Development of Zero-Leg Input Manual Transmission Driving Interface

A Major Qualifying Project

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Abstract

The goal of this MQP is to ameliorate the inability of paraplegics or double-leg amputees to effectively control manual transmission automobiles through the creation of a minimally invasive hand control interface. The inspirations for this project include those who desire the ability to drive a manual transmission vehicle because of their interest in recreational driving or because they own one-of-a-kind cars. While several unique and effective products exist, such as the Kempf Digital Accelerator Ring which allows people with disabilities to drive automatic cars, there are few solutions for standard automobiles. The team evaluates the capabilities of current assistive devices such as the Guidosimplex ‘Duck’ Semi-Automatic Clutch and the Alfred Bekker Manual Hand Clutch. We establish that these products either require the use of one leg or reduce control of the vehicle. The team conducts testing and research in several areas including the analysis of current assistive devices, exploration of driving motions, maneuvers, and ergonomics, and calculation of the dynamics of pedal depression. This leads to the design and fabrication of an ergonomic interface refining existing concepts to allow those without the use of their legs to maintain full control of all of the inputs of a standard transmission vehicle.
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CHAPTER 1. ASSISTIVE DRIVING DEVICES AND CURRENT MARKET NEED

1. Introduction

This project was inspired by those with interests in cars, driving, or car racing who at some point in their lifetimes lose the use of their legs. This handicap can be attributed to a number of events including car accidents, disease, or injury in military service. Hundreds of thousands of individuals live with leg disability in the United States, and permanent prognoses of leg injuries are common. From amputation, birth defect, spinal cord injury, and leg trauma, those who have lost leg function have also lost a large portion of their freedom of mobility. It is estimated that 250,000-400,000 individuals in the United States are currently living with spinal cord injuries. In this group of people there is a 4.5:1 male to female ratio, the average age is 33.4, the median age is 26, and the mode age is 19. Motor vehicle accidents account for 44% of the injuries followed by acts of violence and falls at 24% and 22% respectively (Spinal Cord Injury Facts and Statistics). Racing legends Alex Zanardi and Clay Regazzoni were both severely injured in racing accidents. Following their injuries, there was a long ladder to climb to get back to racing. Alex Zanardi has successfully returned to competitive touring car racing on the international level in a hand-interfaced BMW 320si (Nothing is Impossible: Alex Zanardi, 2012), and Clay Regazzoni successfully competed in the most infamous rally in the world, the Dakar, with a hand-operated rally truck. Advances in assistive driving technologies have helped drivers such as Alex and Clay to be competitive again in varying forms of racing, but their resources are not available to most people affected by their handicap. Car enthusiasts, servicemen and women included, may find themselves suddenly unable to drive due to an immobilizing injury. These individuals may need an assistive adaptation to operate their automobile again.

This project is being conducted to ameliorate the inability of paraplegics or double-leg amputees to drive manual transmission vehicles. Current available systems require the use of one leg or are
designed in such a fashion that the driver occasionally must sacrifice steering wheel control. This project includes evaluation of the design and utilization of current assistive devices for the physically handicapped. The evaluation develops a foundation in the field of assistive technology as well as identifies shortcomings of existing technology in the areas of ergonomics and vehicle mobility and control. The resulting development is an ergonomic, non-invasive interface which allows full coordinated actuation of the inputs of a standard transmission vehicle with zero-leg input from the driver. The interface prototype was manufactured and tested, and analysis of the results determines the success of the project.

In chapter 2 we present the background research that was completed for this project. We develop a need, explore the statistics of disabled drivers and investigate the lack of products available. We examine devices that are on the market today for similar applications such as assistive automatic vehicle control and wheelchairs. In chapter 3 we dissect the mechanical aspects of a standard transmission automobile and its driver interface and conduct an analysis of the various input combinations associated with driving a vehicles with a standard transmission. We then present the design process used in the development of our final design, fueled by our experiments and research. The process begins with task specifications and grows into initial concepts. The initial concepts are analyzed and compared against other possible designs. This chapter presents every aspect of the final design that was chosen including its parts, materials, and a final cost analysis. The chapter concludes with an overview of how the design was brought to life in a proof of concept model that demonstrates the ergonomics and functionality of the design. In chapter 4, we present the conclusions on the success of the interface as well as provide recommendations for future project development and implementation.
CHAPTER 2. ANALYSIS OF DISABILITIES AND EXISTING DEVICES

2. Introduction

Our team found it necessary to research related topics before conducting our experimental testing and beginning the design process. In order to determine the current market need we investigate the disability rate in the United States, and in particular disabilities that may impede leg function. We also evaluate the modern prominence of the manual transmission car. Finally, we investigate currently available assistive driving devices and their drawbacks before creating a complete list of design constraints to consider throughout the design process.

2.1 Disabilities

On May 3, 2008 the Convention on the Rights of Persons with Disabilities, the brainchild of the United Nations, went into effect. The goal of this convention was to change the way that disabled citizens are viewed. Instead as viewing disabled persons as in need of charity, medical treatment, social protection, etc., they would instead be viewed as subjects with rights who are capable of making their own life decisions based on their free and educated opinions. The fundamental message of this act was that those with disability “must enjoy all human rights and fundamental freedoms.” (Convention on the Rights of Persons with Disabilities, 2008)

As of 2005, there are approximately 47.5 million Americans living with a disability according to a survey conducted by the U.S. Census Bureau. This makes up 21.8% of the population; a percentage that has not significantly changed since the last time the poll was conducted in 1999, taking into account population increases. The results of the survey show that the top three causes of reported disability in the United States of America are: arthritis or rheumatism, back or spine issues, and heart trouble. Back and spine issues account for 7.589 million disabilities and are the most likely to be linked to loss of leg function. Overall, women
were more often reported as disabled than men with national percentages of 24.4% and 19.1% respectively. The results were split up into three different age groups, and it was found that for each age group, the percentage of disabled individuals doubled from the previous group. The group from 18-44 years of age reported 11% disability, 45-64 reported 23.9% disability and those of age 65 or older reported 51.8% disability as shown in Figure 2-1.

Some of the more relevant results from the survey were the numbers pertaining to the number of individuals in the United States who may have some impairment of the legs specifically. These relevant results include the numbers of individuals with: cerebral palsy (223,000), missing limbs/extremities (209,000), paralysis of any kind (257,000), head or spinal cord injury (516,000), and stiffness or deformity of limbs/extremities (1,627,000). Also, throughout the United States, there are 3,260,000 disabled persons who rely on the assistive aid of a wheelchair. This data comes from the Survey of Income and Program Participation (SIPP) and has been analyzed by the CDC and the U.S. Census Bureau. The SIPP is a longitudinal panel survey that is designed to represent the entirety of the population that is not currently living.
in institutions (ex: nursing homes). The complete set of data includes every address in the United States, and the sample data is stratified by various socioeconomic and demographic characteristics. The sample data is acquired by selected households and inviting all members of the household to participate in the panel that would be active for two and a half to four years. Interviews of these panels occur in 4-month waves, and this report is based on the disability module that was conducted from June-September in 2005. In this sample there were 70,312 persons, all of at least 18 years of age, from 37,400 households. The survey basically involved asking each of the participants if they have difficulty performing a variety of activities due to some disability. (Prevalence and Most Common Causes of Disability Among Adults --- United States, 2005)

A publication from The National SCI Statistical Center goes into detail on the number of individuals with spinal cord injury, and breaks down some of the information based on different metrics. There are about 12,000 new cases of SCI each year, which amounts to 40 new cases per one million people. The current total estimate in the United States is 270,000 persons. The average age at injury has been steadily increasing and is now at 41 years, up from 28.7 years in 1979. In general, males are the most commonly affected, taking up 80.6% of reported spinal cord injuries. Most (89.3%) of SCI victims continue living in their homes, or some non-institutional residence after their injury, while others reside in nursing homes or other assistive living situations.
2.2 Manual Transmissions

