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Go Baby Go Senior Design

Laura Pickering
pickerin19@up.edu

Ally Fox
foxa19@up.edu

Parker Elliott
elliottp19@up.edu

Jacob Wolwowicz
wolwowic19@up.edu

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Go Baby Go! – Assistive Technology

Capstone Final Design Report

Department of Mechanical Engineering

University of Portland

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Report Submitted by: Parker Elliott, Ally Fox, Laura Pickering, Jacob Wolwowicz

Abstract

Go Baby Go is a non-profit organization focused on bringing many different modes of movement to children with cognitive or movement inhibiting disabilities to help ensure that disabled children reach important development milestones. In the past they have used 6-Volt ride-on toy cars with simple stop/go switches on the steering wheels as an alternative to the gas pedal, to enable children to move and explore independently, an important development milestone. This solution does not work well for older children, as the 6-Volt cars are meant for ages 2-4, or the group of children whose disabilities limit them to head movement, as the cars have conventional steering wheels. The goal of this project is to develop a new system for these children that activates a head controlled timed switch, powering a 12-Volt car for a short time. The design aims to be easily customizable to each child's needs, and grant them the ability to go left, right, and straight. The project also hopes to integrate a stop switch to allow for parent intervention as needed. This project report describes the team's design method on, as well as the progress of, the project up to this point.

Acknowledgements

The team has been fortunate to have a wonderful support system throughout this project, whether it be helping with technical problems, brainstorming ideas, or pushing the team to succeed. The team would like to acknowledge some of these fantastic individuals:

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Mrs. Bethany Sloane, the team's Go Baby Go advisor, providing the team with background to the project, sharing her passion for the project with the team and helping the team see the bigger picture and adjust their ideas to reach a larger range of children who can benefit from this project.

Reid & family, for working with the team, testing the car and giving the team constructive feedback on the project.

Mrs. Kim Elliott, the team's Community Vision advisor, who connected the team with Bethany Sloane and Reid, allowing the team to see the final project in use.

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Background

Observations

Observing videos of children driving the 6-Volt Power Wheels cars provided by Go Baby Go proved that simple switch buttons were sufficient for activating the circuit and providing forward motion, but it was difficult or impossible for some children to steer the car on their own with the built-in steering wheel. Providing improved steering capacity was a critical criterion, in order to ensure the design provides children with movement impairment enhanced explorative capabilities.

The team's first meeting with Kim Elliott illuminated different facets of assistive technology design. One of the critical realizations was the difference between specialized vs universal design. Most assistive technology is either "specialized" for one person or a small community or is made to "universally" benefit a larger group or population. This design project encompasses the idea of universal design, making it accessible to everyone without a specific disability or child in mind. This choice was made because it would have a larger societal impact, as well as give Go Baby Go a more versatile and capable design to maximize their impact on children with movement impairments.

Another critical design decision came from our first meeting with Bethany Sloane, a partner at Go Baby Go, who acts as the team's industry advisor. She explained the need of the exploration to be child driven, indicating how critical it was to not only give the children a design that provides them with control over stop and go of the car, but also the ability to control the direction the car moves, allowing them the ability to explore more on their own, an important developmental milestone.

Experiences

The team attended Go Baby Go community builds, in order to learn what resources are available to parents and volunteers working with Go Baby Go and the process they follow to implement the modifications. During these builds, most modifications are completed with drills, glue, and solder. Parents and volunteers often need assistance getting drills set up with the proper drill bits, and often need to be helped with or taught how to solder.

Parents and volunteers require a high level of detail and instruction in order to do the modifications correctly. A typical Go Baby Go modification guide has lots of pictures and steps, and details where every component of the circuit goes in order to complete the modification. It normally contains a list of materials needed first, such as how many PVC pipes of what lengths are needed, any screws/glue needed and any electrical components. These are then referred to throughout the guide during the different steps. The modifications are often broken up into different parts, such as the "Physical Support Modifications" and "Electrical Modifications."

During these builds the team learned valuable information about the type and level of modifications the team could make on the project. They learned they needed to use materials and tools to modify that Go Baby Go has and can easily provide to parents and volunteers. Therefore, much of the physical modifications of the car were made with pieces and components easily purchased from a hardware store and modified with the tools Go Baby Go has. Any other components had to be easily ordered and shipped to Go Baby Go. All the circuit components can be easily found and purchased on Amazon. The team also learned it would be critical to write down the type, size, and amounts of any components we used to make the modifications to ensure that Go Baby Go parents and volunteers would have all the pieces necessary to perform the modifications on their own.

Literature Search

The team first started doing research over the summer, in order to find a 12-Volt car of choice and start to look at some of the different aspects of our project. We used this preliminary research to foster ideas, and project potential budgets. The preliminary research was broken into two main areas: (1) feasibility of rewiring a 12-Volt car and (2) different control switch ideas for gas/brake/steering), and how to wire them into circuits. The team found circuit diagrams, as well as online sources that indicated feasibility of modifying a Power Wheels ride-on car circuit [1 & 2]. The team also researched potential control switch products, such as plate switches [3], pressure sensors [4], small button switches [5], and a switch from the Enabling Device Company which has a goose neck, allowing for customizability [6]. This research served two main purposes: (1) developing initial budget estimations for the project for research and development and (2) vetting available switches and technology to inspire and drive brainstorming possibilities for the greater system.

Intellectual Property

The team's initial front wheel steering design and directional control concepts were based off a 6-Volt car that Go Baby Go loaned to the team. This design was created by Joshua, Benjamin, and Randy Phelps, a family affiliated with the Go Baby Go community [7], in order to make the rear-wheel steering of the car more effective and give joystick control to any user. The use of swivel wheel casters and a 2x4 stock lumber allowed for wheels that would easily adjust to any turning force created by the back wheels. These wheels were anchored into the plastic chassis of the car (shown in Figure 1), which cannot be done for the 12-Volt car the team will be modifying on our current project. The back wheels were independently controlled by a joystick and can spin in different directions in order to produce left, right, and straight directions. The team's design for the 12-Volt car uses similar directionality concepts in the design but take a modular approach to achieve it.

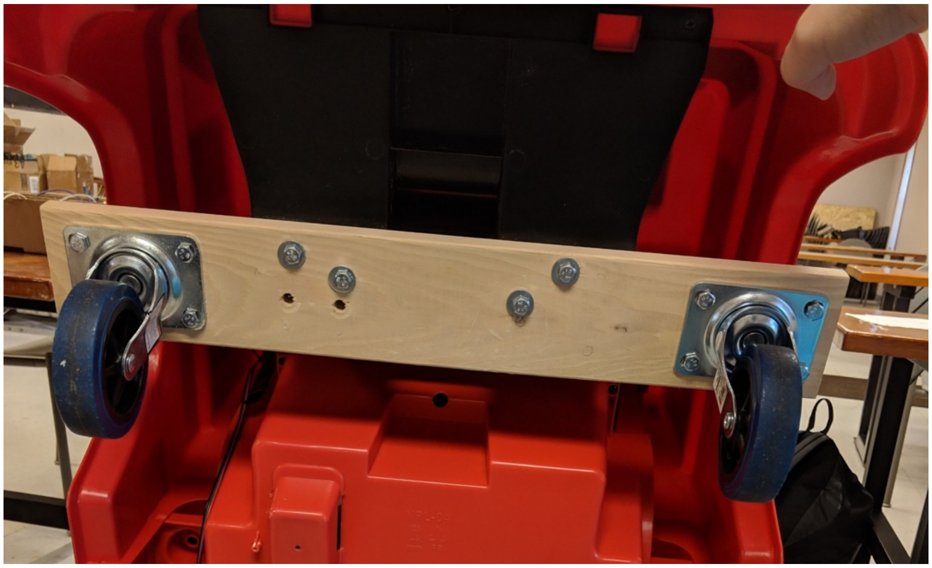

Figure 1: Swivel wheel system for previous Go Baby Go car design

The adjustable PVC elbow joint fitting design (discussed later in the Development section) was based off a product sold at Walmart, developed by Circo Innovations, Inc. It uses a bolt to provide a tension joint, which allows for both adjustability and joint position locking capabilities

[8]. The joint design developed for this project was custom made to use similar joint adjustability/locking technology, while allowing for easier chord management for the overall system's wiring integrity and reducing the overall cost of the joint.

Existing Solutions

The current solution employed at Go Baby Go involves adapting 6-Volt cars. These cars are modified such that a simple on/off switch is put on the steering wheel. The child must maintain contact with the switch in order to keep the circuit running, since the car does not contain a switch timer that allows for short, timed responses when the circuit is activated. The seats are modified with PVC pipes covered in pool noodles and combined with a child boogie board to provide stability and support for the child operating the car. The button placement can be moved, depending on the needs of the child. This is an excellent solution for some children but is not adaptable when children with more severe movement impairments cannot use the steering wheel. This means that these children do not have as much control over their environment, increasing parent need for supervision decreasing their independence and reducing critical movement-based development [7].

