November 6, 2014

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby, BC Canada
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Re: ENSC 440 Design Specifications for the Smart Stroller Braking System

Dear Dr. Rawicz,

Attached is the Baby Guerrero's Design Specifications for the Smart Stroller Braking System. The goal of the project is to design and build a braking system on an existing baby stroller which will stop the stroller automatically whenever the user is not holding on the handle.

The document provides an overview of the methods used to design each unit of the prototype of the automated stroller braking system. Also, it includes a test plan to verify that the design specifications meet the functionality and features Baby Guerrero Technologies intend to achieve.

Baby Guerrero Technologies was created to provide effective solutions to real societal problems. If you have any concerns or questions that might prevent us from reaching our goal, please contact myself directly at 778-317-8995 or by email at esiddiq@sfu.ca.

Sincerely,

Elyas Siddiq
Chief Executive Officer
Baby Guerrero Technologies

Baby Guerrero Technologies

Design Specifications for the Smart Stroller Braking System

ENSC 440/305 Capstone Project

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Proposed to: Dr. Andrew Rawicz, Steve Whitmore
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ABSTRACT

Over 12,000 stroller reported injuries have been reported in 2012 alone. Baby Guerrero Technologies will not tolerate this and will put a stop to such alarming fatalities. A newborn should be cared in all aspects of their lives as they are in the most vulnerable stage. Baby Guerrero's sole purpose is to reduce the amount of injuries that can occur from stroller mishaps, rollaways and unfortunate deaths.

The Design Specification document lists the mechanical, electrical and software components that are essential to the development of the smart braking system. The system uses a sensor that detects the touch of the user which in turn releases the brakes for pushing pleasure. Upon release of the sensors, the brakes engage in a smooth timely manner that minimizes braking distance while maximizing safety and reducing any injury that may be due to deceleration on the infant.

This document delves into the technicalities of how the electrical, mechanical and software components interacts with each other with an inclusion of an in depth test plan to ensure that the product meets the standards that we have set upon it. Along with the component interaction and the test plan, we will also include the justification of each part and its respective role in its functionalities of the stroller.

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GLOSSARY

Encoder	An electro-mechanical sensor used to calculate the speed of the wheel
Microcontroller	A small programmable computer that takes inputs, performs computations, and produces outputs
Peripheral component	A device that is not part of the computer but connects to and works with the computer
Peripheral initialization	To make the device familiar to the computer
Pinch Points	Areas in the system where one or more of the user's body parts might be caught, causing injury
Portable	Can be lifted by and possible user
Standard Usage Policy	The braking system will function explicitly under the following Weather conditions: rainy, arid and humid Usage Condition: No less than 1 year with regular brake and battery replacement. Temperature Condition: Between 0^{o}C and 50^{o}C Speed of the stroller shall not exceed 10km/h Weight of the load placed on the stroller shall not exceed 60lbs System shall operate at a maximum altitude of 2000m above sea level WARNING: Stroller must not be used in icy, snowy, oily, lubricated, submerged or airborne conditions.

1 INTRODUCTION

1.1 Scope

This document has been designed as a follow up to the previously submitted Functional Specifications of the Smart Stroller Braking System. It will follow the same general layout and serve to provide a more technical discussion on how each functional specification will be met in our proof of concept prototype. It will provide the motivation behind the components we have selected, and will cross-reference the relevant functional specifications. This document will also include a test plan which we will use to evaluate the success of our prototype in meeting our functional requirements and objectives.

1.2 Intended Audience

The document titled Design Specifications is to be used by all members of Baby Guerrero Technologies during the design process, development, and testing stages of the Smart Stroller Braking System. It will also be used as a guideline during the process of building the prototype. In addition, this document will be used as a reference for future developments on the initial design.

2 OVERALL SYSTEM REQUIREMENTS

2.1 System Overview

The complete system flowchart is illustrated in Figure 1.

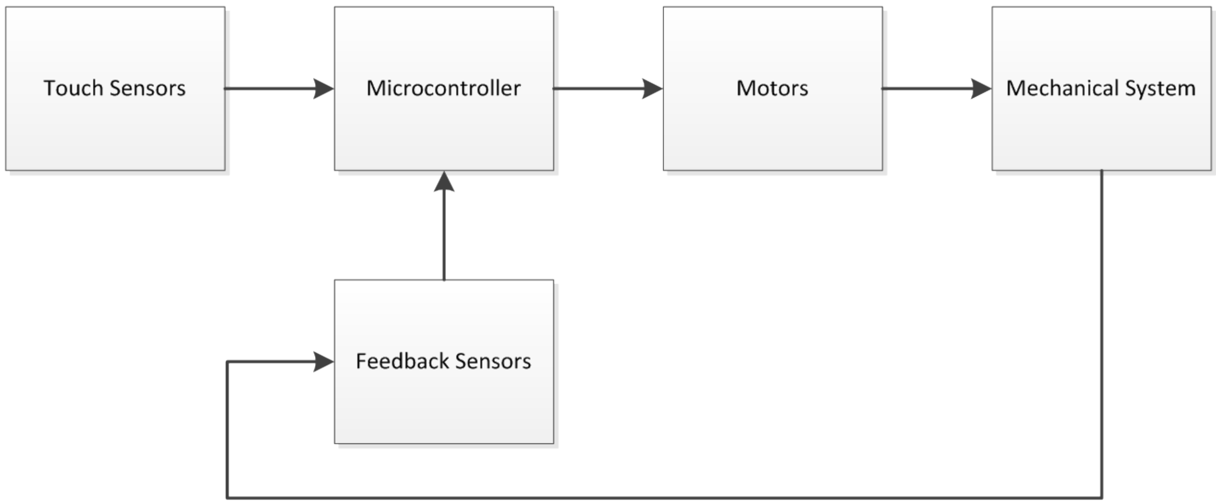

Figure 1:Flow chart of how the system will be implemented

The complete braking system will include several subsystems as illustrated in Figure 2.