In recent years, manual transmission cars have accounted for about 4% of all new car sales in the United States. This figure jumped in the first quarter of 2012 to about 7%, showing a rise in the interest in manual transmission cars. One potential for this increase is the
development and implementation of new devices that are designed to make manuals more appealing to drive. One example would be the Rollback-ready Hill Start Assist feature that is available on GM cars, which aids the driver in reducing rollback while starting a manual transmission on a hill. Other potential reasons for increased usage of manual transmission cars are the cheaper prices and generally improved gas mileage. Overall, there were 12,778,885 cars sold in 2011, an increase of 1.2 million over the sales in 2010. (Changing Gears: Is Knowing)

The following graph from a report by the Environmental Protection Agency shows a brief outline of the percentage sales of various transmissions over time. In the key to the right, the letters represent the type of transmission, automatic ‘A’, manual ‘M’, automatic with lock-up ‘L’, continuously variable ‘CVT’, and other ‘OT’. Following the letters, if applicable, there is a number that specifies the number of gears available on that transmission. (Quality, 2012)
2.3 Alex Zanardi

Alex Zanardi was most prominent in his career in the late 1990s and was well known for his race pace and daring passes. During his term at Chip Ganassi Racing, he won two Cart Indy car championships and had fifteen wins overall. On September 15, 2001 Alex was the victim of a devastating accident on the track when another car ripped through his car and the lower half of his body. By the time he got to the hospital, he had less than a liter of blood left. Alex recovered spectacularly, with as much motivation as ever. He designed his own prosthetic legs and returned to the scene of the accident two years later to finish the last 13 laps of the race. He
continued racing with hand controls in modified Indy cars and BMW touring cars. He had his first win after the accident in 2005 and had three more wins over the next four seasons. In addition to continuing his racing career, he became an avid handcyclist and won the Venice, Rome, and New York City Marathons. He has also recently competed in the 2012 Paralympics (Nothing is Impossible: Alex Zanardi, 2012). However, Zanardi is not back to his former glory as a racecar driver, after the European Touring Car Championship two years after his injury he is quoted as saying, “I’m only partially satisfied, although I knew I wouldn’t be totally, totally competitive. I’ve competed at the highest level and won big races, so I can’t be happy with seventh place.” He is also quoted as saying “my fastest lap wasn’t so far away from the best, so I think I’ve shown I haven’t forgotten how to drive.” (Alex Zanardi Returns, 2007) If our project is successful, it will bring people like Alex Zanardi, back to their full capabilities.

2.4 Existing Devices

Our project does not seek to ameliorate a complete market absence of assistive driving devices. There are a multitude of electrical and mechanical driver aids in existence today for driver impairments ranging from deafness, partial blindness, arthritis to back pains all the way to amputations and paralysis. Our project instead seeks to identify, consolidate and correct the shortcomings, pitfalls and flaws of mechanisms that help those suffering from the latter two ailments to comfortably and safely drive a manual transmission automobile. In this section we will discuss the devices that closely share our application and discuss where they need improvement, devices used for those with single-leg mobility, mechanisms used to operate automatic vehicles, and assistive models used in other vehicles.

Automatic hand-only input devices vary mostly amongst three major types: push-rock, push-pull, or twist-push (Products: Hand Controls). Push-rock interfaces include a hinged lever
mated to two pushrods. Rocking the hinged lever actuates one input, while pushing the whole assembly downward activates another (Figure 2-5). Push-pull interfaces are very straightforward, with the pushing of a lever actuating one pedal, and pulling controlling another (Figure 2-6). The third major variant is the twist-push, which incorporates a twist-throttle and a push-brake (Figure 2-7).
Devices designed for pedal-free manual transmission operation are broken into input function: throttle, brake, and clutch. There isn’t a modern device that offers all three at once, as each individual component can be marketed to many different handicap types (hemiplegics, paraplegics, single and double amputees, etc.). First, we will focus on the clutch input. Clutches vary wildly in actuation force, from “light” hydraulic clutches of modern cars to “heavy” hydraulic and mechanical clutches of sport, race, classic and supercars, as well as many trucks. This creates a problem with some of the designs already available, as some are not powerful enough or are not designed to operate heavy or mechanical clutch mechanisms. That aside, there are two main types of controls for clutches: manual and electronic. Both utilize hand-input to function; it’s the control over actuation of the clutch that is either manual or electronically controlled.

Some, like Alfred Bekker Co.’s right hand clutch control, uses a lever with a handle located on either side of the steering wheel. When this handle is pulled toward the user, an
electro-hydraulic mechanism depresses the clutch pedal (Right Hand Clutch Hand Control). Slowly releasing this lever engages the clutch. The operator can combine this device with any number of automatic driver aids, such as push-rock, push-pull, or twist-push mechanisms.

![Alfred Bekker hand control](image)

Other designs that can be assimilated with automatic hand control devices are available. Beneficial Designs offers a modified existing control system to accommodate clutch use. This mechanism utilizes a motorcycle throttle-style twist-input to the left of the steering wheel, added to a push-brake mechanism. This entire assembly is mounted on the driver’s door side of the steering wheel, and incorporates many independent inputs into a fluid combination of actuations. Pushing the mechanism downwards actuates the brake, twisting the handle clockwise engages the clutch pedal, and a counterclockwise twist actuates the throttle, all through mechanical linkages (Adaptive Driving Controls for Standard Transmission Vehicle, 1994-2001). This input mechanism, according to the manufacturer, requires great dexterity, coordination, and arm and hand strength.
Electronic clutch actuation for manual vehicles is a relatively new and technology driven industry. Elap, a UK design, manufacture and installation company for mobility products, offers two hand-clutch interfaces for manual transmission cars. Its first, the “SynchroDrive” clutch, is a button mounted to the gear selector that operates with a computer which reads the engine’s RPM, the car’s speed, braking and acceleration input. When the button is released, the clutch is engaged at a rate decided by the computer. This renders the vehicle nearly impossible to stall, as control the clutch is left to the clutch control unit. It can be adjusted statically to fit different driving techniques, but not dynamically, so on-the-fly adjustment of the clutch engagement is not possible. Elap also offers the “Duck” clutch, which is another semi-automatic clutch control system that offers a variable lever instead of the SynchroDrive’s button. The lever operates the clutch by a fly-by-wire method. (Clutch System Vehicle Adaptations)

![eLap SyncroDrive Clutch](image1)

![eLap Duck Clutch](image2)

Figure 2-9 eLap Clutch Designs

Other patented clutch-control or manual-transmission interfaces for the handicapped include one with three under-dash mounted levers, each one mounted to a rocker shaft with
pushrods connecting to the pedals (patent #3,192,784, filed June 8, 1962), and another utilizing a valve mounted on the gear selector that works to pneumatically actuate the clutch (patent #5,996,792, filed Dec. 7, 1999).

All of these existing designs are well executed and most render the vehicle operable by their entire user group. However, be they designs that integrate all three pedal inputs into one device or designs that work in conjunction with other mechanisms, they all offer the same major pitfall. While they efficiently and effectively manage the three pedal inputs, the actual gear-changing motion the driver undertakes seems to fall by the wayside. With this in mind, we investigate the driver ergonomics during driving with these devices. For lever-actuated clutches, such as the Alfred Bekker mechanism, when paired with any of the automatic hand controls to offer full leg-free operation, the driver must release the throttle, engage the clutch, shift gears, disengage the clutch and apply acceleration. These inputs use both of the operator’s hands simultaneously, which means that the steering wheel is unmanned.