Other Go Baby Go solutions involved modifying the mechanism needed to activate the cars. One of the cars requires the children to stand up to activate the switch, which promotes skills of standing, balance, and weight bearing [9]. This is a great solution for simple switch functionality but does not address children who do not have the capability to bear their own weight. Another solution involves harnesses and pulley systems, also developed by Go Baby Go. This solution isn't portable or available in multiple areas, but in a child's home this type of system can be arranged to give children with motor disabilities enough support that small movements can translate to large, meaningful movement [10]. This is helpful for children that have the capability to hold themselves up but is not suitable for kids with only normal or minimal head movement.

There is no similar technology currently available for this group of mobility impaired children, who are older than four years old or have only (normal or restricted) head movement capabilities. While there are many motorized wheelchairs and other options that provide aid for many disabled children, these alternatives are not available to kids under three, which is when they need access to these technologies for critical development through movement and exploration. This critical lack in technology for disabled children led to the foundation of Go Baby Go [11]. Oftentimes, the only modifications made during Go Baby Go's 6-Volt car builds are moving the final position of the button, so kids with limited or no control of their limbs can activate it with their heads. This does allow them to go straight but limits their ability to explore the environment since they cannot turn on their own. It also requires more parent involvement, because they must help them steer the car in order for the child to safely maneuver around their environment.

Impact

This project has positive consequences for society. It will contribute to a significant learning advantage for children with severe movement impairment, empowering them to live their lives fully, and interact with the world around them in a way they couldn't before. The project design will use items mostly purchased commercially off the shelf items, and some items from McMaster-Carr. Once these cars have run out of utility for their original family, they are recycled by the Go Baby Go community and given to another family in need. This means the design will only be made as needed and will be recycled. This benefits the environment by reducing plastic waste and material consumption through maximizing each car's lifespan, reducing the project's impact on the environment. Economically, this project will have good outcomes. The goal of Go Baby Go is to make affordable solutions for families, and our project is no exception. The design was being created with cost, reproducibility, and ease of assembly in mind. This will increase the accessibility and affordability of our project and broaden the impact on society that the project can make.

Problem Statement

The present Go Baby Go technology is not fully effective for children with severely impaired mobility, such as only full or minimal head movement. The goal of this project is to make a system that will better suit the needs of these children and bring them improved mobility.

The user will be a child with severe mobility impairment. The child we are designing for has only full or limited head mobility. The design is focused on bringing this child the access to mobility and experiences they would not otherwise have. The child, as well as family and loved ones that care for the child will benefit from this positive enrichment of the child's abilities and opportunities.

Short term benefits are increased development for the child, increased opportunity to interact with and learn from the world, and increased quality of life [12]. Other benefits may include increased cognitive growth in these movement impaired children that was not previously thought to be possible [13]. It could also change the lives of many different children in the entire Go Baby Go community, depending on the success of the project and if the design is adopted by the Go Baby Go community.

The scope of this project is to adapt a 12-Volt ride-on toy car, with a design allowing the child to control with their head for as little cost as possible. This will broaden access to the design and thereby increase its potential impact. All designs need to focus on reproducibility, being as easy as possible for parents or hospital staff with minimal engineering knowledge to be able to replicate. Another critical part of the design is adjustability, to make our design more universal. Other goals include adding a stop switch to enable the parents to intervene and adding measures to control acceleration and deceleration rates of the car.

Design Criteria

Constraints

The most essential constraints of this project are cost and reproducibility. The 12-Volt ride-on car donated to the team for the project specifically, must be easily modified by someone with limited technical knowledge and should be reproduced with a low budget. The overall budget of the project was provided to the team by The Shiley School of Engineering, and the final budget and expenditures are shown in Table 7 of the Appendix. To make the car easily used by a wider range of children, the head array needs to be adjustable in order to fit any size of child while also being comfortable. The head array will be designed to hold the sensor buttons, which control the movement of the car near the child's head. The head array also needs to be durable and withstand any amount of force the child presses the sensors with while lasting a long time.

Functional Requirements

The modified ride-on car should be easily controlled by the driver from the head array and should also be used easily by the guardian. The car should be able to be shut off by the guardian. To increase safety and decrease the possibility of harming the child with neck or head injuries, the car should accelerate and decelerate at a gradual speed with little to no impulse. To increase safety, the seat needs to firmly support the child while in movement and when stationary. Durability of the sensors is also important, as it is expected to under-go many on-off cycles in use. The sensor should be able to be adjusted to fit the child and should be durable for large forces but sensitive enough to work with kids who have a limited ability to move their head.

The design criteria were discussed and ranked by the team, as shown in Table 1. A high priority means that the criteria cannot be compromised and will be more heavily weighted in the design matrix, which is shown later in Table 3. The team also discussed specific quantitative metrics to measure how well the criteria are met by the design in the final product. These quantitative metrics defined the type of testing done on the components of the design.

Table 1: Design Criteria Table

Criteria Description	**Priority**	**Quantitative Metric**
Durability – sensors and switches need to last throughout child's use	High	Sensors should still activate car after 10,000 maximum load cycles.
Acceleration/deceleration – safe, gradual rate	High	Acceleration and deceleration rate should be under 0.025 ft/s^2 (half of stock acceleration)
Implementation of kill switch – emergency kill switch for parents to stop car	High	Immediately take power away from motors and easy to press.
Ease of use – easily used by child and parents	Medium	Parent should not have to be next to car constantly during child's ride time. Head array should be adjustable for the child and their level of disability.
Cost – lowest cost as possible to work with Go Baby Go budget	Low	Production cost is $150 or lower (not including cost of car itself).
Reproducibility – easily reproduced by a non-engineer or mechanic	Low	Less than 2-3 pages of instructions with pictures.

Selection Methods

During the brainstorming process, many ideas were discussed by the team to get the most out of the project. The ideas discussed were both technical and aesthetic and revolved around either a mechanical or electrical system. Table 2 summarizes the design considerations and how they apply to the project.

Initially, the team devised a plan to drive the car using primarily parent-assisted mechanical steering concepts, so the children would not be able to control the steering of the car, only its forward motion. After meeting with the industry advisor, it was clarified that Go Baby Go wanted the team to create a car in which the child could completely steer and control the car on their own. The team made the decision to use electrical steering to achieve this. The team then had to decide how to implement the electrical steering, by either using rear wheel steering or a servomotor. To make the final design decision, the team ranked the head array design concepts and electrical steering design concepts against the criteria on a scale of 1-5, five fitting the criteria exceptionally, in Table 3. The criteria were weighted based on priority and a weighted score of each concept was calculated. The higher scored components will be implemented as the team's final design.

Table 2: Design Consideration Table

Design Consideration	**Application to Project**
Mechanical Steering – Attached to steering wheel	Gives guardian control of steering the car from the steering wheel while child will have control of stop/go.
Mechanical Steering – Attached under car	Gives guardian control of steering the car from the axle while child will have control of stop/go.
Electrical Steering – Servo	Gives child total control of moving and turning the car through a servomotor.
Electrical Steering – Rear wheel	Translates signals from the head array to either the opposing or synchronized direction the wheels spin.
Head Array – Sensor pad	Sit near head, adjustable. Child touches head to one of three pads which control left, right or forward motion.
Head Array – Headband	Wraps around head. Easy to use, as headband senses their head tilt. Adjustable child to child.
Head Array – Head ring	Ring hovers around head. More range of where the child can hit their head to activate the car, adjustable.
Kill switch	Increase safety of the car for the child when a guardian needs to stop the car immediately.
Remote Control	Gives parent complete virtual control of the car, while giving the child access to exploration.
Traction Tires	Gives the child the ability to better use the car outside, further expanding their exploration.

Table 3: Weighted decision matrix for design concepts

Criteria	**Head Array**			**Electrical Steering**	
	Sensor Pad	**Head Band**	**Head Ring**	**Rear Steering**	**Servo**
Durability (0.9)	2.7	1.8	1.8	3.6	2.7
Acceleration & Deceleration (1.1)	0	0	0	4.4	4.4
Implementation of kill switch (1)	0	0	0	0	0
Ease of Use (1)	4	3	4	4	4
Cost (0.5)	2	1.5	2	2	1
Reproducibility (0.6)	2.4	2.4	1.2	2.4	1.2
Score	**11.1**	**8.7**	**9**	**16.4**	**13.3**

After looking at the scores on the criteria table, it was clear that the best options for the design would be to implement the sensor pad design for the head array and rear steering for the electrical steering. The chosen design was broken down into 3 main subsystems.

Subsystems and Key Features

The current design can be divided into 3 subsystems: the head array, the steering system, and the controls system. Each subsystem is listed and described below. A diagram of how these subsystems will be implemented into the car is shown below in Figure 2.

1. Head Array – Consists of a PVC structure around the car and a removable U-shaped head array system, able to conform to a specific child's needs. The U-shaped head array consists of three panels, each has a sensor button attached to it, the panels are connected using angle hinges that allow the system to range from 180 degrees to 90 degrees when being adjusted for the child. The head array's focus is to be able to be adjustable and able to fit a wide range of children.
2. Steering – The front wheels will be replaced with a system consisting of a piece of flat wood for support to attach two swivel wheels using two bolts to secure the metal rod to the piece of wood. This allows for easy turning of the car when the rear wheels are activated in different directions.
3. Sensors/controls – The sensors will be attached to the head array; one signals the car to move straight forward, one signals the car to turn left and one signals the car to turn right. All sensors will be wired into the circuit, which uses an Arduino as the center of controls.