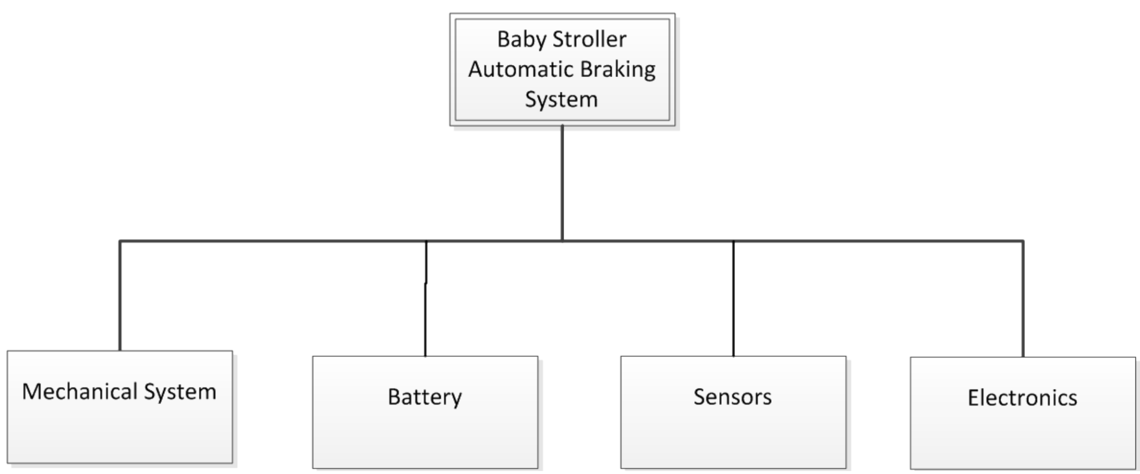

Figure 2:Smart Stroller Braking System with its subsystems

2.1.1 Stroller

The design of the stroller is one of the most vital component of the entire project, because is the base on which the braking system will be built. Due to budget and timing constraints, Baby Guerrero Technologies couldn't design and manufacture a stroller that would fit with the system seamlessly. Instead a stroller had to be purchased and the braking system had to be implemented into the system.

The most important feature of the stroller that Baby Guerrero Technologies was concerned with was the wheel assembly, existing braking system and the overall sturdiness of the stroller. Since we chose to use bicycle brakes, the wheels of the stroller have to be compatible with these brakes. The search concluded with the purchase of a ***Peg Perego Culla*** stroller as shown in Figure 3 [1].

Figure 3: A (left) and B (right)

As can be seen from Figures 3a and 3b above, the metallic wheels are compatible with conventional bicycle brakes [R010,R011]. Upon further inspection, we also note the sturdiness of the stroller and a tray area to fix the battery and the motor. In addition, we can see that the Peg Perego stroller has a well placed horizontal pushing bar that is ideal for sensor placement.

2.1.2 Overall Design

Baby Guerrero technologies have designed a smart braking system that takes the touch input of the user which in turn disengages the brakes of the stroller. We integrated touch sensors, a microcontroller, a DC motor, a motor controller, gears, and pulleys which disengage the bicycle brakes. By implementing a touch activated motor control circuit, the user can effortlessly engage/disengage the brakes at their will. This design choice will satisfy requirement [R026].

Since our system introduces a number of new components, it is essential that our implementation does not take anything away from the primary function of the original stroller. To ensure this, all components are mounted in a fashion that does not interfere with the natural rolling and steering of the original unit. The battery, motor, and pulleys are mounted below the bassinet as to ensure maximum stability and robustness.

The mounting system of the brakes was done to ensure that in a fully disengaged state, the brakes do not rub or influence the rotation of the wheels in any way. These design choices will satisfy requirements [R029, R034, R049, and R063]. Figure 4 below shows the concept design of the stroller with the smart braking attachment.

Figure 4:3D model of the system to illustrate how the units are installed

Table 1: Legend for Figure 4, Mapping of unit installation

Component	Corresponding System
1	Motor and Gearbox
2	Pulley
3	Brakes
4	Microcontroller
5	Sensors

Our product is going to be used exclusively with children, so it is essential that safety is considered as a number one priority during the design process. Measures have been taken to address the potential electrical shock risk posed passenger, driver, or any bystanders. All electronic components, including the battery, will be placed in an insulated enclosure and fastened below the bassinet, out of reach of the child, and hidden from view. In addition, all sensors and human contact points will be electrically grounded and insulated to protect all users. This will satisfy requirements [R006, R023, R056].