Each device listed above has this same pitfall. Some manufacturers tout the ability to hold the steering wheel with the thumb of the non-shifting hand during shifting motions as an advantage. The entire shifting activity, from beginning to end, can vary greatly from driver to driver, with up to three to four seconds not being unrealistic. Operating a 3500 pound vehicle at sixty miles per hour with one’s thumb for four seconds creates many safety concerns. Emergency and evasive maneuvers, defensive driving and panic operation all are real concerns when in control of a vehicle. With an average nearly quarter-second lapse between visually identifying something and physically reacting, the last thing a driver should have to do is abandon shifting to find the steering wheel and brake. A device that allows manual transmission operation while maintaining a hand on the wheel at all times is necessary.
The second shortcoming of these devices is their limitation on driving style. While certain clutch controls like Elap’s Synchrodrive are programmable to change aggressiveness of the clutch, there doesn’t exist a clutch-brake-gas interface that is dynamically adjustable the way that pedal operation by able-bodied drivers is. One with full lower-body functionality can get in the driver’s seat of a manual-transmission vehicle and decide to shift slowly and deliberately, with fuel consumption in mind, drive to a race track and then, without any modification to the vehicle, launch the vehicle down a straightaway, heel-toe into a corner, and clutch-kick the car sideways in a dizzying sensory overload of tires screams and smoke. For handicapped car enthusiasts, this freedom does not exist.

Heel-toeing, or the activation of all three gas, brake, and clutch inputs while downshifting to match engine RPMs to transmission RPMs, is not possible with any existing hand-control technology. Each input can be actuated independently or two-at-a-time, which is common for street driving, but nothing offers the driver the ability to execute advance input maneuvers like the heel-toe. There is no device to give the driver the full freedom and full control of the vehicle.

2.5 Design Considerations

2.5.1 Materials for Production

An important part of any design project is the consideration for materials of production. The automobile is a complex device which is produced with many different materials. The top five materials that are used in automobiles are steel, aluminum, plastic, rubber, and glass. A majority of the weight of the vehicle comes from the metal components. Most automobiles use steel as the metal of choice. Steel is used for structural and weight bearing components such as the chassis, door frames, and structural car body. Aluminum is a metal that is slowly but steadily emerging onto the car scene. Aluminum is not as durable as iron, however it is much lighter and
easier to machine. This metal is being used to manufacture components such as chassis parts as well as rims for tires. The amount of aluminum that is being used in automobiles is increasing. In 1970 only 2% of the weight of the car was due to aluminum. In 1990 it increased to 5% and in 2009 increased again to 9% (Top 5 Materials Used in Auto Manufacturing).

The field of assistive and rehabilitation technology has several devices and mechanisms. Some include crutches, canes, walkers, grabbers, and wheelchairs. When designing assistive devices there is a lot to take into consideration. It is important to choose the right material because materials impact component characteristics such as durability, strength, cost, appearance, manufacturing flexibility, weight, and user compatibility. For structural components, an important consideration is the strength to weight ratio. However, a material with the greatest strength to weight ratio may not necessarily be the best choice due to budget limitations. Therefore, common materials for devices include Aluminum or Alloy Steel. These metals offer a favorable strength to weight ratio while still remaining at a reasonable cost. Other materials could include metals such as titanium or nonmetallic materials such as polymers and composites.

Important considerations when selecting materials to for a project include physical properties, mechanical properties, material cost, and the materials ability to be shaped, formed, or machined.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Modulus of Elasticity (GPA)</th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Yield Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>69</td>
<td>110</td>
<td>95</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>180</td>
<td>860</td>
<td>502</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>11.6</td>
<td>170</td>
<td>40</td>
</tr>
</tbody>
</table>
2.5.2 Evolution and Variation of Automobile Cockpits

When designing an assistive device to be used in automobiles, it is important for the design to be universal. A universal device could be adapted into nearly every automobile that has been in production. Automobiles have been in existence for over 100 years and in that time there has been a multitude of models, styles, and automotive breakthroughs that have caused the cockpit of the vehicle to change. A physically handicapped or paraplegic man or woman could have any one of the many types of standard transmission vehicles and for our device to be successful it should be able to accommodate almost all of them. A compilation of pictures has been placed in APPENDIX D, as a visual reference to the great changes that have occurred.

One prominent feature among all automobiles is the steering wheel. Staying true to its roots and name, the steering wheel has primarily stayed circular throughout the time that automobiles have been in existence. However, shape is about the only thing that has stayed consistent. Today, the steering wheel varies greatly in size. Some of the most common steering wheel sizes are shown below in Table 2-2.

<table>
<thead>
<tr>
<th>SIZE</th>
<th>DIAMETER</th>
<th>GRIP CIRCUMFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>15-6</td>
<td>2.75-3.125</td>
</tr>
<tr>
<td>AX</td>
<td>14.5-15.5</td>
<td>3.25-3.5</td>
</tr>
<tr>
<td>AXX</td>
<td>14.5-15.5</td>
<td>3.625-3.875</td>
</tr>
<tr>
<td>B</td>
<td>16.5-17.5</td>
<td>2.75-3.125</td>
</tr>
<tr>
<td>BX</td>
<td>16-17</td>
<td>3.5</td>
</tr>
<tr>
<td>C</td>
<td>14.5-15.5</td>
<td>3.875-4.5</td>
</tr>
</tbody>
</table>

As car manufactures have begun to show, the steering wheel is a place for so much more to occur then just controlling the direction of the vehicle. Ergonomic research on human interaction with the steering wheel has shown that devices and control switches can be safely
added to the steering wheel interface without interfering the driver’s control of the vehicle (Gkikas, 2011).

Another feature that varies in automobiles is the steering column. There are several different types of steering columns. There are telescoping steering wheels, adjustable steering wheels, and swing-away steering wheels. The main reason for these variations of steering wheel design is to increase the ease and comfort of the driver. Tilt steering wheels allow the driver to tilt the wheel at a comfortable angle in which they would like to drive the car. Telescoping steering wheels allow a range of motion to adjust the height of the wheel. Ford motor company introduced one revolutionary type of steering wheel in 1961. First installed on the 1961 Ford Thunderbird, the swing away steering wheel had the feature of being able to move nine inches to the right once the car was in park. This greatly increased the ease of entrance to and exit from the car.

Throughout the history of automobiles, the shape and size of the steering column has changed greatly. This can be seen in the images in APPENDIX D. In the 1970 Corvette as well as in the 1967 Ford Mustang, the steering column is a long cylindrical column protruding from the lower portion of the dashboard. This columnar style protrusion was popular in both cars and trucks. It is also found in the 1979 Ford F150 Truck. As time pressed on, and different styles of steering columns were developed, such as the tilt column, there was a change in the physical presentation. The area of protrusion from the dashboard has moved up to the upper portion of the dashboard. Even though the mechanical aspects of the tilt column steering wheel have not drastically changed, the shape of the column covering has.

One of the most significant aspects of a standard transmission automobile is the shift lever and shift knob. This is the mechanical device that the driver uses to select the drive gear of
the transmission. The only thing that has stayed consistent with this device is its function. The shape style and placement varies greatly between cars and trucks. One of the main differences is the length of the shift lever. The design of early trucks mainly consisted of bench seats and open floor space. This led to the long shift levers as shown in the 1979 Ford F150. Cars, which sit lower to the ground, often have their transmission protruding into the driver’s compartment. This led to cars having two distinct foot wells as well as a center console. Because the shift lever would protrude from the center console it did not need to be as long as the lever from the floor of trucks. This can be seen in most of the pictures of the cars, especially the 1967 Ford Mustang. As cars evolved, and car manufacturers tried to fit more components and controls into the driver’s compartment, the average shift lever has drastically decreased. As shown in the pictures of the 2013 Porsche 911 and the Nissan 350Z, the shift lever only protrudes a few inches out of the center console.

The evolution of automobiles has come a long way since the early 1900’s. Automobiles are constantly being designed to be bigger, faster, and stronger. In this evolution, the driver’s interface of a standard transmission vehicle has gone through great aesthetic changes. However, every standard transmission automobile has had and will have a steering wheel, a steering column, and a means of shifting, which will serve as valuable references for our design.

