using ATD pins.

The main need for general I/O pins comes from the LCD. The controller chip in the LCD requires 10 pins to control. If the availability of pins becomes short, the LCD may also be controlled via the SPI by using an external shift register to free up some pins. Additional I/O might be needed at a later time to facilitate the addition of various status LEDs, vehicle lighting (headlights, tail lights, and turn signals), safety features, and other accessories.

2.3 On-Chip Peripheral Requirements

The current flowing through the motors will be controlled using a pulse width modulated signal. Having precision control over this signal will aid immensely in creating a stable and robust control algorithm; therefore this design will require two 16-bit PWM channels for motor control. This will be the primary limitation on the microcontroller used in this application.
All of the motion sensors have analog outputs, necessitating multiple on-chip analog to digital converters. The accelerometers will need 2 ATD channels, the angular rate sensor will need 1 ATD channel, the steering mechanism will need 1 ATD channel, and the battery level monitoring circuit will need 1 ATD channel. A total of 5 ATD channels will be needed, with 10-bit resolution being preferred for precision.

2.4 Off-Chip Peripheral Requirements

The only off-chip peripheral used in this design is the controller chip that is built into the LCD. Instructions are clocked into it through a parallel interface, and then it will take care of interfacing directly to the display.

2.5 Power Constraints

The Two Wheel Deal's power supply needs are centered about the needs of the two large motors. The power needs of all other components in this design are extremely small compared to the needs of the motors. The battery will need to supply current up to 400 amps to the motors for very short periods of time at an operating voltage of 24 volts[3]. The batteries also need to be rechargeable and be relatively compact, as the small nature of this vehicle limits the amount of space available for batteries.

2.6 Packaging Constraints

The majority of the packaging constraints stem from this vehicle's required ability to traverse areas that pedestrians would typically occupy. This means that it needs to be narrow enough to fit through a door, have enough ground clearance to pass over imperfections in the terrain without rubbing off expensive electrical components, and be strong enough to carry a normal sized passenger.

2.7 Cost Constraints

The primary constraint on cost is that The Two Wheel Deal must be built such that it is competitive in price to the real Segway. Doing this is a trivial task, as a new Segway comes with a price tag of at least $4000. The target build cost of The Two Way Deal is approximately $1500, less than half the price of a new Segway. The price of the prototype version will be minimized through the aggressive pursuit of donations and product samples.

3.0 Component Selection Rationale

Microcontroller

The needs for the microcontroller outlined in sections 2.1, 2.2, and 2.3 are all satisfied by the two microcontrollers shown in Table 3.0.1 in Appendix C. The PIC was comparable to the Atmel in almost every attribute[4][5]. Both microcontrollers had all of the needed I/O, sufficient flash memory, and both come in a DIP package for easy development. Price is not a large factor for this part, as the microcontroller is only a very small portion of the total cost. The Atmel ATmega32 was chosen due to its high quality and readily available development tools. The AVR series is well documented and has a huge amount of support online [6].

Accelerometer

This design needs to have a dual axis high sensitivity accelerometer to detect the angle of tilt on the vehicle. A couple of accelerometers were considered, and their features are compared in Table 3.0.2 of Appendix C. The Analog Devices accelerometer was chosen for this project primarily due to its 5V operating voltage, high sensitivity, and simple pin out[7]. The additional cost of the Analog Devices chip is minor when the additional circuitry required for the Freescale chip is taken into consideration. By choosing only 5V devices for this design, the amount of overhead circuitry is minimized and the overall design simplified.

Angular Rate Sensor

To determine how fast the vehicle is tipping over, a sensor that detects the rate of change in angular position is vital. Theoretically, this value could be obtained in software by differentiating the reading from the accelerometers, but in reality, the accelerometer reading will be too noisy to accurately differentiate, and any filtering would delay the response time of the system, therefore, a dedicated angular rate sensor is required. The selection of the angular rate sensor depended primarily on the needs of the control algorithm. An angular rate sensor of medium sensitivity is preferred so that the output of the sensor does not easily saturate during quick changes in position, yet is sensitive enough to detect a decent range of movement speeds. The gyroscopic angular rate sensors in Table 3.0.3 of Appendix C were considered. The Melexis part was chosen for this project because it provides the best compromise between cost and sensitivity of the three[8].

