

# Purdue ECE Senior Design Semester Report

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| <b>Course Number and Title</b> | ECE 477 <i>Digital Systems Senior Design Project</i> |
| <b>Semester / Year</b>         | Spring 2008  |
| <b>Advisors</b>                | Profs. Meyer and Johnson                             |
| <b>Team Number</b>             | 12   |
| <b>Project Title</b>           | The Two Wheel Deal                                   |

| Senior Design Students – Team Composition |       |  |                          |
|---|-------|--|--------------------------|
| Name                                      | Major | Area(s) of Expertise Utilized in Project | Expected Graduation Date |
| Pete Dudash                               | EE    | Software/Packaging                       | May 2008                 |
| Greg Eakins                               | EE    | Electromechanical Interfacing/PCB        | May 2008                 |
| Eric Geier                                | EE    | Software/Interfacing                     | May 2008                 |
| Jeremy Gries                              | EE    | Hardware/PCB                             | May 2008                 |

**Project Description:** Provide a brief (two or more page) technical description of the design project, as outlined below:

- (a) Summary of the project, including customer, purpose, specifications, and a summary of the approach.

The Two Wheel Deal is a compact, two wheeled, and self-balancing personal transportation device. It works on the inverted pendulum control theory. It is powered by two 12 volt, sealed, lead acid batteries tied in series, and it is driven by two brushed, DC motors that are geared down. Each motor is controlled independently using H-bridges that are fed PWM signals from the microprocessor. The PWM signal is determined using a PD controller which takes readings from an accelerometer and a gyroscope. The accelerometer reads the angle the vehicle has tilted from vertical and the gyroscope reads the rate at which the vehicle is rotating. The rider can move the vehicle forward and backward by leaning forward or backward respectively. The vehicle can be turned using a joystick located near the handle bars. Data such as speed, angle, and battery life are displayed to the rider on an LCD.

The purpose of the Two Wheel Deal is to serve as an economical and practical alternative to most forms of short range transportation, including cars, bikes, and walking. The target customer is anyone who wants a little more excitement or fun on a typical everyday walk or adventure or anyone who would like some relief from long hours of walking. The vehicle can be used by businesses in industrial settings for traveling throughout a plant, or for policing a mall. It can also be used recreationally in parks and trails. Having only two wheels gives The Two Wheel Deal a small footprint for enhanced mobility over conventional means of transportation.

The idea for the project stemmed from a mutual interest in control theory and motor control. An initial idea proposal consisted of variants on the autonomous robot/vehicle that could travel from point to point using GPS. This type of project had been done quite often though so while searching for different ideas, we came across a project where a group made a miniature, self-balancing robot. This appealed to everyone in the group, but we wanted to take it one step further and create a full-size vehicle similar to the Segway. The first step toward completing the process was to research similar self-balancing projects as well as all of the theory and design considerations behind every part of the vehicle. We were able to use some of the advice and major components used by the other people to aid in the selection of components for the Two Wheel Deal. It was decided that the motor controllers would be built from scratch due to the huge cost of commercial controllers. This part was heavily researched to prevent a catastrophic failure due to the high current requirements of the circuit. Samples and parts were ordered and the schematic was started on both the microcontroller board and the motor controller boards. The initial PCB layouts were then created as well as a Bill of Materials. The schematic and PCB layout were continually refined (and at one point, entirely redesigned based on feedback from the course staff) in the week or so after the initial design. The software was then started and an

initial draft was completed about the same time the PCBs were finished. Each board was populated one part at a time and a logical sequence of debugging was performed during the build up. Once the chassis and electronics were complete, testing and debugging was performed until the vehicle behaved nearly optimally.

- (b) Description of how the project built upon the knowledge and skills acquired in earlier ECE coursework.

This project built upon extensive knowledge and skill acquired throughout ECE coursework. One of the most important courses was ECE 382 where knowledge of how a PD controller works and is implemented was learned. The PD controller is the main algorithm that keeps the Two Wheel Deal stable and controllable. Another crucial course was ECE 362 where microcontroller design and interfacing was learned extensively as well as how to read datasheets. A great number of design considerations (accelerometers, part selection, and power consideration, scope of project) were learned during the mini-project in ECE 362 that carried over to this project. Also, the mini project helped prepare the group for a long term design project that was started with nothing except an idea. PLD knowledge learned in ECE 270 was used in the project to create the combinational logic that converts the microcontroller outputs into meaningful inputs to the motor controllers. Basic circuitry knowledge learned in ECE 201 was crucial in helping determine how much current would be flowing through the boards to determine how big the traces must be to ensure they would not burn up. This knowledge also helped when designing the schematics. Knowledge of how a brushed, DC motor is controlled and modeled, which was learned in ECE 321, came in use when understanding and designing the four quadrant chopper (H-Bridge). CS 158 and ECE 264 provided extensive knowledge of how to program using C.

- (c) Description of what new technical knowledge and skills, if any, were acquired in doing the project.

The most important new technical knowledge or skill acquired while completing this project was how to design and create a PCB layout. The software had never been used before so that took some time to understand how to do the necessary operations. Also, no team member had designed a PCB before so there were considerations such as placement of certain components, how to lay traces, and minimizing vias that were learned as the board was completed. Another technical skill acquired was how to determine which parts to use in the project. There are so many different types of the same hardware component so knowing which component will work that doesn't have a lot of overkill is important in industry. Learning to use AVRStudio4 and an Atmel chip was another technical skill acquired during this project. Previously, the only microprocessor work that any team member had done was on a Freescale chip so the new software and interfaces had to be learned. Learning how to keep a good lab notebook and work in a team environment were also good skills learned throughout the course as well as how to give technical and non-technical presentations.