CHAPTER 3. ZERO-LEG INPUT DRIVING DEVICE

3. Introduction to Our Engineering Design Process

As Professor Robert Norton states in his Machine Design textbook (Norton, 2010), “The process of design is essentially an exercise in applied creativity.” This process which contains several defined steps, takes engineers through the process of problem formulation and background research, into the development and iteration of design concepts, and finally to the
realization of a solution. The Ten Step process is outlined below in Table 3-1. The previous two chapters have shown the completion of the first three steps. Chapter 3, outlines the remaining seven and in detail describe the creation of the zero-leg input driving device.

Table 3-1: Outline of Norton’s 10 step design process

<table>
<thead>
<tr>
<th>The Design Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Identification of Need</td>
</tr>
<tr>
<td>2 Background Research</td>
</tr>
<tr>
<td>3 Goal Statement</td>
</tr>
<tr>
<td>4 Task Specifications</td>
</tr>
<tr>
<td>5 Synthesis</td>
</tr>
<tr>
<td>6 Analysis</td>
</tr>
<tr>
<td>7 Selection</td>
</tr>
<tr>
<td>8 Detailed Design</td>
</tr>
<tr>
<td>9 Prototyping and Testing</td>
</tr>
<tr>
<td>10 Production</td>
</tr>
</tbody>
</table>

The zero-leg input driving device is a system that must create a user interface and effectively relay inputs to the car. Maintaining control of a manual automobile will require coordination between the driver and all the necessary driving inputs including the gas pedal, brake pedal, clutch pedal, steering wheel, and gear selector. This is a complex task, but through ideation, analysis, and iteration, a successful solution has been developed

3.1 Performance Specifications

A great guiding factor in the design process is the completion of Step 4 of Norton’s Design Process, which is the creation of task, or performance specifications. These specifications are critical for bounding the problem and limiting the scope of design. They designate what our system should be able to do and determine the success of the design.
Therefore they must be measurable and quantifiable. These task specifications have been divided into four sections for organizational purposes.

**Capabilities in Automobile**

1. Device must allow driver to drive in vehicle safely in forward and reverse
2. Device must allow driver to operate throttle, brake, and clutch independently
3. Device must allow driver to engage any combination of all three input pedals at one time
4. Device must allow driver to keep one hand on the wheel during all operations
5. At least one brake input must always be located in a consistent, easy to reach location
6. Pedals must be able to be actuated with ignition off
7. Response time between controls and pedal actuation cannot exceed .01 seconds
8. Pedal actuation system must allow pedals to be fully depressed in .25 time seconds
9. Pedal actuation system must allow pedals to be fully relieved in .25 seconds
10. Device must have an emergency pedal relief

**Implementation**

11. Device must be minimally invasive and not cause any permanent damage to vehicle
12. Must be able to be implemented in 75% of standard automobiles in use
13. System much be produced with components totaling under $2000
14. Interface must be able to be installed in a vehicle and calibrated in under 2 hours

**Manufacturing**

15. All components must be able to be produced on a macro scale

**Human Interface**
16. Controls must be intuitive for any licensed driver with experience operating a standard automobile

17. Device must be ergonomically designed for safe and efficient interaction with the user

3.2 Early Obstacles

As the team began to brainstorm our initial design concepts, there were several obstacles to design around. The first is the fact that cars, especially cars designed in the past 5 years, have been designed to fit as many components in the smallest space possible. This space crunch in the cockpits of newer cars severely limits the space that our device can take up on or around the steering wheel. While older vehicles often have long steering column protrusions, a goal of our design is to be a universal as possible, which would create an issue when designing for a mounting position behind the steering wheel of the vehicle.

Even though all standard automobiles have three input pedals in the foot-well these pedals can have a variety of configurations. Almost every aspect of the pedals is variable, including pedal shape, lever shape, pedal size, pedal spacing, input force required, travel path, and full depression distance. While pedal shape and size are variables that can be easily be designed for, significant challenges exist as the hinge position and travel path of the pedals can vary. Any solution developed incorporating the direct controls of the pedals will have to be able to adapt the various methods of depression similarly to how the human leg can extend and swing to follow the pedal while still maintaining force to continue depression. Another important factor of any solution is the magnitude of the forces and power that must be exerted on the pedals to provide full depression. This varies greatly from car to car as well as from pedal to pedal. A full evaluation of these forces was calculated and is presented later in the chapter. Also included
in this analysis is the speed at which these pedals must be actuated because driving a vehicle, especially at high speeds, requires quick pedal actuations. Swift and efficient pedal actuation mechanisms, on the magnitude of depression of the pedals in fractions of a second, must be present if the design is expected to effectively control an automobile.

Additionally, as with any project or product, there are monetary constraints which must be taken into consideration. For the zero-leg input driving device there are two levels of constraint. The first is price of the designed end product because there are other devices on the market with similar capabilities. It is important to be in the same price range as, or hopefully lower than, these other options in order to be competitive with them. A new product extremely above the current market price will not grab any attention. The second constraint is the allocated budget for construction of a prototype. For this project the team was allocated $480 of department funding. This quantity is not able to cover the purchase size and quality of the final design which has an upper constraint of $2000. Therefore these funds were appropriated for the production of a proof of concept scale model.

3.3 Mechanics of Driving an Automobile

Driving an automobile is a privilege for millions of Americans. Some people will always remember the day they got their driver’s license or took a drive in their first car. However, driving an automobile is not always easy and can be dangerous and complicated, especially at high speeds. Driving, especially driving a standard transmission vehicle, requires coordination of several inputs. When a person drives a standard transmission automobile, they have four primary means for providing input to the car, two hands and two feet. These 4 input means are used to control at least 6 car inputs:

1. Gas – Right Foot
2. Brake – Right Foot
3. Clutch – Left Foot
4. Shift – Right Hand
5. Steer – Both hands when not shifting, Left hand while shifting
6. Possibly Turn Signal, Windshield Wipers, Radio…

When a user attempts to drive a car with zero-leg input, they must still have full control of the vehicle, and therefore still control all 6 inputs. This means all 6 inputs must still be independently controlled, which means that 6 inputs must be controlled by two hands. This coordination is summarized in the list below.

1. Gas – Right Foot (Hands)
2. Brake – Right Foot (Hands)
3. Clutch – Left Foot (Hands)
4. Shift – Right Hand
5. Steer - Both hands at least when not shifting
6. Turn Signals, Windshield Wipers

This conversion is what the zero-leg input driving device must enable the driver to perform. This can be done by creating coordinated hand controls that allow multiple inputs to be actuated at once using different parts of the hands. For example, this device must enable the driver to independently use the thumb from the rest of the fingers or the palm from the rest of the fingers.

3.4 Experimental and Observational Testing

As a way to continue to develop a baseline for the maneuvers that the zero-leg input driving device must be able to control the car through, as well as the experience that it must create, the group performs a series of observatory tests with drivers of varying experience levels and car types. The tests include taking various measurements of the position and layout of the components within the cockpit, noting driver preferences for body and hand positions, and
recording driver actions as they controlled their automobile through a series of common driving maneuvers.

3.4.1 Photographs and Measurements

The test began with several interior photographs of the vehicle. These photographs are valuable for determining the overall layout of the automobile cockpit as well as the dimensions of the components. The list below outlines the still photographs that were taken of vehicle.