Motors

The motors were selected based on the physical needs of the system. The Two Wheel Deal should have a top speed of at least 15 mph, and have enough torque at that speed to recover from a tilt from vertical of 15°. By using some simple physics calculations, it was determined that high torque, low RPM motors were needed. Two motors made by National Power Chair were determined to be appropriate for this application. The abilities of the two motors are compared in Table 3.0.4 in Appendix C. While both motors satisfied the requirements of this project, the

NPC-T74 met them by a greater margin[3]. The donation of the NPC-T74 motors solidified the decision.

Batteries

All of the requirements for a power supply are met by either using two small 12V lead acid batteries in series, or a string of 20 1.2V NiMH D cell batteries. The two options are compared in Table 3.0.5 in Appendix C. The sealed lead acid batteries were chosen primarily due to the huge difference in cost. The D-cell NiMH batteries would have given the vehicle tremendous battery capacity in a small volume, but they come at a high price. The lead acid batteries selected are commonly used in wheelchairs, and the selected motors are also from wheelchairs, showing that this

LCD

Only a few constraints guided the selection of the LCD screen. It had to use the Hitachi HD44780 LCD driver due to previous experience with this display, it needed to be large enough and customizable enough to display a few pieces of information to the rider, and it needed to be backlit for nighttime and indoor visibility. A large number of LCD screens fit these criteria. Two of them are compared in Table 3.0.6 in Appendix C. The deciding factor came down to cost, and the LCD20x4BL from Futurlec came out on top.

Packaging

The limiting factor to the width of the vehicle is the depth of the motors, so the motors will be mounted as close together as possible so that the width of the vehicle is much smaller than a standard doorway. Ground clearance is achieved through the selection of 20" high quality plastic bike wheels made by Skyway Wheels. These wheels will give a ground clearance of 10" from the middle of the motor shaft, leaving room for the width of the motors and other large components hanging off the bottom. Replacement tires for these 20" wheels are easy to find at any store that sells bikes, which greatly improves the serviceability of the vehicle. The target passenger load is 100 kg (220 lbs), and will be limited by the strength of the chassis.

4.0 Summary

Through the careful selection of all components required for this project, all of the major design constraints have been met. The microcontroller's high resolution outputs to the motors combined with the appropriately chosen accelerometer and angular rate sensors should enable a high precision control loop for balancing the vehicle. The powerful motors combined with the capable and small batteries will ensure that the vehicle has enough muscle to move the vehicle in any way that is required. These design decisions should ensure that The Two Wheel Deal becomes a viable alternative to walking.

List of References

[1] Segway, "The Science of Segway", [Online Document], [cited 31 January 2008], http://www.segway.com/about-segway/science-of-segway.php

[2] BetaNews, "Segway Offers Financing to Push Sales", [Online Document], May 2006, [cited 31 January 2008], http://www.betanews.com/article/1149106883

[3] Robotmarketplace, "NPC-T74", [Online Document], [cited 31 January 2008], http://www.robotmarketplace.com/products/NPC-T74.html

[4] Atmel, "Atmel ATmega32 Description", [Online Document], [cited 31 January 2008], http://www.atmel.com/dyn/resources/prod_documents/2503S.pdf

[5] Microchip, "PIC16F87XA Datasheet", [Online Document], [cited 31 January 2008], http://ww1.microchip.com/downloads/en/DeviceDoc/39582b.pdf

[6] AVR Freaks, "AVR Freaks homepage", [Online Document], [cited 31 January 2008], http://www.avrfreaks.net/