3 MECHANICAL BRAKING SYSTEM

The mechanical braking system includes a motor, a pulley, a worm gearbox, and braking pads. The design specifications of this system are outlined below.

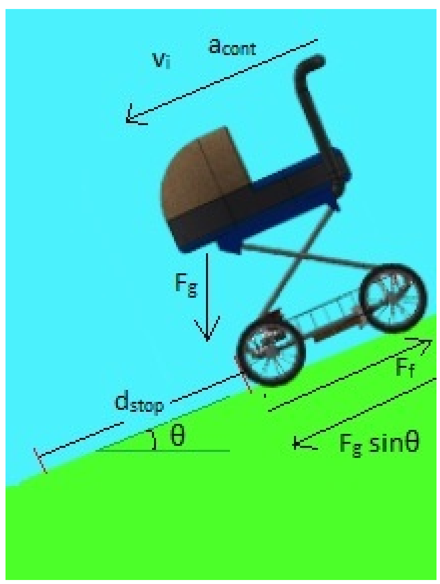

Figure 5: Diagram showing variables of calculations

3.1 Motor

To engage the brakes, their cables have to be pulled. To pull the cables, we choose to use a motor, gear, and pulley system. Based on previous knowledge, we estimate that this type of mechanical system is more effective, simpler, and more cost-effective than other possible systems such as linear actuators and spring-loaded solenoid actuators.

To select a motor and gearbox, we had to find the optimal mix of torque, angular speed, size, price, electrical compatibility, and ease of control. The first criterion in selecting a motor is choosing between the different types of motors on the market: DC, servo, and stepper. We eliminate servo motors because their range of motion is limited (cannot complete a full revolution) and because it is relatively expensive. Then, we have to choose between stepper motors and DC motors. Although a stepper motor would provide more precise control over the angle of rotation, it is relatively more expensive than DC motors and more complex to control. So we decide to choose a DC motor instead.

There are many choices of DC motors to choose from, so we narrow the choices down to DC motors that fit within our budget, have built-in encoders, are compatible with the selected gearbox, and operate under 12 V (to be compatible with our battery and meet [R038]). Of course, we also take into consideration (based on preliminary estimation) the torques and speeds of the different motors while eliminating possible motors [R040]. We finally choose the Pololu line of geared DC motors shown in Figure 6. We choose the gear ratio based on the calculations in the next section.

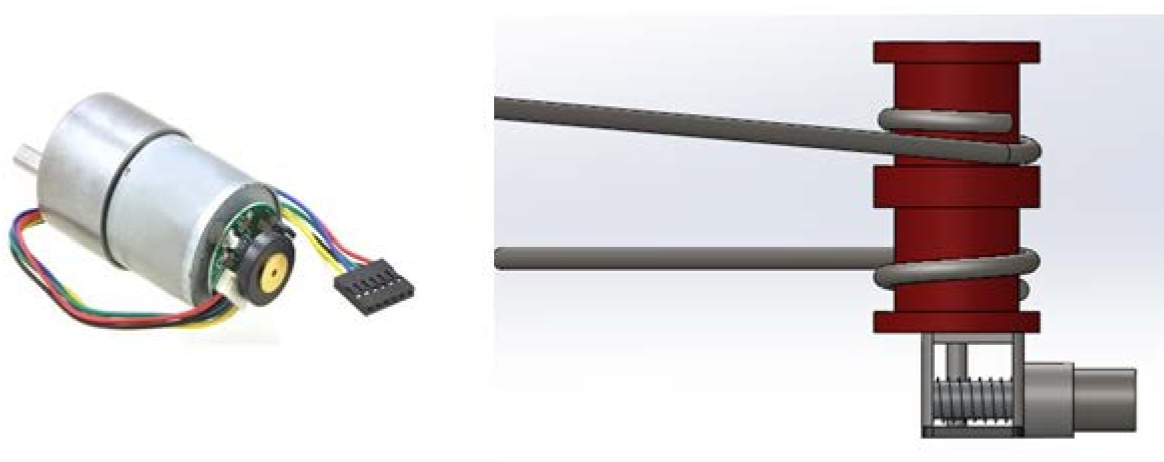

Figure 6: Pololu Motor (left) and 3D Model of Motor and Worm GearBox (Right)

3.2 Pulley

The cables will be attached to a pulley, which will be turned by the motor/gearbox assembly. The diameter of the pulley is important. If the pulley is too small, the time it takes for the brake pads to contact the rim will be too long, which will increase stopping distance. If the pulley is too large, the pulling force on the cables will be too small, which will also increase the stopping distance. To optimize the pulley size, we performed a MATLAB simulation based on the following calculations.

Our objective is to find the optimal radius of the pulley that would result in the best stopping distance in the worst case scenario. The worst-case scenario is defined by selecting the maximum values for the variables that would affect the stopping distance of the stroller when operating under the conditions of the Standard Usage Policy. The maximum speed the stroller may be used at is stipulated in the Standard Usage Policy as 10km/hr. This is based on roughly estimating the fastest speed that a person would run while pushing the stroller. The steepest street in Canada is recognized as The Côte St-Ange in Chicoutimi, Quebec with a percentage gradient of 33% [2], which makes the incline 18 degrees in the worst-case scenario. The worst case for the weight of the stroller and load was selected to be 18 kg. This includes the 8kg weight of the stroller and bassinet, plus the 10 kg maximum stroller load which was specified by Peg Perego for their Culla model stroller.