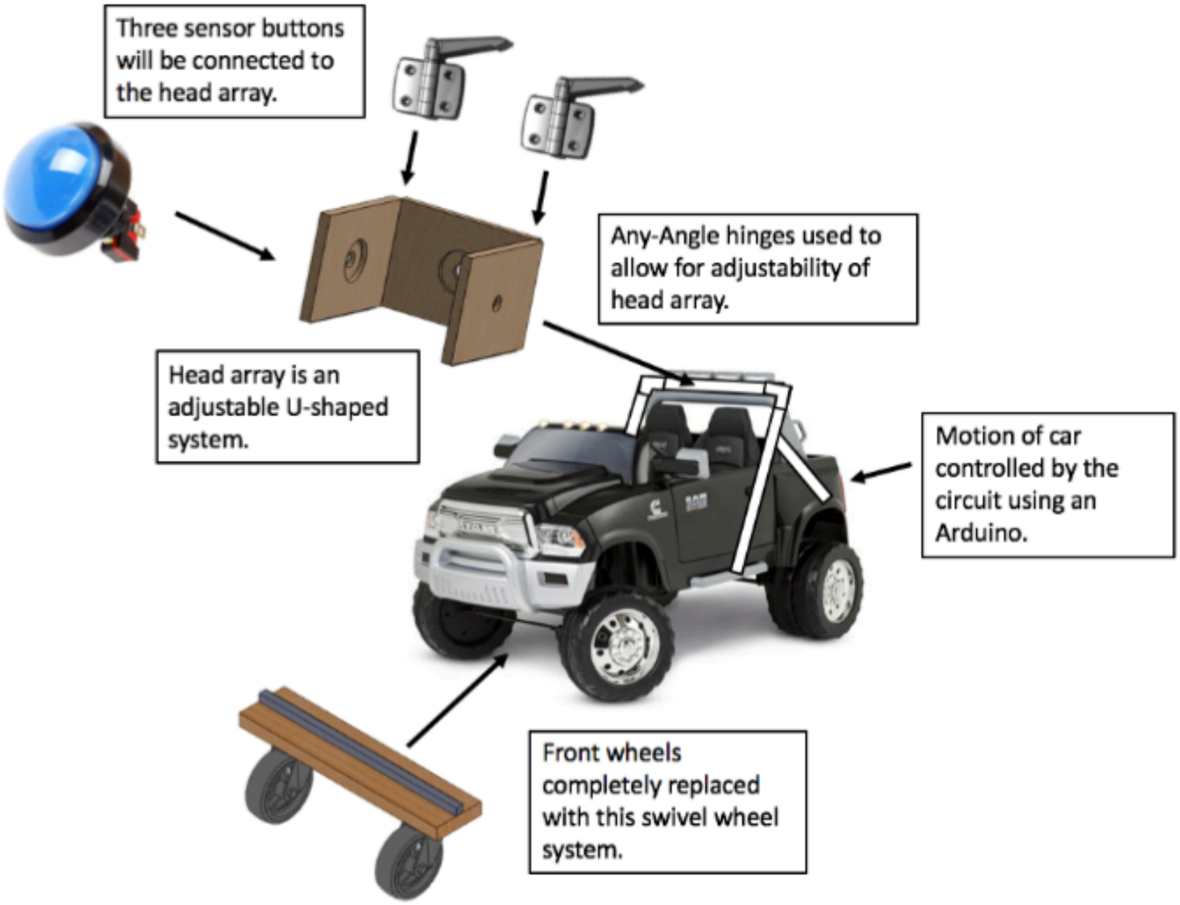

Figure 2: Diagram of the full car system

Development

Electrical Modeling

The block diagram in Figure 3 represents the general layout of the team's electrical circuit. The circuit is controlled by three buttons which will be held by a head array, and the buttons will direct the car forward, left, or right. To move the car forward, equal power is applied to the left and right motors. To turn left the left motor is reversed to turn backwards, and the right motor continues opposite of the left motor, forward. To turn right the right motor is then reversed to turn backwards, and the left motor rotates in the forward direction.

The buttons are connected to an Arduino module, which is hooked up to an 8-switch relay. The relay allows forward, backward and differential control of the motors. The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices. The MOSFET works by electronically varying the width of a channel along which charge carriers flow and is connected to both motors to help control the acceleration and deceleration. This system is powered by the Power Wheels' 12-Volt battery.

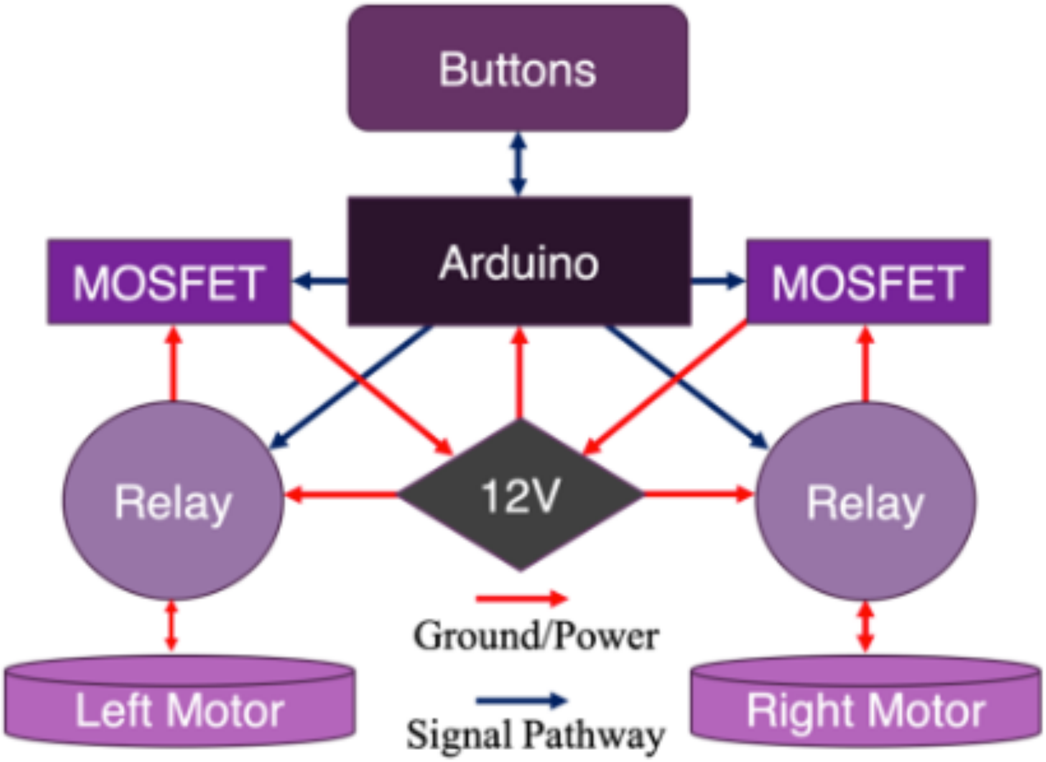

Figure 3: Block diagram of electrical circuit

The circuit diagram in Figure 4 represents the 12-Volt system through the circuit. The 12-Volt car battery is linked to an emergency stop switch and an on/off switch. From there, the ground from the battery connects to the MOSFET driver, which is connected to both motors to alleviate power to the motor, thus helping to slow down the acceleration of the vehicle. All these items are connected via an 8-switch relay print which is connected to both the left and right motor, located on the rear wheels of the car. To help step down the voltage, an LM 2596 DC buck converter was implemented and attached to the Arduino. Also, to help prevent a current spike when the buttons are initiated, six fly back diodes were added to the circuit. Two are attached to the MOSFET boards, and the other four are attached to the relays that power each respective motor. Lastly, to protect the integrity of the circuit, a 25-Amp fuse was attached in case the current was ever to spike to unsafe levels, either due to a motor stall or an excessive amount of torque.