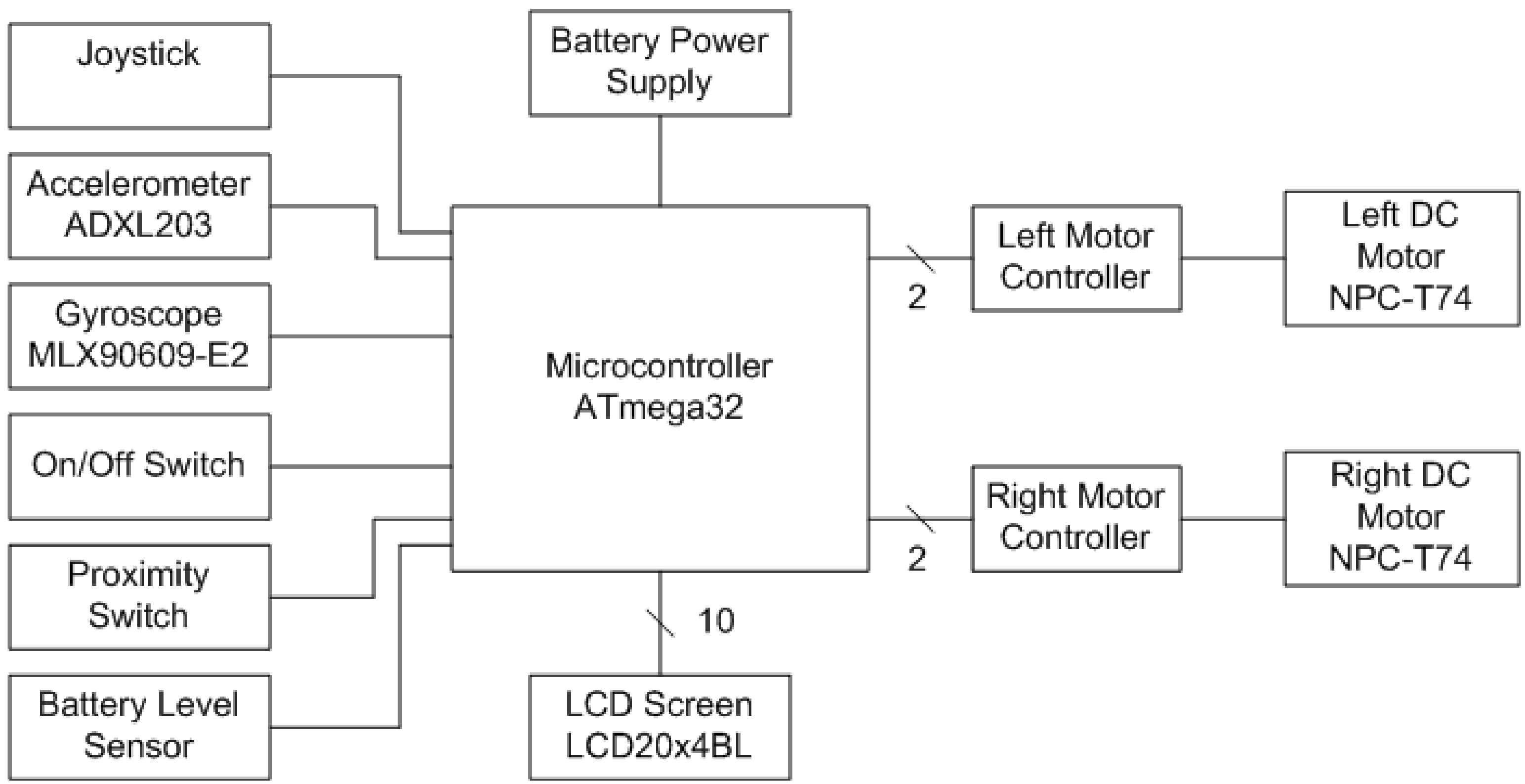
[7] Analog Devices, "Analog Devices ADXL103/ADXL203 Data Sheet", [Online Document], [cited 31 January 2008], http://www.analog.com/UploadedFiles/Data_Sheets/ADXL103_203.pdf