We will first assume that the brake pads are very close to the rims and that the cable has to be pulled a distance of 1 cm to force the brake pads to contact the rims. This distance is *s*. We also know the stall torque, τ_s, and maximum angular velocity (free spin), ω_f, of the motor/gearbox assembly.

We calculate the time it takes the brake pads to contact the rims, t_{cont}, using the following equation:

$$t_{cont} = \frac{s}{\omega * r} \qquad (1)$$

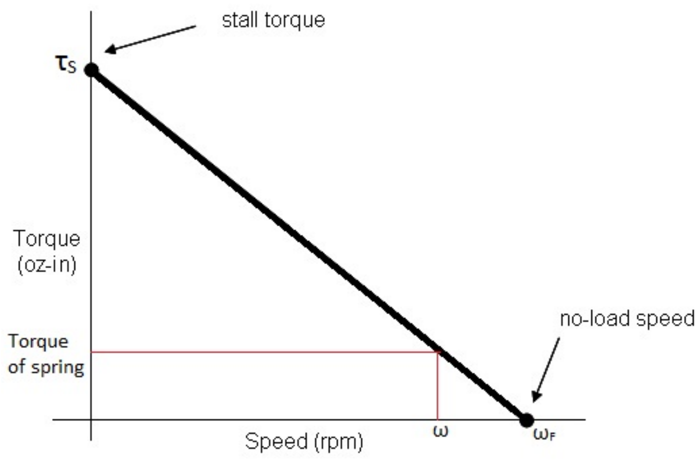

Figure 7: Calculating Angular Speed of Pulley

Of course, the angular velocity, ω, is less than ω_f because of the counter force applied on the motor by the brake springs. We calculate ω with the following equation:

$$\omega = \left(-\frac{\omega_f}{\tau_s}\right)\left(rF_{spring} - \tau_s\right) \qquad (2)$$

We then find the acceleration, a_{cont}, of the stroller based on the following equations:

$$F_g = m * g \qquad (3)$$

$$\sin\theta * F_g = ma_{cont} \qquad (4)$$

We find the distance covered by the stroller before brake-pad contact, d_{cont}, with following equation:

$$d_{cont} = v_i * t_{cont} + \frac{1}{2} * a_{cont} * t_{cont}^2 \qquad (5)$$

We then calculate the velocity of the stroller at the time of contact with the following equation:

$$v_{cont} = v_i + a_{cont} * t_{cont} \qquad (6)$$

To find the distance covered from the time of brake-pad contact to complete stop, d_{br}, we first need to calculate the force applied by the pulley on the cables, F_a, with the following equation:

$$F_a = \frac{\tau}{r} \qquad (7)$$

where τ_s is the stall torque of the motor/gearbox assembly.

We calculate the force of friction, F_f, between the brake-pads and the rims with the following equation:

$$F_f = \mu_d * F_N \quad (8)$$

Where μ_d is the dynamic coefficient of friction between the brake pads and the rims. We assume this is approximately 0.5 [3].

The normal force, F_N, is controlled by tangential force applied by the pulley, F_a. We first assume that the force of the springs is negligible compared to F_a produced by the large stall torque. Second, to allow for lever (caliper) mechanical advantage and non-perpendicular forces, we divide F_a by a factor, α, which we assume is 2. We find F_f based on F_a with the following equation:

$$F_f = \frac{\mu_d}{\alpha} * F_a \quad (9)$$

Based on this F_f we find the deceleration of stroller, a_{br}, with the following equation:

$$a_{br} = \frac{\sin\theta * m * g - F_f}{m} \quad (10)$$

We calculate d_{br} with the following equation:

$$d_{br} = -\frac{v_{cont}^2}{2 * a_{br}} \quad (11)$$

Finally, we calculate the total distance covered from the moment the driver released the stroller, d_{total}:

$$d_{total} = d_{cont} + d_{br} \quad (12)$$

We plot the stopping distance vs. the pulley radius to find the optimal radius of the pulley that would result in the shortest stopping distance. We mark this optimal point with a red asterisk. We repeat these calculations for every gear ratio of the Pololu geared DC motor as shown in Figure 8. We find that the best gear ratio to use is 19:1. The optimal gear radius is approximately 2 cm.

The stopping distance in this scenario is less than 2 m. This is acceptable considering the extreme initial conditions. The contact time (time for brake pads to contact the rims) based on the above calculations is approximately 0.2 s, which meets [R033].