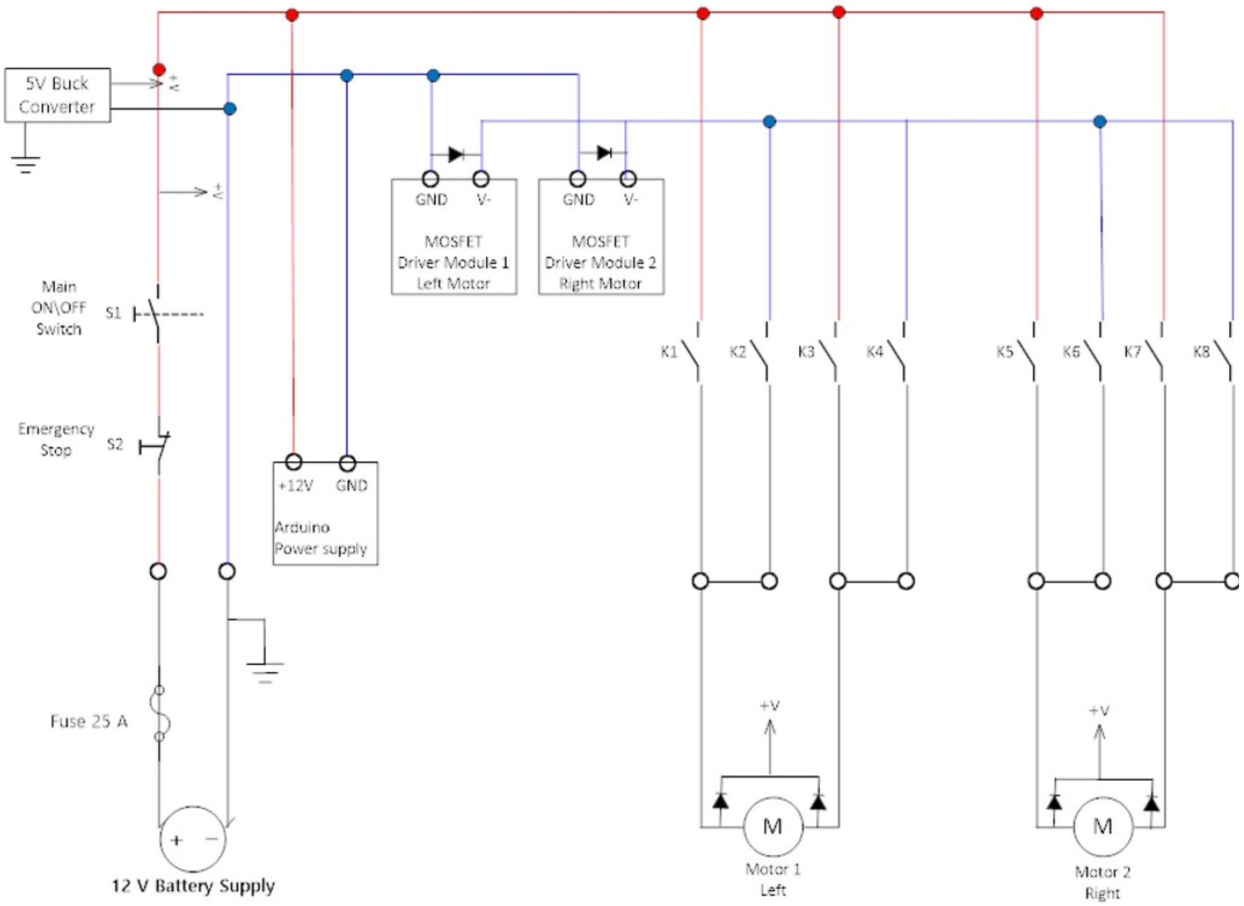

Figure 4: 12-Volt system though the circuit

The circuit diagram in Figure 5 represents the final 5V system. Once the buttons (either left, forward, or right) are activated the Arduino sends out a 5-Volt signal to activate the relay, and the relay sends a signal to activate the motors. The MOSFET's are also part of the system and will be activated once the buttons send out a signal. A detailed list of the materials used in the circuit are shown in the budget table (Table 7) in the Appendix.

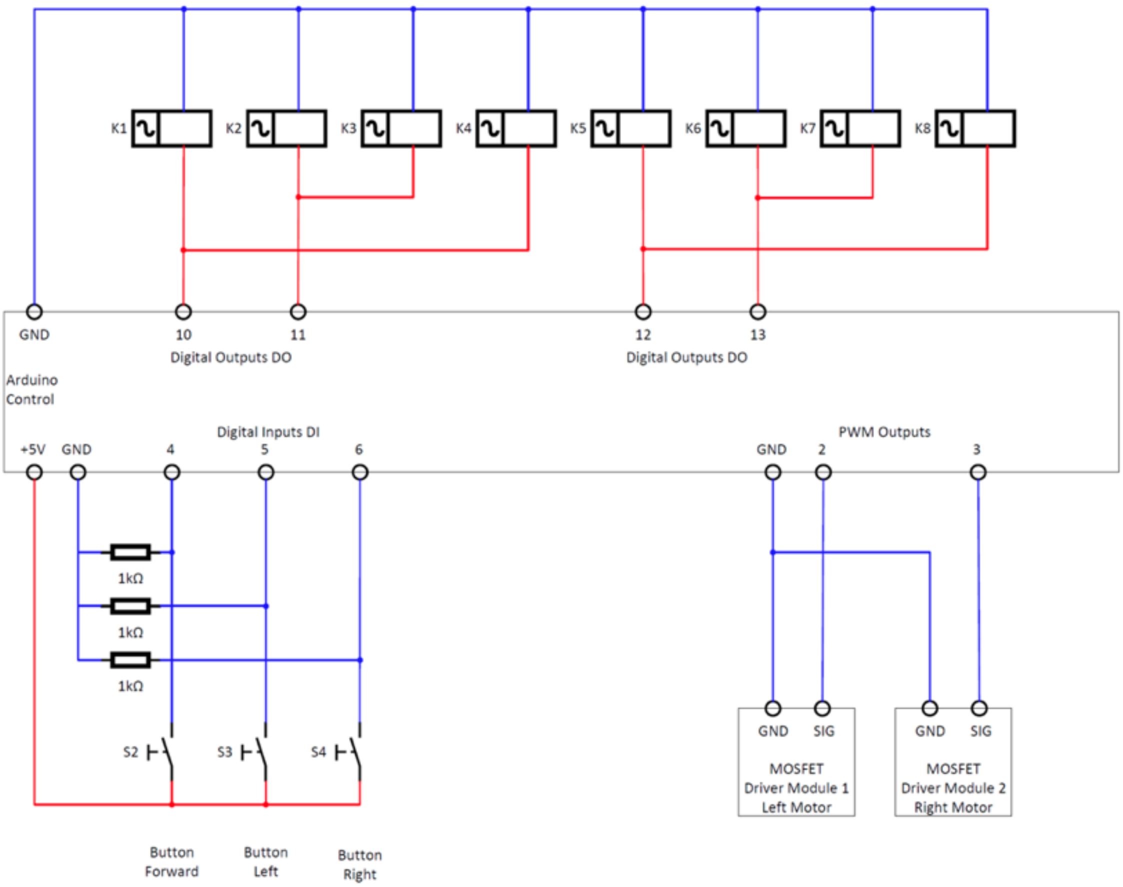

Figure 5: 5-Volt system through circuit

Head Array Modeling

Originally, the design for the head array consisted of three mechanical arms that could be adjusted and set to any position on the child's body that they could reliably use to control the car. This idea was eventually replaced with the current PVC structure on the car, which was used to prevent the excess displacement that resulted from the arm design. To prove the merit of the PVC structure versus the arm design, an FEA model of both the arm and the PVC structure were made. With the same load applied in the same direction on both structures, and with both scales adjusted to have the same maximum displacement, it was clear from Figure 6 that the PVC structure would be a much more reliable method for anchoring a head array, since the arm design experienced 11 times more displacement than the PVC structure did.

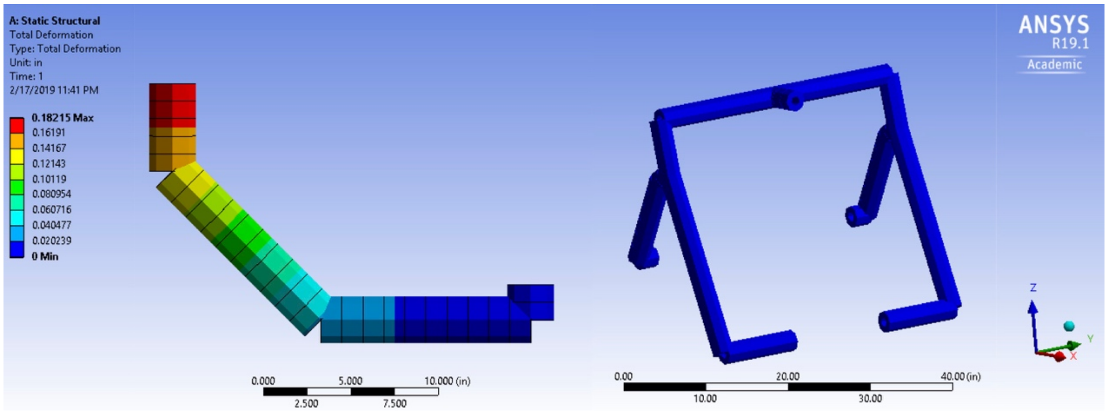

Figure 6: FEA displacement results for the head array structure designs

Once the PVC structure was decided on, the head array was designed to ensure that it could be easily connected and disconnected from the PVC structure. After many different design considerations for the head array, it was decided that it should be a design with three wooden panels connected by adjustable hinges, as shown in Figure 7. In this way, the side panels with the button could be easily adjusted to fit a large range of head sizes. The back panel also features a metal flange that is combined with a 1¼ in threaded to 1” non-threaded PVC connector, such that the design can easily be put on a piece of PVC connected to the PVC structure. This can be seen in Figure 8. A physical model of the head array was made to see if the design was effective.