[8] Melexis, "MLX90609-E2 Angular Rate Sensor Datasheet", [Online Document], [cited 31 January 2008], http://www.melexis.com/prodfiles/0005095_MLX90609E2_web_datasheet.pdf

Appendix A: Parts List Spreadsheet

Vendor	*Manufacturer*	*Part No.*	*Description*	*Unit Cost*	*Qty*	*Total Cost*
Atmel	Atmel	ATmega32	8-bit microcontroller	$8.00	1	$8.00
NPC-T74	National Power Chair	NPC-T74	Wheelchair Motor	$324.00	2	$648.00
eBay	Generic	none	Sealed Lead Acid Battery	$44.99	2	$89.98
Melexis	Melexis	MLX90609-E2	Gyroscopic Angular Rate Sensor	$39.95	1	$39.95
Analog Devices	Analog Devices	ADXL203	Dual Axis Accelerometer	$12.00	1	$12.00
Futurlec	Futurlec	LCD20X4BL	20x4 LCD	$20.90	1	$20.90
Skyway Wheel	Skyway Wheel	WHL4015	20” Tuff Wheel	$19.10	2	$38.20
Digikey	Fairchild Semiconductor	HRF3205-ND	100A MOSFET	$1.46	24	$35.04
Intersil	Intersil	HIP4081AIP	Full bridge FET driver	$6.24	2	$12.48
Digikey	Diodes Incorporated	SD101AW-FDICT-ND	Schottky Diode	$0.31	24	$7.44
Digikey	National Semiconductor	LM2574HVN-12-ND	Switching Voltage Regulator	$4.85	1	$4.85
				TOTAL		**$916.84**

Appendix B: Updated Block Diagram



Appendix C: Component Comparison Tables

	Atmel ATmega32	Microchip PIC16F877A
PWM	2 x 16-bit	2 x 16-bit
ATD	8 x 10-bit	8 x 10-bit
I/O Pins	32	33
SRAM	2048	368
Flash Memory	32 kB	14 kB
DIP Package	Yes	Yes
Price	$8.00	$3.71

Table 3.0.1 – Microcontroller Comparison

	Analog Devices ADXL203	Freescale MMA6280QT
Measurement Range	±1.7G	±1.5G
Sensitivity	1000 mV/G	800 mV/G
Operating Voltage	5V	3.3V
Pins	8	16
Price	$12.00	$2.65

Table 3.0.2 – Accelerometer Comparison

	Analog Devices ADXRS150	**Melexis MLX90609-E2**	**Silicon Sensing CRS03-02**
Measurement Range	±150°/s	±150°/s	±100°/s
Sensitivity	12.5mV/°/s	13.33mV/°/s	20mV/°/s
Operating Voltage	5V	5V	5V
Price	$30.00	$39.95	$338.34

Table 3.0.3 – Comparison of Angular Rate Sensors

	National Power Chair NPC-T64	**National Power Chair NPC-T74**
Torque at 0 RPM	825 in-lbs	1480 in-lbs
Peak Current	110 A	210 A
Max Speed	230 RPM	245 RPM
Recovery Angle at 15 mph	20°	37°
Price (for 2)	$572.00	$648.00

Table 3.0.4 – Comparison of Motors

	Sealed Lead Acid	**NiMH D-Cells**
Voltage per Cell	12V	1.2V
Theoretical Current	1000 A	600 A
Total Capacity	36 Ah	130 Ah
Internal Resistance	12 mΩ	2 mΩ
Number Needed	2	20
Total Price	$90	$470

Table 3.0.5 – Battery Comparison

	LCD20X4BL	**CFAH2004A**
Driver	HD44780	HD44780
Backlight	Yes	Yes
Documentation	Yes	Yes
Size	20x4	20x4
Price	$20.90	$29.53
Interface	Parallel	Parallel

Table 3.0.6 – Comparison of LCD Screens