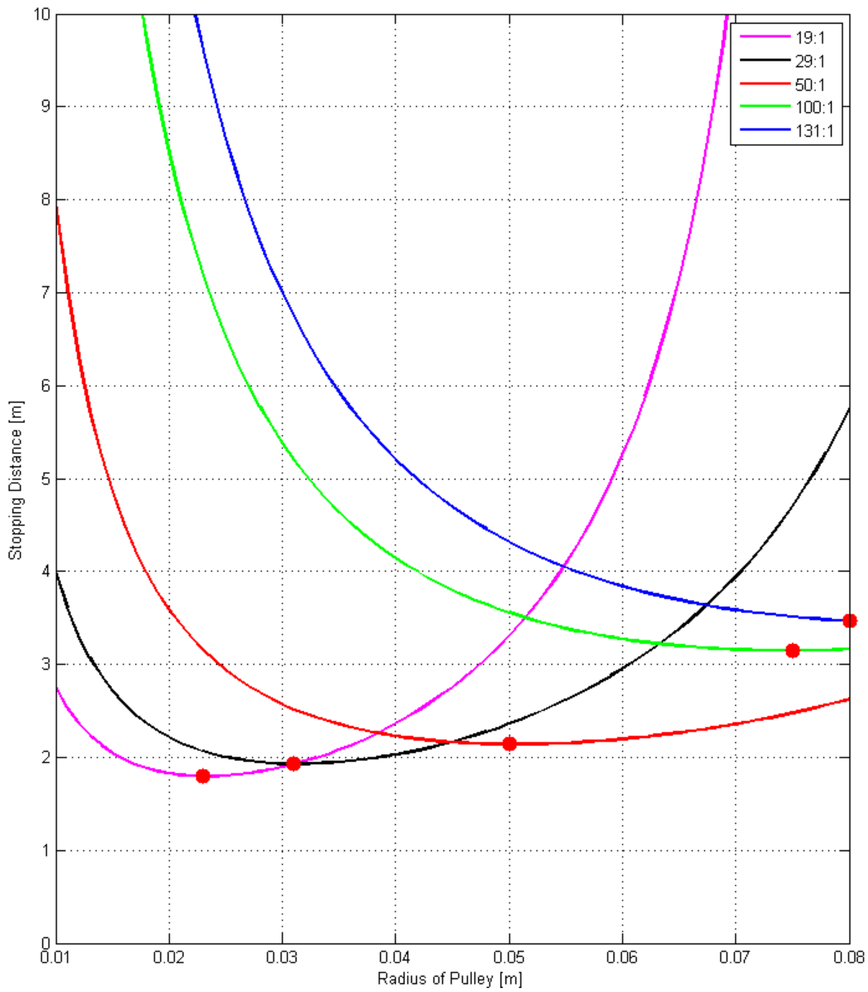

Figure 8: Stopping Distance vs. Pulley Radius for Various Gear Ratios of the Motor

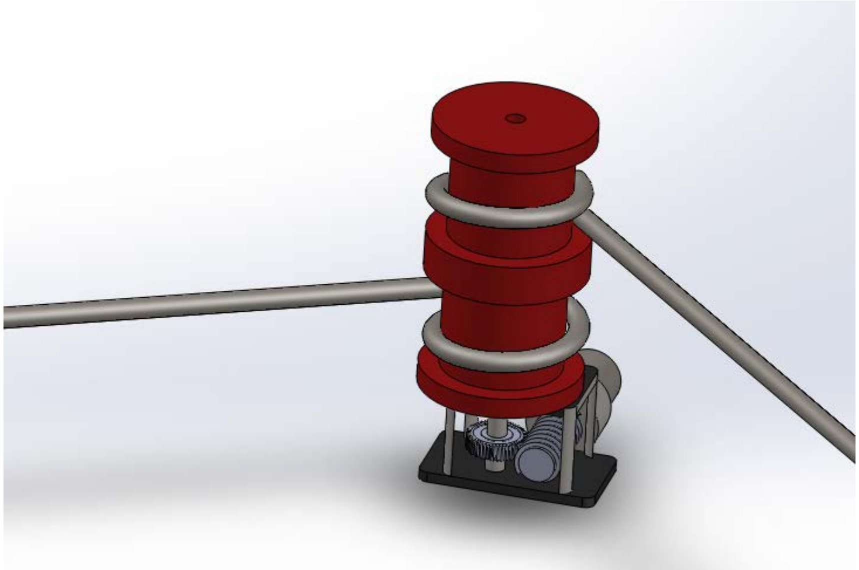

Figure 9: Isometric View of 3D model of Pulley

3.3 Worm Gearbox

The braking system requires large amounts of torque in order for the brakes to engage in a forceful manner as stipulated in [R040]. In addition to a large torque requirement, we also require that the gear be non-back driveable to prevent the brakes from disengaging when power is not supplied to the motor which satisfies [R039] and [R012]. The best solution to this impending problem is the implementation of a Worm Gearbox into the mechanical system.

The motor will drive a shaft in the Worm Gearbox and through a series of gears, the output of the gearbox will have a 30:1 gear ratio. The Worm sacrifices RPM for much needed torque. The more torque that the system outputs, the more normal force we can apply on the brake pads. In addition to an increment of torque, the Worm Gearbox provides the essential added benefit of being non-back driveable. The members of Baby Guerrero selected the Vertical Shaft 30:1 Worm Gearbox to fulfill our mechanical requirements. Figure 10 below showcases the selected Worm Gearbox.