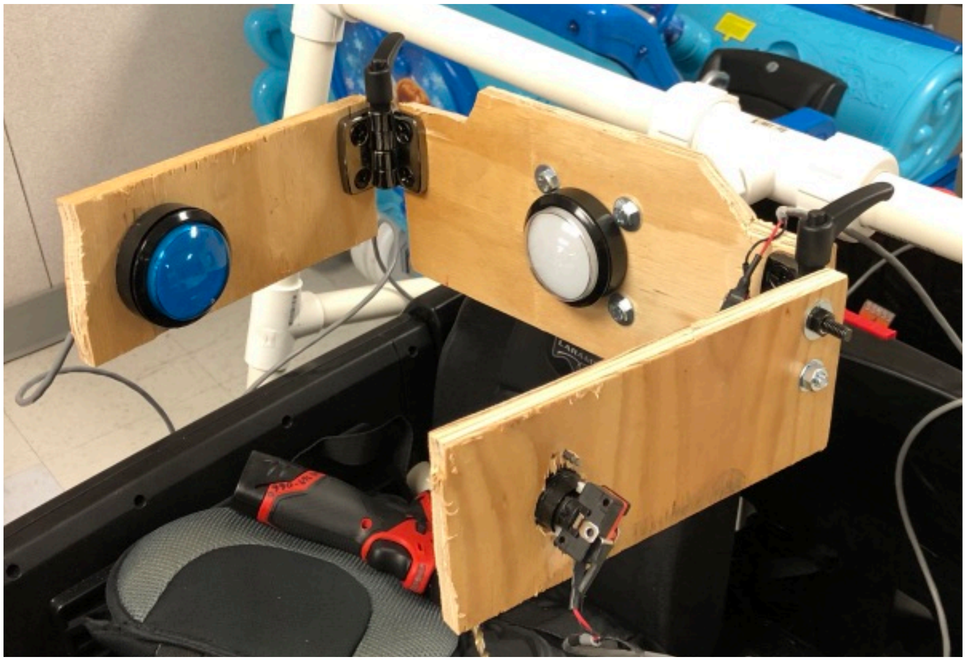

Figure 7: Initial design concept for head array

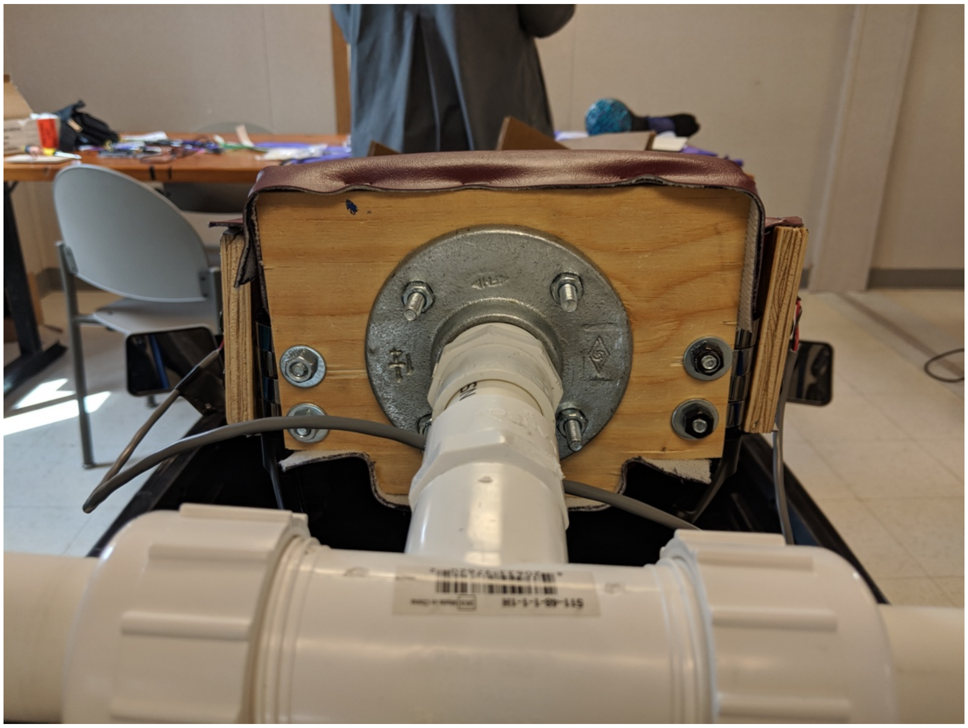

Figure 8: Head array connection method

Front Steering Modeling

In order to allow the car to turn easier with a rear wheel steering method, the team decided to make modifications to the front wheels by replacing the tires that came with the car with swivel caster wheels. These wheels will be screwed into a piece of wood which was drilled into the metal, square structural rod on the car. This assembly is shown as a CAD model in Figures 9 and 10.

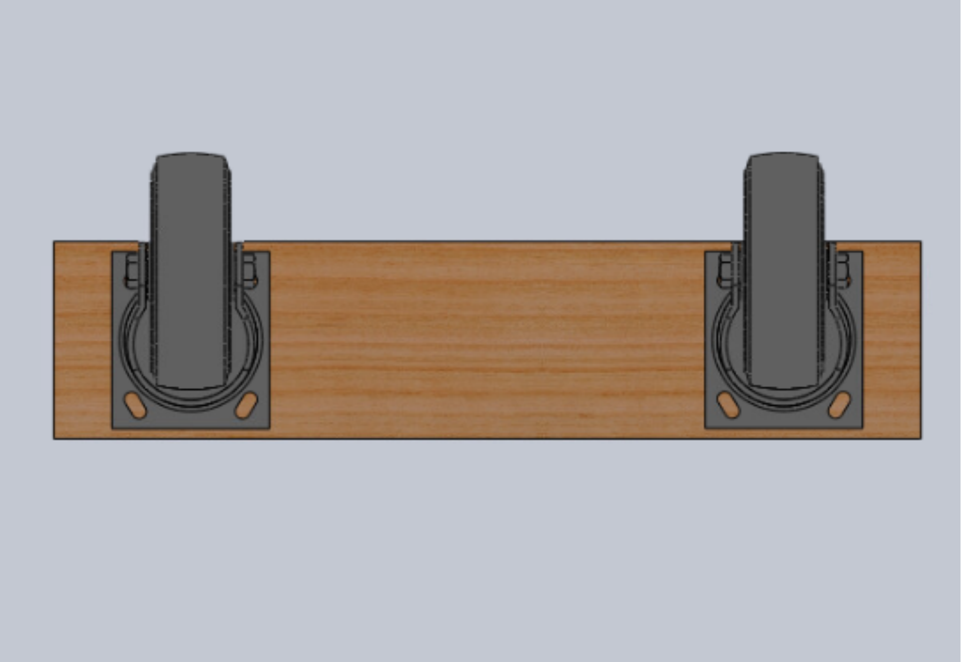

Figure 9: Bottom view of wheel system

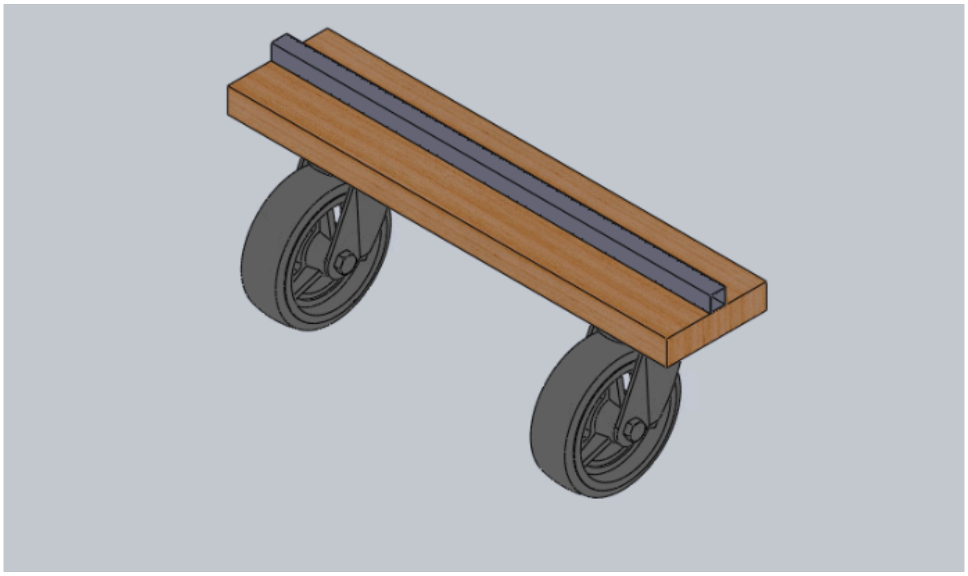

Figure 10: Full steering assembly

Calculations

Assuming each of the four wheels hold an equal amount of the load, the load on each wheel is calculated out to be 55.25 lbs. with the max amount of rider weight in the car.