1. Steering Wheel
2. Gear Selector
3. Center Console
4. Pedals

Examples of interior photographs that were captured during these tests are shown below. All internal photographs show a ruler for a size reference. These dimensions are crucial when designing the Assistive Driving Device. Figure 3-2 below shows the comparison of the steering wheel of a 2010 MazdaSpeed 3 and a 1974 Chevrolet Corvette. The steering wheel, which has been proven as a great candidate for the location for the placement of additional controls, can have many shapes and sizes. The exterior diameter varies greatly as well as the circumference of the ring. Additionally, the insides of the wheel can be very different.
In addition to the variation in steering wheels, the shift lever, which is another major component of the driving interface, varies greatly in shape and size. The figure below shows the shift lever of the MazdaSpeed 3 and the Vintage Corvette. Shift knobs are often various shapes, designs and sizes. Additionally, the shape, size, and neutral position of the shift lever can be a variety of shapes ranging from small to thick shafts and in the case of the Vintage Corvette, rectangular with rounded corners.
Other crucial views and dimensions that were recorded include the foot well and pedal layout. These dimensions are crucial for determining the clearances of any devices which will be mounted in the foot well as well as determining the location of or types of physical connections which will be made with the pedals. Figure 3-4 below shows the pedal configuration and dimensions of a 1974 Chevrolet Corvette.
The second part of the testing included taking photographs of the exterior of the vehicle as well as overall views of the cockpit. An important aspect of this data collection is the preferences of the driver. Each driver was photographed in their comfortable driving position. Clearances between the driver’s legs and both the steering wheel and pedals, as well as the reach to the shift lever and distances were also noted. An outline of the exterior photographs is shown below.

1. Door open view of driver’s seat
2. View driver in seat (posture recorded with both hands on steering wheel as well as one on the gear selector and one on steering wheel)
3. Overall views of car (license plate and identifying information will be censored)
3.4.2 Driving Maneuvers

The final portion of the test involved observing the driver control their vehicle through a series of maneuvers that they could find themselves performing in normal daily driving, as well as during racing or recreational driving situations. The list of the maneuvers that the subjects performed is below.

1. Driving around the specified route as shown in Figure 3-6
2. Start from stopped, accelerate through all gears to 4th gear, stay in 4th for about 3 secs and decelerate to a stop
3. Start from stopped, accelerate through all gears to 4th gear, stay in 4th for about 3 secs and decelerate through all gears to a stop
4. Start on an incline
5. Perform a 3-point or k-turn
6. Any specialty maneuvers
For this portion of the experiment the drivers were first brought through the course on a practice run so they could learn the route. They were then recorded performing the six maneuvers listed above. For the data collection process, two video cameras were utilized so the team could get clear views of all car inputs. One camera was mounted beneath the steering wheel to record the motions of the driver’s feet and the pedal inputs, and the other was held by the passenger to record the hand and body motions as the driver turned the steering wheel and changed gears. The two videos were then edited so that both camera views could be seen on the same screen. Footage from two drivers is shown below in Figure 3-7 and Figure 3-8.
This video footage provided insight into the mannerisms of different drivers and how they coordinate the different pedals to perform operations. The pedal combinations and input controls were recorded and a time lapse graph of the maneuvers was produced, recording which pedals were being used, for how long, and the percentage of depression. The time lapse was then broken up into the sections of the course that the maneuver occurred on. Figure 3-9 shows the
time lapse from the first two legs of the first maneuver. Refer to Figure 3-6 for the map and segment definition.

The review of the video footage and the time lapse graphs was very helpful to the team in defining what the zero-leg input driving device must be capable of accomplishing. These tests reiterated the facts that all three pedals need to be able to be actuated independently. At certain times the drivers would use separate portions of their foot, the toes and the heel, to depress both the gas and the brake at the same time. This footage also revealed to the team how swiftly and frequently the pedals must be depressed and released.

While performing these tests, safety was the first priority. The group was sure to follow the safety precautions outlined below which were agreed upon by both the team and the test drivers.
1. Seatbelts must we worn

2. All equipment must be securely fastened

3. Setup crew must ensure equipment doesn’t interfere with drivers normal motions

4. Car being tested must be inspected, registered and insured

5. The driver of the vehicle must be a licensed legal driver in the state the test is occurring

6. All tests must be executed on a predetermined route that does not include main roads

7. The test vehicle must not exceed posted speed limit of road

8. The driver of the vehicle may stop that test at any time or refuse to perform any actions asked by the group

3.5 Outputs of Zero-Leg Input Driving Device

The outputs of the final design are the devices that relay the input commands from the user to the car itself. In order to comply with the project objectives, the output devices must further the goal of providing universal functionality for all vehicles. They must also provide fast and safe communication of the user inputs to the car. Finally, they must be precise so that they can respond to subtle changes from the user inputs.

3.5.1 Vehicle Control Mechanisms

The nature of the interface between the device and the car is important to consider with respect to the ease of installation and the method of actuation. One possible method would be to approach the gas, brake, and clutch individually and tap into the internal mechanisms of the vehicle. A small actuator that directly opens and closes the throttle body could control the amount of air flowing to the engine.
This actuator could either receive a signal through wireless transmission or by means of a wire that is connected directly to the hand interface. Tapping into the existing hydraulics system of the vehicle could then control the brakes and clutch. In nearly all-modern cars there is a vacuum booster that utilizes a vacuum created by the engine to assist the user in pressing down the brake pedal. Theoretically, this system could be modified to allow an additional input. A hydraulic master cylinder connected to the clutch pedal actuates a slave cylinder at the clutch pressure plate. This hydraulic system could be taken advantage of by using different cylinder geometries.
The other method of interface between the device and the car would be to actuate the pedals directly, as if to replace the driver’s feet, through the use of mechanical, electrical, hydraulic, or pneumatic devices.

Using different actuation methods for the gas, brake and clutch separately could potentially allow for the vehicle to be shared with individuals who have the use of their legs, however this would also add complexity to the device and its installation. Also, if the devices were to malfunction, there would very limited direct access to them. So the better option is to drive the pedals directly in order to increase the simplicity, ease of installation, and overall safety of the device. Furthermore, the pedals of the car were specifically designed to be a comfortable and efficient method of controlling the car. It is important to keep in mind that if using this method, the mechanisms used to actuate the pedals will need to be able to sustain constant load so that the pedals can be held in a constant position.
3.5.2 Pedal Depression Analysis

In order to aid in the selection of a pedal actuating device we determine the forces and speeds that would be necessary to depress the pedals in a similar fashion to that of a human leg. By placing a bathroom scale on the gas, brake, and clutch pedals in turn and reading off the force corresponding to a pedal displacement as measured by a ruler we can create the following plots. This data was gathered using a standard transmission 2000 Volkswagen Passat.

Figure 3-11: Force required to depress throttle as a function of distance travelled

\[ y = 2.8617e^{33.069x} \]

\[ R^2 = 0.9776 \]
Figure 3-12: Force required to depress the brake pedal as a function of distance travelled

![Graph showing the relationship between force (in Newtons) and pedal depression (in meters) for the brake pedal. The equation is given as $y = 31271x^2 + 3112.7x - 3.0977$ with $R^2 = 0.989$.]

Figure 3-13: Force required to depress the clutch pedal as a function of distance travelled

![Graph showing the relationship between force (in Newtons) and pedal depression (in meters) for the clutch pedal. The equation is given as $y = -52290x^2 + 6223.3x + 2.534$ with $R^2 = 0.9799$.]
It is then helpful to translate this data into a value that would depict power requirements necessary to depress each pedal in a specific time because motors and other similar devices are rated by power. By recording and analyzing videos of test subjects quickly depressing each pedal in order to mimic an emergency situation we were able to select a time of 0.2 seconds for maximum pedal depression speed. The integral of the equations from Figure 3-12, Figure 3-13, and Figure 3-14. was taken over the length of each pedal depression to find the total necessary work, and this value was then divided by 0.2 seconds to find the power in Watts. The results of this analysis are shown in Table 3-1.