Figure 10: Vertical Shaft 30:1 Worm Gearbox [4]

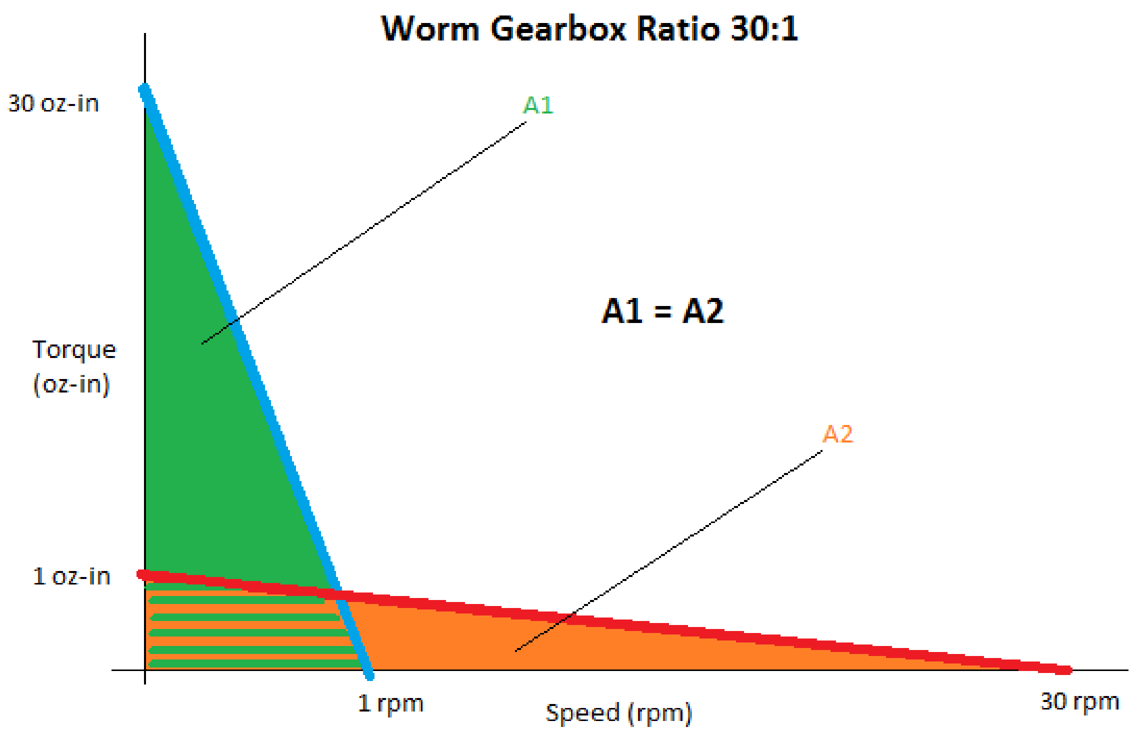

Figure 11: Torque vs. Speed for Worm Gearbox 30:1 Ratio

3.4 Brakes

Bicycle brakes were selected as the primary braking device in the implementation of the smart braking system of the stroller fulfilling [R010]. Bicycle brakes, as opposed to conventional stroller brakes, provide smooth braking fulfilling R028. In addition to the advantageous functionalities provided by ready-made bicycle brakes, they are also cost-effective and easy to install.

In order to fulfill functional requirement [R011] and [R042], an optimal material should be selected for the brake pad to complement the aluminium wheels of the stroller so as to maximise the coefficient of friction. The consequence of selecting an inappropriate brake pad material would lead to extended time taken to bring the stroller to a halt. If more time is taken to stop the stroller, a larger torque would be required from the motor which would increase the cost of the project. Due to tight budget constraints, the selection of the brake pad material would be integral. After much consideration and research, rubber was determined to be the most optimal and cost effective solution. Once all the above functional requirements of the brake pads were taken into consideration, the brakes were selected. Figure 11 below shows the brakes that will be implemented into the stroller. The mount for the brake installation is shown in Figure 12 below.

Figure 12: SuperCycle Long Side-Pull Bike Brake Calipers [5]

Figure 13: 3D Model of Brake Mounting

4 BATTERY

Our battery choice is limited by a few constraints. First, the battery has to be rechargeable [R007]. Also, the battery has to be compatible with the electrical parts including the motor, microcontroller, and other electronic components, so a 12 V battery is required. In addition, the battery has to have enough charge to run for a whole day [R052]. The battery has to be as cost-effective and light-weight as possible. In order to satisfy these requirements, we decided to use a readily available 12 V Lead-Acid 8 Ah battery by GS Battery. This battery is cost-effective and has a high capacity (8 Ah) in a small package. Figure 14 below shows the battery that will be implemented into the prototype design.