Car Weight = 91 lbs.
Max Total Rider Weight = 130 lbs.
Total Max Weight = Car Weight + Max Rider Weight = 221 lbs.
Load on Each Wheel = 55.25 lbs.
Max Load the Casters can hold = 410 lbs. each

The casters chosen to replace the front wheels can hold a max load of 410 lbs., which is well over the load placed on the original wheels, which had 55.25 lbs. applied to each wheel. A factor of safety of five was chosen, accounting for the center of gravity being assumed to be at the center of the car when it is not. With the chosen factor of safety, the wheels would need to carry a load of 276.25 lbs. each, which is more than obtainable with the chosen casters.

Manufacturing and Construction

The final design is a product of two semesters of engineering, design, and fabrication effort. The first sub-system of the project to be built was the electrical circuit, with the basic model completed fall semester, it allowed the team to troubleshoot and modify the acceleration and deceleration commands to the motor, which was a key criterion. The front wheels steering system was also completed in fall semester, allowing the car to turn with the signals being outputted by the circuit. By having the front wheel system completed as well as the circuit, the team was able to confirm that the circuit worked as hoped with the front wheel system. With the foundation of the circuit and the front steering complete, the team was able to focus on improving and troubleshooting both designs in the spring, allowing both designs to be completed in the middle of spring semester. This allowed the rest of spring semester to be devoted to the head array and completing that sub-system. After the first iteration of the head array complete, all testing was able to be completed, allowing for all sub-systems to be improved based on the results recorded. The majority of spring semester was spent constructing the sub-systems in the shop and implementing them into the design, then concluding with design improvements.

Multiple iterations were made throughout the project for the circuit, front steering system, and head array. The circuit was an ongoing process that consisted of many iterations, the main iteration made would be implementing the MOSFETs into the circuit. At the end of fall semester, the team had a working circuit, which did not include the MOSFETs. This iteration of the circuit was functioning but did not implement the acceleration and deceleration that the team was trying to achieve. Spring semester is when the second iteration of the circuit began, implementing the MOSFETs correctly, adding diodes and connecting the Arduino to the 12-Volt power supply.

The front steering system consisted of two iterations, the first was designed fall semester and had the caster wheel directly attached to a piece of wood, which was then attached to the existing metal rod with four z-shaped brackets, which can be seen in Figure 11. The brackets did not provide a stable enough connection, causing the front wheel system to move easily when force was placed on the car. Due to the slight displacement occurring when a force was applied, a second iteration was designed early on in spring semester. This consisted of drilling two holes in the metal rod and wood, and directly connecting the two pieces with bolts. This provided a much more stable system, and no displacement occurs when a force is applied.

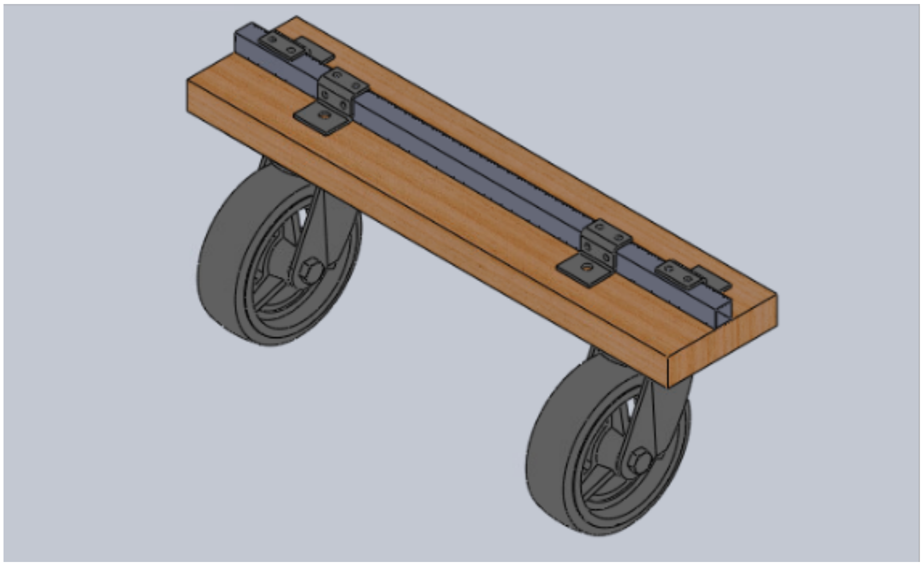

Figure 11: Front steering system iteration 1

Lastly, the head array had multiple iterations as well. The initial design concept was to have the head array consist of 3-D printed arms that would hold the buttons and be adjustable, after doing an FEA analysis the design changed to the current design of a U-shaped head array. The first iteration of this design consisted of a PVC structure to hold the head array, and a U-shaped head array made from three wood panels and two adjustable hinges, which can be seen in Figure 12. After testing the head array and meeting the child who will be sitting in the car, the second iteration of the head array was completed. This iteration consisted of shortening the wooden panels based on the child's head measurements and reducing the surface area of the panels in general. The PVC structure was also changed to line up with the child's head and where it will be located when they are sitting in the car. Foam and a cover was placed onto the wood to add support and protection for the child.

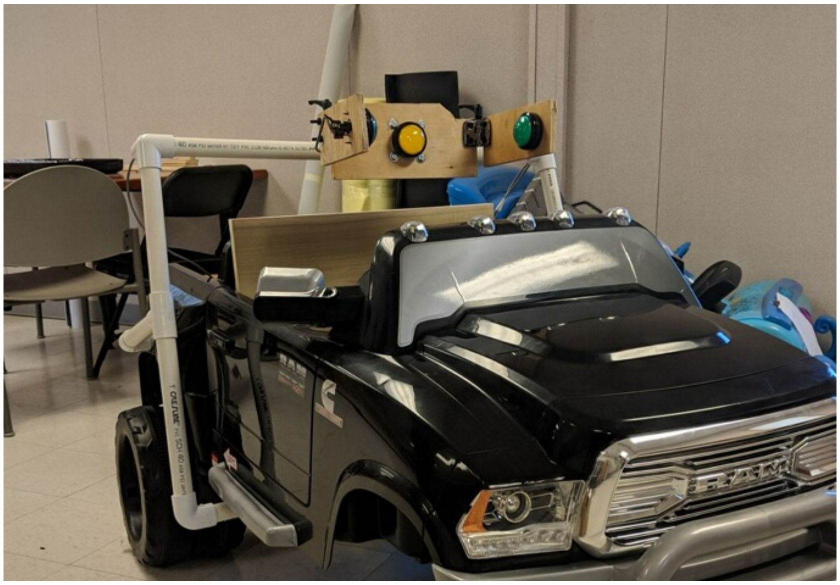

Figure 12: Head array system iteration 1

Head Array Displacement Testing

To test the reliability of the head array, the team focused on the strength of the hinges. Depending on the strength or severity of the muscle movements of the child driving the car, the head array side panels might experience different forces and stresses depending on how far the button is placed from the hinge. This would increase the torque on the adjustable hinge due to changing the location which the force loading is applied, which the team realized could be a critical point of failure in this design.

The head array was tested by making an apparatus such that the head array was supported on its side, as shown in Figure 13. By anchoring the head array in this orientation, a stress-applying device could be placed on the head array that applied a stress over a consistent area using only masses and gravity. This force was applied in the center of the side panel, since this is where the button would be located, and was tested at 1-inch from the hinge to 6-inches from the hinge in 1-inch increments. This panel was not tested at the 5-inch mark, because there was a 1-inch hole in that location due to the placement of the button on the panel. At each distance from the hinge, the force the stress-applying device delivered was increased by adding weights from 0-grams to 5500-grams at 500-gram intervals. This, combined with the weight of the stress-applying device, achieved a total applied force on the panel ranging from about 0.3 pounds-force to 12.4 pounds-force. Each time mass was added to the stress-applying device, the angle between the back panel and the side panel was measured using a protractor attached to the back panel. This ensured that data collected showed a correlation between applied force and resulting angular displacement of the head array.

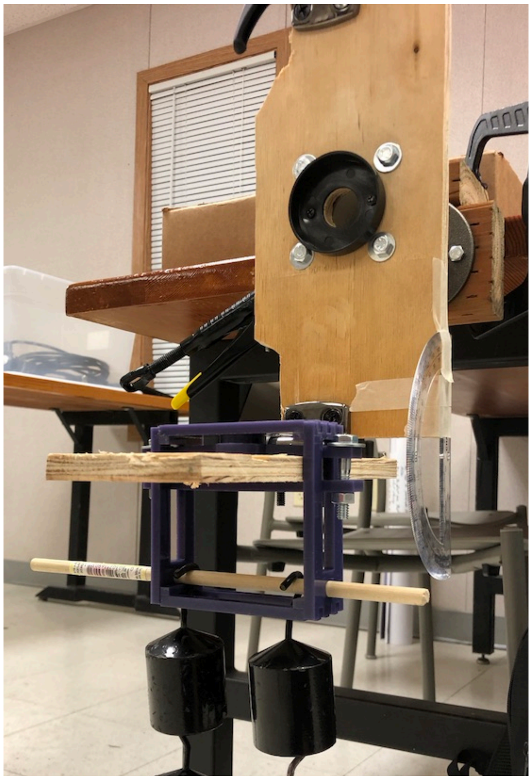

Figure 13: Set-up for head array testing

Figure 14 shows the results of the head array testing. The testing revealed that the closer the button was placed to the hinge, the less of an affect the changing torque had on the overall angular displacement of the side panel. In order to use this data to guide what the length of the side panels should be, the team used the maximum force that could be seen and the maximum displacement acceptable for the head array to find the ideal panel length range. The team chose 9 pounds-force as the maximum force to test on the head array, because according to a study by Donald F. Huelke, the weight of a child's brain ranges from 70-95% of an adult's brain mass from 12 months to 10 years old respectively [14]. Since an adult's head mass is 1350-grams [14], the worst-case weight of a child's head would be 95% of that, or about 3-pounds. The worst-case scenario was assumed to be the force exerted on the panel by gravity acting on the mass of a child's head, which was 3 pounds-force. A factor of safety of 3 was applied, resulting in the maximum force the head array could experience being around 9 pounds-force. The results from the test in Figure 14 show that the joint performs better when the overall torque on the joint is reduced, as expected. The maximum displacement was decided to be an angle of 10°, which was when the panel would start to displace further and not restore to its initial 90° position. A factor of safety was placed on this, resulting in a maximum displacement of 3.5°. These two lines intersected on the 4" trend line, seen in the graph. The team decided this mandated that the maximum distance between the button and the hinge should be between 3 and 4-inches.