<table>
<thead>
<tr>
<th>PEDAL</th>
<th>WORK REQUIRED [Joules]</th>
<th>POWER REQUIREMENTS [Watts]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>0.62</td>
<td>3.1</td>
</tr>
<tr>
<td>Brake</td>
<td>8.75</td>
<td>43.7</td>
</tr>
<tr>
<td>Clutch</td>
<td>14.15</td>
<td>70.8</td>
</tr>
</tbody>
</table>

It is also important to show the necessary force and speed that would be required to actuate each pedal if the point of action were to be moved towards the pivot on the lever arm. This is because the various possible methods of actuation provide different combinations of force and speed. Table 3-2 relates the necessary force and speed to the displacement along the lever arm.
Table 3-3: Relating speed and force requirements to position on pedal lever arm

<table>
<thead>
<tr>
<th>Position (cm)</th>
<th>Necessary Speed (cm/s)</th>
<th>Max Force: Gas Pedal (Newtons)</th>
<th>Max Force: Brake Pedal (Newtons)</th>
<th>Max Force: Clutch Pedal (Newtons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>3.2</td>
<td>222</td>
<td>3269</td>
<td>1868</td>
</tr>
<tr>
<td>5.1</td>
<td>6.4</td>
<td>111</td>
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<td>7.6</td>
<td>9.5</td>
<td>74</td>
<td>1090</td>
<td>623</td>
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<td>10.2</td>
<td>12.7</td>
<td>56</td>
<td>817</td>
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<td>15.2</td>
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<td>1</td>
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<td>10</td>
<td>12.5</td>
<td>5</td>
<td>74</td>
<td>42</td>
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</tbody>
</table>

3.5.3 Methods for Pedal Control

Possible approaches to actuate the pedals of the car include the purely mechanical means (pulleys, cables, and levers), servos, linear servos, hydraulics, and pneumatics. The use of only pulleys, cables, levers, etc. was quickly dismissed because this would only transform and transmit the input power to the pedals. The amount of power available from the hands and fingers of the user would be less than sufficient to accurately and efficiently depress the pedals.
Using servos would be a cheap method of providing the additional power necessary to depress the pedals. One of the notable drawbacks of using servos would be that their implementation would be considerably more complex than other methods. This is primarily because the servos provide a rotational motion and pedal depression is mostly linear. Therefore, a linkage would be required to transmit the power, the power transmission would be non-linear throughout the stroke, and the feedback from the servo would not be proportional to the displacement of the pedal.

A hydraulic system would also provide a large amount of force at a slow speed. These types of systems require much more equipment than electromechanical systems because they require pumps to move the fluid. In addition to this they are more difficult to control, and would require external monitoring of the pedal displacement. Pneumatic systems are better in terms of speed; however, they share many of the same drawbacks.
Linear servos would solve many of the issues with traditional servos. They would be easy to use, simple to install, and they could directly drive the pedal in a consistent and linear fashion. The disadvantages of linear servos are that they are expensive and slow. However, they often have a high force output, so attaching them closer to the pivot point on the pedal could compensate for their speed. We find that using linear servos to directly actuate the pedals would provide the best option for our design.

The linear actuators need to be mounted on a structure that would not only be able to provide the proper support for the servos, but would also be flexible in allowing the positions of the servos to be modified for different cars. This structure would also have to be easily installed into any car. To this end we looked into flat-bar steel and Telespar. Both types of materials provide all of the necessary requirements, and only require the addition of specific mounting brackets for the actuators. Additionally, they would only require some drilling into the foot-well for the bolts and they could even rely on the existing mounting positions used by the driver’s seat.
3.6 Human Interaction with Zero-Leg Input Driving Device

3.6.1 Defining Grip Force

Keeping in mind the high forces necessary to actuate pedals by leg, we realized the need for a lighter hand force and investigated the output methods above. Deciding on electro-mechanical actuation because of its simplicity and ease of installation, we moved onwards and began acknowledging the requirements of the hand inputs. First, we set a range of required forces to actuate our inputs. Two grip types were investigated for this: the crush grip and the pinch grip. The crush grip would be the grip one uses when grabbing a barbell or squeezing a sponge. The pinch grip is the grip one would use to grab a book. These two very common grips range in maximum force depending on gender and grip type. By seeing these values and through experimentation we had a general idea of sustainable and comfortable hand input forces with which we could actuate our controls.
If a motion were to include a sustained crush grip, no more than ten pounds (an order of magnitude less than the average) should be required. For a pinch grip, no more than two pounds should be needed (an order of magnitude less than the average of thumb, index and middle finger pinch grip).

3.6.2 How Inputs are Used

As described above, our in-car experimentation gave us information about how and when driving inputs occur. Pedals are actuated using many techniques, from slowly to very quickly with sustained or varying displacements in between. Changing gear requires clutch and throttle, cruising requires throttle, braking requires brake and occasionally clutch, and heel-toe-ing requires all three.
The clutch and—in specialized situations—the brake require use of the left leg, while the throttle and traditional use of the brake require the right leg. The hands have the exclusive responsibilities of steering, operating the gear selector, and manipulating other devices on the vehicle console. Hands are placed either both on the steering wheel, or separated between controlling the wheel and the gear selector or other devices.

With these activities in mind, we designed our hand-control interface. Drawing initial inspiration from existing hand controls, we investigated what the interface would look like if we were to combine gas/brake controls on the market with the clutch controls available, thus relinquishing all leg use and giving pedal responsibility solely to the hands.
With the existing systems in play, obvious shortcomings were noted: to operate the addition of the clutch, the operator—in every different combination of existing examples—had to give up control of another input. In the example shown in Figure 3-19, the driver must let go of the gas/brake input to shift. In other examples that allow control of both gas/brake and clutch, steering wheel control is compromised. Abandoning the brake or steering wheel during operation is unacceptable, and avoiding this was one of our primary design goals.

3.6.3 Organizing the Interface

To fulfill this requirement, we took into account both foot and hand motions of conventional driving operation and specifically the synchronized inputs. Any time use of the shift lever is necessary, the clutch is also engaged (with the exception of clutchless shifting, in which case the clutch can simply be omitted from the movement). All three pedals can be used in any combination, including all three in tandem. It was clear then that the pedal operations must be controlled by two hands, as the dexterity needed to operate all three with one hand is uncommon. Placing the clutch operation on the gear selector proved to be our best option.
Location of the throttle was a bit more difficult. Conventional hand-throttle mechanisms are lever-actuated and located next to the steering wheel. We knew that with our clutch mechanism in place the throttle could not be located anywhere that would require the operator to let go of the wheel at any time.

A wheel-mounted throttle would be necessary, but the movement of the steering wheel meant that any hard-mounted lever would change location as the wheel spun, which would make it difficult to locate during cornering. A spinner-knob mounted control system had the possibility of spinning if the operator slipped. A design similar to The Kempf Digital Accelerator Ring and Guidosimplex Accelerator Ring was the design that allowed these concerns to be addressed.
A ring operated by the thumbs mounted concentrically with the steering wheel allows one-handed operation while still holding the steering wheel, even while shifting. During a shift, the operator could release the wheel with the inside hand, release the throttle and engage the clutch, shift gears, re-engage the clutch and re-apply the throttle, all while holding the steering wheel. This location also allows for ease of starting carbureted vehicles that require throttle metering or old diesels that require throttle depression to start. The location of this ring also allows the operator to steer the vehicle freely without worry of losing the position of the throttle.

Finally, the third input needed placement. The brake input in conventional hand-control systems is a lever mounted next to the steering wheel or center console. This brings about similar issues as the throttle position, but considerably more dangerous. To panic stop, the operator has to let go of the steering wheel with both hands in order to operate the clutch and the brake. With no control over vehicle heading, the car is at the mercy of brake pull and surface conditions. We drafted a design with the brake mounted to the shift lever, which would allow a hand to be on the wheel while braking.
Figure 3-21: A design iteration using a concentric throttle ring with gear-selector mounted clutch and brake controls

To swerve defensively with two hands during a panic stop, the operator would have to let go of the clutch and brake, which adds time and detracts from control. With the brake mounted away from the wheel, it also adds time for the operator in an emergency to locate it. Our brake mechanism needed to also be mounted to the steering wheel and—like the throttle—cannot move position as the wheel turns.