- (d) Description of how the engineering design process was incorporated into the project. Reference must be made to the following fundamental steps of the design process: establishment of objectives and criteria, analysis, synthesis, construction, testing, and evaluation.

To establish the objectives and criteria for the project, the team determined what the most crucial parts of the project were and used these to create the five Project Specific Success Criteria. This included things such as independently controlling motors, ensuring some safety features, displaying data to the rider, balancing autonomously, and navigating through tilting and use of a joystick. This is what was used to determine whether the project would be a success or failure. Next, a basic block diagram was made that showed all the crucial parts such as the microcontroller, motor controllers, motors, LCD, joystick, and batteries. Analysis then began by

researching various options for the hardware choices. Each choice was carefully examined and the most efficient components with the least amount of overkill (but with a substantial safety margin) were selected. These components were used to create schematics and PCBs which helped to ensure the synthesis of all the parts.

Construction began with the return of the fabricated PCBs and the assembly of the vehicle chassis. The vehicle dimensions and material had been determined during the analysis stage, and materials were cut and created throughout the semester. Testing occurred at both a hardware and software level. Hardware testing occurred as the PCBs were populated. One group of components such as the power components would be added then thoroughly tested to ensure there were no issues. The motor controllers were tested using only one FET per leg and the minimum support components. Once the testing was complete, a new block of components would be added and tested. Software testing and debugging occurred almost entirely through the LCD interface. It was the first component successfully implemented. As code modules were written for the rest of the project, data was output to the LCD to ensure the correct numbers or values were being calculated. The project was evaluated at the end of the semester by assessing whether the Project Specific Success Criteria were completed and whether any additional features could be added in the amount of time that was left.

- (e) Summary of how realistic design constraints were incorporated into the project (consideration of most of the following is required: economic, environmental, ethical, health & safety, social, political, sustainability, and manufacturability constraints).

**Economic:** Some economic constraints included designing and building H-Bridges from scratch rather than purchasing commercial ones to save money. Also, having the motors, steel hubs, and some metal used on the chassis donated helped to lower the project cost. Finally asking for samples of hardware components rather than purchasing them kept the out-of-pocket cost low.

**Environmental:** Some environmental constraints included choosing parts that are RoHS compliant. Also sealed, lead acid batteries were chosen since they can be recharged to reduce the amount of battery waste due to the vehicle.

**Ethical:** Since the Two Wheel Deal can easily hurt a rider if it is not operated correctly, a training DVD and session would be offered if the vehicle was ever sold to anyone. Also anytime a student asks to ride the vehicle, a team member is always present to train the new rider as well as give him/her tips on how to operate it most efficiently. Finally, a user manual has been created that helps answer any questions a rider may have as well as provide warnings on what not to do with the Two Wheel Deal.

**Health & Safety:** The most important safety constraint on the Two Wheel Deal is that the wheels shut off once the vehicle reaches a certain tilt angle. This helps to ensure the rider is not run over or hurt even more if he/she happens to fall off the vehicle. Other safety considerations include placement of warning labels in areas that can harm the rider such as near the battery connections or spinning fans on the motor controllers.

**Social:** This is a socially redeeming project. It was created as an efficient alternative to driving short distances in a car or walking. It can also be used as a more fun alternative to riding a bicycle or skateboard. These constraints were kept in mind throughout the project design.

**Political:** One main political constraint is to create an efficient and fun vehicle that will help persuade politicians to seriously start considering alternate forms of power for vehicles.

**Sustainability:** One sustainability constraint was to ensure the vehicle would still operate regardless of possible vehicle crashes. The chassis was designed around protecting the batteries and the electronics. The vertical shaft protrudes past the vehicle platform in order

to protect the PCBs at the front of the vehicle, and metal protectors are placed on the front of the batteries to prevent them from being scraped on the ground. All of the PCBs are securely mounted behind the side rails and underneath the main platform for protection.

**Manufacturability:** A major manufacturing constraint was to assemble and package the project in a way that could easily be created without too much mechanical experience. Since this was an Electrical Engineering project the focus was on the electronics rather than the appearance or materials used. If the vehicle would be mass produced, it would probably be made out of a more user friendly material that didn't have as many razor sharp corners and could be made quickly and efficiently on some sort of assembly line.

(f) Description of the multidisciplinary nature of the project.

The major concepts present in this project are Electrical and Computer Engineering. The main control algorithm is based on the inverted control theory and a PD controller. This is a strong Electrical Engineering concept, but is also used by all sorts of engineers. Another strong Electrical Engineering concept is the DC motor control performed using two four quadrant choppers (H-Bridges). Since the heart of the vehicle is a microcontroller, Computer Engineering plays an important role. Mechanical Engineering concepts are also present through the design and manufacturing of the steel wheel hubs as well as the overall packaging of the vehicle. Knowledge of basic physics aided in understanding the nature of the inverted pendulum, as well as the data received from the sensors. Non-engineering skills are also present. Project management skills were important in ensuring major obstacles were overcome in a timely manner to help guarantee the project would be finished by the deadline. General writing skills and communication skills were used and developed throughout the semester during the homework and technical presentations. Ergonomics were also considered when determining where the joystick and handlebars would be located.

(g) Description of project deliverables and their final status.

The deliverable project is the Two Wheel Deal vehicle. It consists of a metal platform with a vertical shaft connected to the front. At the top of the vertical shaft, a box is mounting containing the LCD, rider/no rider switch, and the steering joystick. The handlebars are mounted underneath the box. The LCD displays the tilt angle, vehicle speed, and battery life. The vehicle has two sealed, lead acid batteries and two brushed, DC motors under the platform. The steel hubs and wheels are attached to the motor shafts. Also under the platform are two motor controller boards and a microcontroller board. Everything is accounted for and working except the LCD which was broken during testing and debugging.