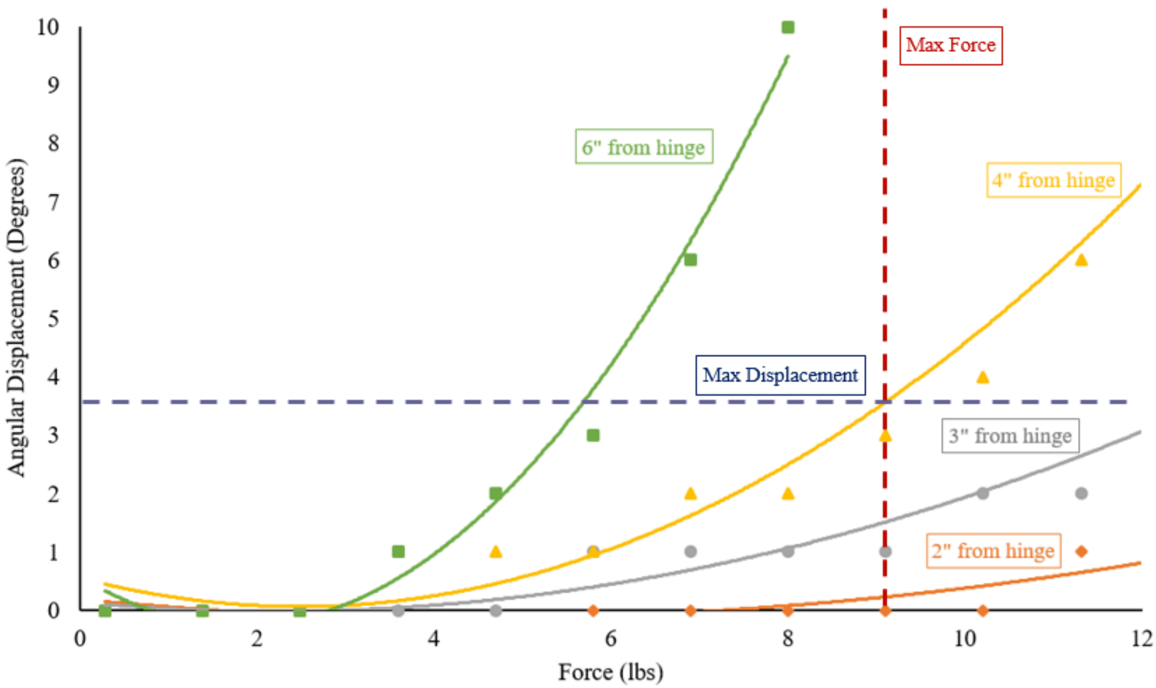

Figure 14: Joint performance at varying button distances from hinge

Circuit Heat Testing

To test the safety of the circuit, the team conducted a heat test to ensure the Arduino and the rest of the circuit was operating at a safe temperature when the car was running for a longer period. A thermal imaging camera was used to measure and record the temperature of the circuit, with a focus on the Arduino specifically. Two examples of these images are shown in Figure 15 and Figure 16. To simulate the child's weight, 38.6 lbs. was placed in the car and the car was driven back and forth on a straight path, taking a photo of the circuit and Arduino every two minutes for a total of eight minutes. This weight was similar to the weight of the child the car was being adapted for, and the temperature of the circuit and Arduino were still low enough to not warrant issues with over-heating, as an Arduino's safe operating range is below 185°F and a maximum temperature of only 100°F was recorded when being run constantly for 8 minutes. In normal operation, the child will likely operate to motors intermittently, which is less severe than this test car. Table 4 shows the test results.

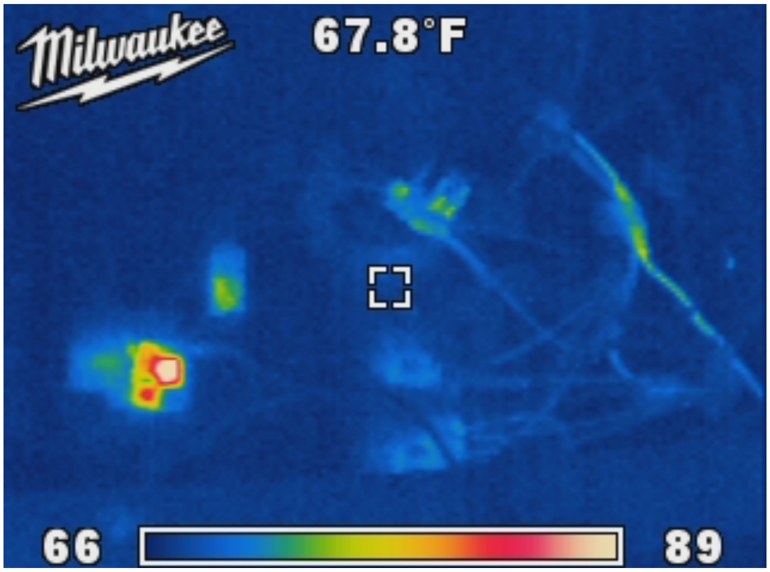

Figure 15: Circuit thermal imaging photo after 4 minutes

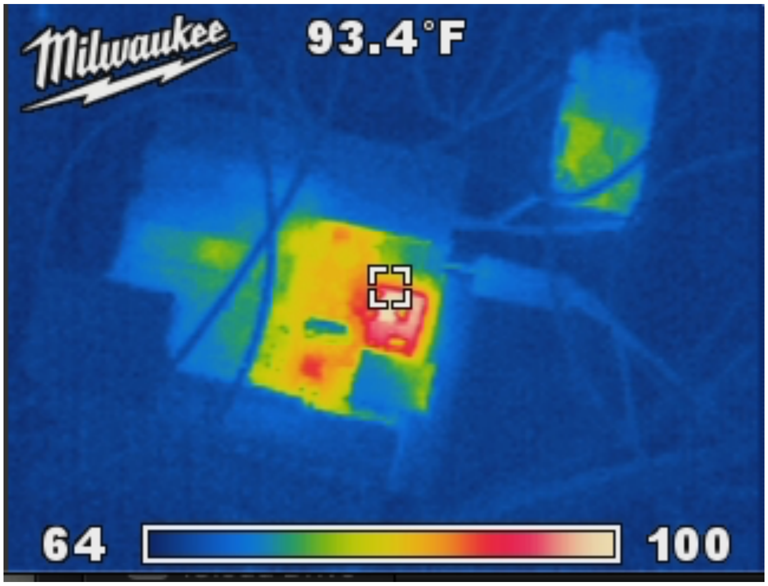

Figure 16: Arduino thermal imaging photo after 4 minutes

Table 4: Heat testing results

Whole Circuit Heating		**Arduino Heating**	
Time (s)	**Temp (F)**	**Time (s)**	**Temp (F)**
0	70	0	70
120	85	120	96
240	87	240	100
360	89	360	98
480	91	480	104

Acceleration Testing

To test the implementation of gradual acceleration by the Arduino, the team conducted acceleration tests on the car with and without modifications in the Arduino code to reduce acceleration. In order to do this, a 10 second video of the wheels was taken starting as the forward button was pressed, showing the gradual acceleration and another 10 second video was taken after 1 minute of running of the car, showing steady state speed. These videos were taken for the modified circuit which controls the acceleration via the Arduino and the stock installation circuit. The results from these tests are shown in Table 5.

Table 5: Acceleration test results

Time (s)	**Stock Installation**	**Arduino Acceleration Control**
1	1.06 rpm	0.25 rpm
10	132 rpm	102 rpm
60 (steady state)	6.9 ft/s	6.3 ft/s
Average Acceleration	0.0555 ft/s^2	0.0131 ft/s^2

The results from the first second of the car running prove that the acceleration of the modified system is significantly less than the unmodified system, creating a safer drive for the child. The modified acceleration is also less than 0.025 ft/s^2, meeting the acceleration and deceleration criterion. At 10 seconds, we can see that the modified car is not yet up to steady state speed, proving the gradual acceleration impact of the car. The steady state speeds of the car show that power of the car has been reduced slightly, making it easier for parents to catch up with the car in case of emergency and making the car easier to control.