The push-pull mechanisms of conventional hand controls led us to the design of a concentric ring that can be pushed for the throttle and pulled for the brake. The efficient design had a major flaw, however, in that it made actuation of both gas and brake impossible in situations like left-foot braking or heel-toeing. Since we sought full and independent control of all the inputs, this design was abandoned for a separate control system.
Another concentric ring was our design choice, as it allows the operator to always know where the brake is located as well as apply clutch and brake while maintaining control of the steering wheel. Locating this ring on the driver-facing side of the steering wheel concentric to the throttle would mean the operator would have to quickly choose between the two rings if an emergency were to occur to find the right input. With one smaller ring inside another, larger ring, independent and non-interfering control of each would be difficult. The risk of actuating both at the same time seemed very high.

Our design, with this in mind, was to place this brake ring on the dash-side of the steering wheel, allowing the operator to squeeze it towards the wheel with the fingers while driving. From this position, the driver can fully apply both brake and clutch while stopping or at a standstill in-gear without letting go of the steering wheel. This design also allows the operator to engage the clutch and brake and still steer the car, a necessity in defensive and emergency maneuvers.
3.6.4 Complete Vehicle Control

With the brake and throttle as concentric rings mounted on opposite sides of the steering wheel and the clutch mechanism on the gear selector, our final design allows control over every pedal combination without sacrificing steering wheel control. If the operator performs a hill-start, the brake can be applied to avoid backward rolling while the clutch is released and the throttle is opened, allowing for an easier hill-start than most cars operated traditionally without
hand controls. Heel-toeing can be conducted even while controlling the vehicle’s heading, as the rear ring can be squeezed to brake, the operator can grab the gear selector and engage the clutch and begin the gear change, the throttle can be blipped and the clutch released while removing only one hand from the steering wheel.

CHAPTER 4. CONCLUSIONS

The final goal of this project is to design a mechanism that will be able to afford paraplegics and double leg amputees the ability to fully control a manual transmission vehicle. In order to accomplish this goal we break the process up into three important steps. The first is to evaluate the current state of driving assistance devices and determine the market need for our project. Then, we want to design a first generation prototype of a product that would be minimally invasive, safe to use, and that would grant the user full control of the vehicle. Finally, we find it necessary to construct and test a scaled down proof of concept device that would verify our design’s plausibility.

This project is inspired by those with some relation to, or interest in, manual transmission cars, who are left without the use of their legs. This includes individuals who own classic or one-of-a-kind cars that they want to drive without excessively modifying the vehicle. There are also some who simply love the thrill of the drive or enjoy racing and need to be allowed full control of their vehicle at all times in order to be competitive in racing circuits. A prime example of this is racing icon Alex Zanardi who lost full use of his legs in a devastating racing accident and felt that he could never be as competitive again.

It is estimated that there are between 250,000 and 400,000 individuals that are currently living with spinal cord injuries in the United States. Moreover, there are 3,260,000 persons who rely on the assistive aid of a wheelchair. The lifetime costs to someone that becomes paraplegic
at the age of 25 is over $2,000,000. We hope that our device will help to reduce this number by a small amount.

There are devices on the market today that partially fulfill the goals we set for our project. Some devices, like the Kempf Digital Accelerator Ring, the Guidosimplex Over Ring Accelerator, and the Veigel Classic Hand Control allow paraplegics to drive automatic transmission devices. Other products, like the ‘Duck Clutch’ and the Alfred Bekker Manual Hand Clutch control the clutch pedal only, requiring that the driver use one leg to operate the gas and brake. Four percent of all new cars sold have a manual transmission, a statistic that jumped by three percent in the first quarter of 2012 alone. We believe that these facts and statistics create a definite and growing market for our product.

Before thinking about the design for the product, we find it necessary to gather some data on manual transmission cars and how they are driven. In order to accomplish this we set up a test track and had test subjects drive through the course in different vehicles and using different styles. Throughout the test we record the movements made by the drivers and the inputs that they engage under different circumstances, this helps us to understand what kinds of maneuvers the new interface would need to be able to handle. In addition we record the amount of force necessary to depress each of the pedals in a sample manual transmission car and use this data to then find the necessary work and power that goes into pedal depression. This information assists us in deciding on the proper method for pedal actuation.

For the final design of the device we used an electromechanical system that consisted of user inputs that could be read by a microcontroller through the use of potentiometers. The microcontroller would then send the appropriate signal to the outputs of the system that control the car. It is important that the outputs be able to be universally compatible with manual
transmission cars. They must also efficiently relay the signals from the microcontroller to the car so that the user does not feel a lag in the system. We decided that linear servos would be the most appropriate actuation method because they provide the linear action that approximately matches the movement of the pedals. They are also easy to install and are able to communicate with the microcontroller. Finally, many linear servos are non-back-drivable which helps to maintain force on the pedals without putting excess strain on the motor.

The user interface consisted of the gas, brake, and clutch inputs. From earlier tests and research we decide that these inputs need to be readily accessible, provide haptic feedback, and be able to be operated independently. Also, for safety and convenience they need to be easy to manipulate over long periods of time so that the user won’t tire, and they must not interfere with the airbags or cruise control. The final design of the gas and brake inputs is a set of concentric rings. The gas ring is positioned in front of the wheel and is slightly smaller than the steering wheel itself, it is pushed in by the thumb to increase the depression of the gas pedal. The brake ring is positioned behind the wheel and is slightly larger than the steering wheel. The user pulls this ring towards them to actuate the brake. The advantages of this set up is that it puts the gas and brake in a consistent, easy to reach location, both can be actuated at the same time, and the user does not have to remove their hands from the steering wheel. The clutch hand control is designed as a lever on the stick lever of the car. This is because the driver of the car often has their hand on the shift lever while actuating the clutch. In addition it is a convenient and easy to reach location.

There are a few areas in which the project can be expanded upon in the future. A safety release of the pedal actuators would be necessary in case the system starts to improperly relay inputs to the pedals or perhaps ceases to work all together. In addition to this, a mechanical
brake input would need to be designed so that if the vehicle is otherwise out of the control of the user, they have a back-up method of stopping the car. The code of the microcontroller can also be rewritten to more intuitively convey the user inputs to the pedals. If necessary, there could be an option to switch between ‘casual’ driving and ‘aggressive’ driving with different control styles to match. This system and any future improvements made would need to be tested in a variety of manual transmission vehicles and evaluated against the performance of traditionally operated vehicles. Finally, before the product could be marketed, it would need to be given a more efficient and fashionable structure.
REFERENCES