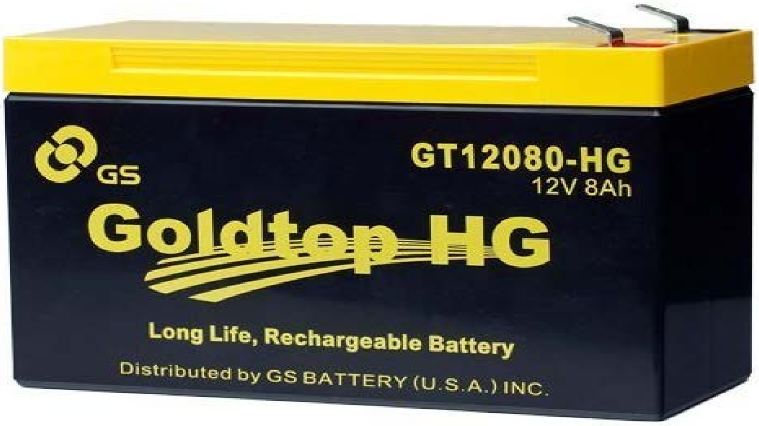

Figure 14: 12 V Lead-Acid 8 Ah battery by GS Battery

5 SENSORS

5.1 IR sensor

The touch sensors serve the purpose of detecting when the user has placed their hands on the handle of the stroller as to disengage the brakes for mobile application of the stroller, and to engage the brakes when they remove their hands. The touch sensors have be easily activated/deactivated to meet [R026]. They have to work in hot and cold weather, even if the user is wearing gloves [R058]. They have to be electrically isolated from the user to eliminate the risk of shock hazard [R068]. Also, they must not interfere with the user's ability to grab the handles of the stroller [R063]. To meet these requirements we choose to use an integrated proximity sensor with infrared emitter, the VCNL3020 from Vishay Semiconductors.

The VCNL3020 operates at low supply voltages in the range of 2.5 to 3.6 V, provides 16 bit proximity resolution giving us a range of up to 200 mm proximity sensing, on chip signal processing, a familiar I2C communication protocol interface [6]. The small size of the VCNL3020, and the proximity sensing feature both comply with requirements [R058,R061,R062,R065], since proximity sensors will not discriminate touches from users wearing gloves.

Furthermore, the VCNL3020 also provides interrupt functionality, making this an ideal chip for our project. Given that the Arduino Uno provides two external interrupt pins, we plan on using two VCNL3020 IR sensors, one for each of the user's hand. However, the microcontroller will only apply the brakes once both hands are off the sensors, differentiating between one hand and two handed touch as per [R059]. Furthermore, the low operating current of the sensor fulfills requirement [R066].

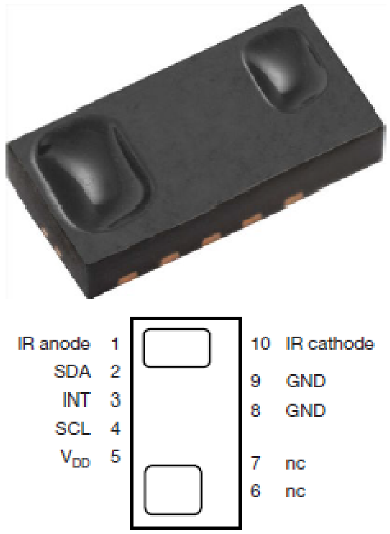

Figure 15: Chip and Pin-out of VCNL3020 IR Sensor

6 ELECTRONICS

The electronic system includes a microcontroller, and a motor driver shield. The design specifications of this system are outlined below.

6.1 Microcontroller

The microcontroller, which is the brain of our system, will be the Arduino Uno. Baby Guerrero Technologies chose this microcontroller because it is simple to use, small in size, and cheap in price. The Arduino Uno will take information from the sensors which are connected to the pins on the board and send signals to control the DC motor which in turn will move the brake according the block diagram of the system is shown in Figure 16.

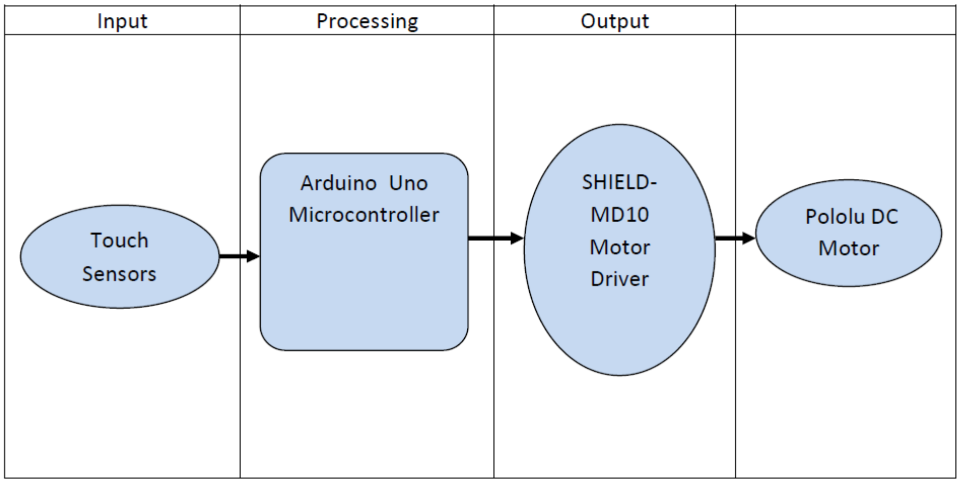

Figure 16: High Level Block Diagram of Electronic System

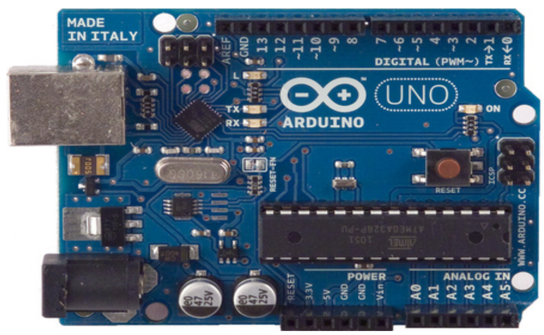

Figure 17: Arduino Uno Microcontroller [7]

6.1.1 Microcontroller Software

The functionality of the microcontroller encompasses not only sensing the touch inputs from the user, but also controlling the motor in charge of activating the brakes through interfacing with the SHIELD-MD10 Motor Driver. The architecture of choice for the software running on the Arduino, given the nature of the project will be implemented as a Superloop architecture. This Superloop architecture, consists of an infinite loop, where incoming events from the touch sensor will be monitored and handled by communicating with the DC motor via the SHIELD-MD10 driver and their corresponding interrupt handlers.