Relevant Engineering Standards

One ASTM standard the team found very relevant and prevalent was ASTM F963 [15]. This document is associated with the standard consumer safety specification for toy safety. In section A8 it discusses the design guidelines for battery-powered ride-on toy cars. In section 4.25.10.1, it is stated that the maximum temperature measures in the circuit shall not exceed the temperature rating of the materials when tested. As described earlier, the team conducted a test to measure the maximum temperature of the circuit and see if it would obtain unsafe temperature levels, as can be seen in Figures 15 and 16. Additionally, in section 4.25.10.3 it is further stated that battery-powered ride-on toys designed with a wiring system shall have a user replaceable device, a fuse, for the primary circuit system. As can be seen in Figure 4, that the local 12V circuit includes a 25-amp fuse to account for the amperage spike if the motor was ever to stall or become over used. Ultimately, ASTM standard F963 helped develop the project into its final stage of safety and quality, thus furthering the guidelines and criteria initially set by Go Baby Go. This standard not only helped to develop a higher caliber vehicle but allowed the team to reach a product on a professional level.

Conclusions

Summary of Project

The goal of this Capstone project was to modify a powered, ride-on toy car to allow children with mobility impairments the ability to explore their surroundings. This project was specifically aimed towards kids with mobility impairments limiting them to full or partial head movement, so the team made the design decision to develop a sensor pad head array so the child can have total control of steering from a button array system surrounding their head. This design concept included a complete modification of the original steering system of the car, replacing the manual steering with an electrical circuit connecting to the two rear tire motors and three button switches that control forward, left and right movements. In order to create a smoother, safer ride for the child, the Arduino was programmed to gradually accelerate and decelerate the car when the buttons were pressed and only allow the car to reach 50% original power. The front wheels were also replaced with a caster wheel system for ease of control and turning. The head array is attached to the car with a PVC system, allowing for adjustability to meet the child's specific height and other needs. Each of the three buttons are attached to three different panels connected by locking angle hinges. These hinges allow for the panels to be shaped at different angles to adjust to the child's need and can also be laid flat for the child to use as a tray. The final design of this project will be used by a child named Reid in order to help him reach important developmental stages, explore his surroundings, and interact more with his peers.

Future Work

The car works to the team's satisfaction, and successfully meets all the criteria initially created. Testing was done on the head array and the circuit, but no testing was done on the PVC structure itself. Ideally, the PVC structure would be tested with varying force loading conditions, to see the overall displacement that the PVC structure exhibits. This should be compared to the theoretical PVC structure displacement from the FEA testing, in order to compare the theoretical and actual behavior of the structure. Another possible design improvement could be adding a slot along the top bar of the PVC structure. By making a slot, the wires could easily slide along with the adjustable head array, making it easier to reposition the child in the car.

The major component of this design that should be further optimized is the acceleration and speed of the car. The car currently has a linear acceleration and deceleration, and while this helps prevent whiplash and ensure the safety of the child, there are other possible types of acceleration that may also prevent whiplash while also decreasing the amount of time required to accelerate and decelerate the car, which would increase the car's responsiveness to the child's actions. The power of the car is also something worth optimizing. Not only does the maximum power of the car determine how fast the child travels in the vehicle, but it also has a larger effect while turning than it does while going straight. Due to the car's method of turning, the car spins very quickly in place, causing a larger angular acceleration of the child than desired. Adjusting the top speed of the car going straight and the top speed turning, separately, would provide the child controlling the car a smoother and more enjoyable movement experience. Testing should also be done with different weights and children to see which speed settings work best for children of different ages and weights, in order to make a table to guide parents in deciding which speed settings are best for their child.

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Appendix

Table 6: Timeline

Date	Milestone
October 26, 2018	Completed project plan and have set sketches of design idea.
November 9, 2018	Consult with Jared Rees on electrical items. Final design decision made.
November 23, 2018	Design Report started. Materials for initial prototyping of front wheels and controller system purchased.
December 3, 2018	Design Report completed. Initial steering system concept built.
December 7, 2018	Controller system/electrical completed. Poster finalized and ready to present.
January 25, 2019	Second iteration of front wheel system complete and start on FEA analysis of PVC head array system.
February 1, 2019	Head array initial structure complete and continue working on FEA analysis.
February 8, 2019	Power Arduino through an external power source other than a laptop and implement MOSFETS into circuit.
February 15, 2019	Power source for Arduino complete, cover for electrical circuit in the trunk complete and FEA on PVC structure complete.
February 22, 2019	Initial head array design decided on and acceleration/deceleration of car complete.
March 1, 2019	Acceleration video testing complete.
March 15, 2019	Heat and head array testing part 1 complete.
March 22, 2019	Bench seat initial design built and heat testing with a load.
March 29, 2019	Head array load testing complete and bench seat tilt complete.
April 5, 2019	Finishing head array iteration and making the car meet Reid’s needs.
April 12, 2019	Presentation complete and ready for assessed presentation.
April 13, 2019	Meet with Reid and family to test car, find any final modifications that need to be made.
April 19, 2019	Product work complete. Final design report and presentation finished and ready to present.
April 26, 2019	Shiley Showcase presentation.

Table 7: Final budget and expenditures

Purchased Item	Quantity Purchased	Total Cost of Item(s)	Cost of shipping
Lever-Nut 5 Conductor	25	$16.95	$19.90
Lever-Nut Assortment	12	$11.99	
Arduino Chips	2	$29.38	$19.58
MOSFET Driver Pack	6	$12.98	$3.68
Arduino Expansion Board	1	$9.98	
Toggle Switch Pack	5	$11.55	$8.36
Push Button Pack	5	$16.99	
Emergency Stop Button	1	$12.99	
Relay Board	1	$35.00	
3M Spray Adhesive	1	$9.99	-
Poplar Board	2	$26.93	-
Locking Hinges	2	$33.12	$29.09
Caster Wheels	2	$47.62	$11.73
Z-Shaped Brackets	4	$4.68	
Mouser Diodes	18	$8.73	$7.99
Mouser MOSFET Chip	4	$3.52	
Fuse Pack	1	$19.99	-
Foam Material (5ft x 2ft)	2	$46.67	-
PVC Material	13 ft + 15 Connectors	$16.99	-
Hardware	-	$15.00	-
Subtotal		$391.05	$100.33
Total Expenses			**$491.38**
Total Budget			**$750.00**
Total Leftover			**$258.62**

Individual Contributions

Parker Elliott

As the team's co-lead, Parker ensured the team was on track for completing its design goals and completing the project. Parker worked to brainstorm designs for the head array and PVC structure with help from his teammates, he was also instrumental in its fabrication and testing. Parker also was a critical part of troubleshooting the circuit during the second semester of the project, helping to ensure that the MOSFETs were correctly implemented and the circuit operated to the team's expectations. Parker helped brainstorm and fabricate the bench seat system with Laura and Ally. He made himself available during the project to help other teammates as needed to ensure the design progressed in a timely manner and contributed to design reports and presentations in order to help get deliverables completed by their deadlines. Parker made sure that everyone's contributed quality work to the project to make the project a success.

As the team's director of communications, Parker made sure to keep the team in contact with industry advisors Kim Elliott and Bethany Sloane, from Community Vision and Go Baby Go respectively, as well as Reid's family. He made sure to email these contacts promptly for any information the team needed from these connections, as well as setting up meetings for the team with Kim Elliott and Bethany Sloane in order to get crucial feedback on design concepts and iterations.

Ally Fox

As the team's secretary, Ally helped facilitate and schedule meetings. Throughout the project, Ally worked alongside Laura on designing and constructing the front steering system and the bench seating. Also, Ally worked with Parker to brainstorm and design the head array system. Ally worked with Laura to model the front steering system in SolidWorks, as well as modeling the system as a whole and where each subsystem is implemented and how it comes together as a whole. Ally was available to help her other teammates as best she could to allow for the project to be completed on time and have the best quality possible.

Laura Pickering

As the team's co-lead, Laura helped schedule and facilitate meetings, keep the team on track and delegate the project work in order to finish everything on time and with the greatest success. Throughout the project, Laura worked with Ally on designing and implementing the front steering system as well as the bench seating, while also assisting Parker in brainstorming and designing the head array system. Outside of the defined roles, Laura also worked on creating the poster presented by the team during the poster presentation in December and putting together the PowerPoints for the three spring project updates and final presentation. She facilitated the work on the three technical reports throughout the year and helped her team in any other way she could.

Jacob Wolwowicz

As the team's card holder and budget manager, Jacob worked throughout the year on creating and managing the budget while holding the team card. Jacob also worked with Philipp, a foreign exchange student who worked with the team during the first semester of the project. Jacob helped Philipp develop the circuit for the vehicle. During the spring semester, Jacob oversaw putting the final touches on the circuit and troubleshooting problems that arose with the circuit that related to wiring, overheating and developing the code.