http://www.wells-engberg.com
## APPENDIX A. DRAWINGS

<table>
<thead>
<tr>
<th>Drawing ##</th>
<th>Description</th>
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<tbody>
<tr>
<td>HM-001</td>
<td>Overview of Throttle and Brake Controls</td>
</tr>
<tr>
<td>HM-002</td>
<td>Overview of Clutch Control</td>
</tr>
<tr>
<td>HM-003</td>
<td>Overview of Actuation Brackets</td>
</tr>
<tr>
<td>HM-004</td>
<td>Custom Clutch Control Lever</td>
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<tr>
<td>HM-005</td>
<td>Bracket for Clutch Control Lever</td>
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<td>HM-006</td>
<td>Bracket Back Plate _Extended</td>
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<td>HM-007</td>
<td>Bracket Back Plate _Flat</td>
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<td>Bracket Back Plate _Recessed</td>
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<tr>
<td>HM-009</td>
<td>Potentiometer Protector Plate</td>
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<tr>
<td>HM-010</td>
<td>Potentiometer Housing</td>
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<tr>
<td>HM-011</td>
<td>Potentiometer Back Plate</td>
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<tr>
<td>HM-012</td>
<td>Aluminum Tubing Lever Shaft</td>
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<tr>
<td>HM-013</td>
<td>Potentiometer - Shaft Connector</td>
</tr>
<tr>
<td>HM-014</td>
<td>Linear Servo Clevis Fixture</td>
</tr>
<tr>
<td>HM-015</td>
<td>Vertical Square Tubing</td>
</tr>
<tr>
<td>HM-016</td>
<td>Top Cross Square Tubing</td>
</tr>
<tr>
<td>HM-017</td>
<td>Support Rods</td>
</tr>
<tr>
<td>HM-018</td>
<td>Angle Support Leg _Left</td>
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<tr>
<td>HM-019</td>
<td>Angle Support Leg _Right</td>
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<td>Potentiometer Gearbox</td>
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<td>HM-023</td>
<td>Potentiometer Gearbox Front Support</td>
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<td>HM-024</td>
<td>Potentiometer Gearbox Rear Support _Left</td>
</tr>
<tr>
<td>HM-025</td>
<td>Potentiometer Gearbox Rear Support _Right</td>
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Figure A-1: Itemized list of Team Handi-Man design drawings
### Zero Leg Input Driving Device Bill of Materials

#### Clutch Control Lever

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#### Pedal Actuation Bracket

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#### Gas and Brake Control Ring Assembly

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Figure A-2: Zero-Leg Input Driving Device bill of materials
Figure A-3: Drawing HM-001 Overview of Throttle and Brake Controls
Figure A-4: Drawing HM-002 Overview of Clutch Controls
Figure A-5: Drawing HM-003 Overview of Actuation Brackets
Figure A-6: Drawing HM-004 Custom Clutch Control Lever
Figure A-10: Drawing HM-008 Bracket Back Plate_Recessed
Figure A-12: Drawing HM-010 Potentiometer Housing
Figure A-13: Drawing HM-011 Potentiometer Back Plate
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Figure A-16: Drawing HM-014 Linear Servo Clevis Fixture
Figure A-17: Drawing HM-015 Vertical Square Tubing
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Figure A-21: Drawing HM-019 Angle Support Right
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Figure A-25: Drawing HM-023 Potentiometer Gearbox Front Support
Figure A-26: Drawing HM-024 Potentiometer Gearbox Rear Support_Left
Figure A-27: Drawing HM-025 Potentiometer Gearbox Rear Support_Right
APPENDIX B. DESIGN ITERATION SKETCHES

Figure B-1: First Stage Design Iteration Sketches
Figure B-2: Second Stage Design Iteration Sketches
Figure B-3: Final Design Concept Sketch
APPENDIX C. MICRO-CONTROLLER CODE

The following code was written by the group as the logic programmed into the microcontroller which will enable the independent control of 3 servo motors with three potentiometers.

```cpp
// Team Handi-Man Arduino Code for Controlling Three Servos Independently with Three Potentiometers
#include <Servo.h>  // Enables Servo Library
Servo GasServo;   // Create Servo Object to Control the Gas Servo
Servo BrakeServo; // Create Servo Object to Control the Brake Servo
Servo ClutchServo; // Create Servo Object to Control the Clutch Servo
int GasPotPin = 0;   // Analog Pin used to Connect the Gas Control Potentiometer
int BrakePotPin = 1; // Analog Pin used to Connect the Brake Control Potentiometer
int ClutchPotPin = 2; // Analog Pin used to Connect the Clutch Control Potentiometer
int GasVal;      // Variable to Read the Value from the Gas analog pin and Send Gas Position
int BrakeVal;     // Variable to Read the Value from the Brake analog pin and Send Brake Position
int ClutchVal;  // Variable to Read the Value from the Clutch analog pin and Send Clutch Position

void setup()
{
    GasServo.attach(9);    // Attaches the Gas Control Servo on pin 9 to the Gas Servo Object
    BrakeServo.attach(10);  // Attaches the Brake Control Servo on pin 9 to the Brake Servo Object
    ClutchServo.attach(11); // Attaches the Clutch Control Servo on pin 9 to the Clutch Servo Object
    Serial.begin(9600);
}

void loop()  // Standard Arduino Operation Loop
{
    GasVal = analogRead(GasPotPin);                   // Reading the Value of the Gas Control Potentiometer
    GasVal = map(GasVal, 30, 220, 1, 45);           // Scaling the Value of the Control Pot to Servo Position
    if(GasVal>45){
        GasVal=46;
    }
    if(GasVal<1){
        GasVal=1;
    }

    BrakeVal = analogRead(BrakePotPin);               // Reading the Value of the Brake Control Potentiometer
    BrakeVal = map(BrakeVal, 20, 150, 1, 45);       // Scaling the Value of the Control Pot to Servo Position
    if(BrakeVal>45){
        BrakeVal=46;
    }
    if(BrakeVal<1){
        BrakeVal=1;
    }

    ClutchVal = analogRead(ClutchPotPin);           // Reading the Value of the Clutch Control Potentiometer
```
ClutchVal = map(ClutchVal, 0, 65, 1, 45); // Scaling the Value of the Control Pot to Servo Position
if(ClutchVal>45){
  ClutchVal=46;
}

GasServo.write(GasVal); // Sets the Gas Servo Position According to the Scaled Value
BrakeServo.write(BrakeVal); // Sets the BrakeServo Position According to the Scaled Value
ClutchServo.write(ClutchVal); // Sets the Clutch Servo Position According to the Scaled Value

Serial.print("GasVal ");
Serial.print(GasVal); // Utilizing the Serial Monitor to View the Real Time Servo Position Command
Serial.print(" BrakeVal "); // All Three Values on the Same Line with a Space Between Each
Serial.print(BrakeVal);
Serial.print(" ClutchVal ");
Serial.println(ClutchVal);

// Code to Test and Calibrate Servo Position
// Use Microseconds to Test Full Extension and Full Retraction
// Use Serial Monitor to Relate Servo Position to Microsecond Range

// Gas Servo Test Commands
// GasServo.write(45);
// GasServo.writeMicroseconds(2000);
// GasVal = GasServo.read();
// Serial.println(GasVal);

// Brake Servo Test Commands
// BrakeServo.write(141);
// BrakeServo.writeMicroseconds(2000);
// BrakeVal = BrakeServo.read();
// Serial.println(BrakeVal);

// Clutch Servo Test Commands
// ClutchServo.write(6);
// ClutchServo.writeMicroseconds(2000);
// ClutchVal = ClutchServo.read();
// Serial.println(ClutchVal);

delay(5); // Delay before Loop Repeats
}
APPENDIX D. COMPILATION OF CAR INTERIOR PHOTOGRAPHS

Figure D-1: 1967 Ford Mustang Shelby GT500 passenger view

Figure D-2: 1967 Ford Mustang Shelby GT500 driver's view
Figure D-3: 1969 Corvette cab cockpit

Figure D-4: 1970 Chevrolet Chevelle Super Sport SS 454 LS5 driver's view
Figure D-5: 1979 Ford F150 passenger view

Figure D-6: 1990 Chevrolet Corvette ZR-1 Coupe cockpit
Figure D-7: 1995 Ford F150 cockpit

Figure D-8: 2009 Chevrolet Corvette Convertible side view
Figure D-9: 2010 Chevrolet Corvette ZR1 driver's view

Figure D-10: 2013 Nissan 370z driver's view
Figure D-11: 2013 Porsche 911 Cabriolet side view
APPENDIX E. EXPERIMENTAL TESTING ROUTE AND RESULT ANALYSIS

Figure E-1: Map of driving maneuver test area in Plymouth, MA

Figure E-2: Pedal depression time lapse for first four course sections
Figure E-3: Pedal depression time lapse for last four course sections