The interfacing between the microcontroller and the SHIELD-MD10 unit will be done through our custom made firmware. The algorithm flowchart for the firmware running on the Arduino is shown in the Figure 18 below. The decision block for user touching sensor will differentiate between single and double handed user touch as per requirement [R058]. The communication between the microcontroller and the SHIELD-MD10 will engage and disengage the brakes according to the user holding and releasing the handle as per requirements [R030,R031].

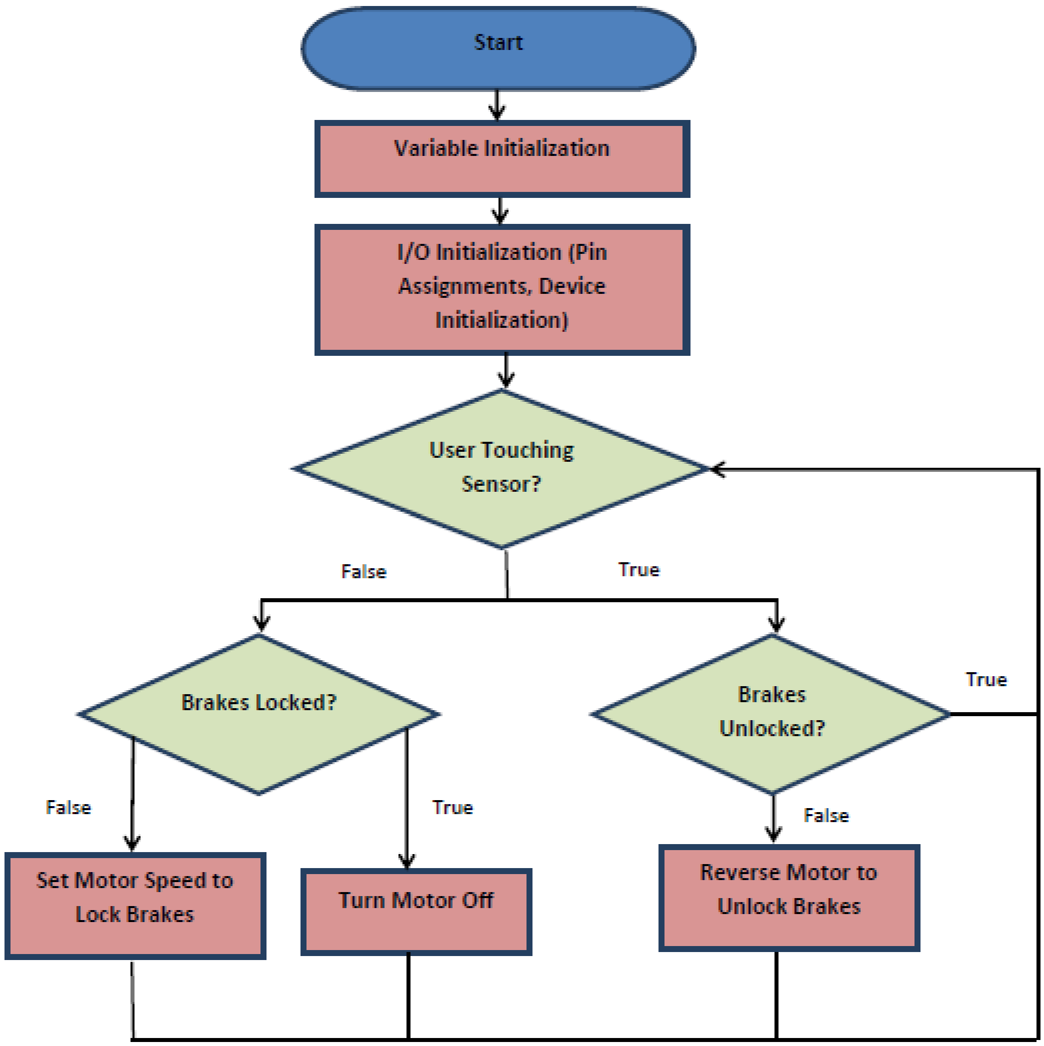

Figure 18: Algorithm Flowchart for Microcontroller Software

6.2 Motor Driver Shield

In order to provide a control interface between the Arduino and the DC motor, we have selected the Cytron 10A Motor Driver Shield (SHIELD-MD10). The selection of this specific motor driver shield is based on our choice of motor, which requires a peak current of 5 amps at stall torque, which falls well within the 10 amps of current that the SHIELD-MD10 is capable of providing. The SHIELD-MD10 comes equipped with the circuitry to control the speed and direction of the DC motor. Furthermore, the SHIELD-MD10 provides a simple interface for the Arduino to control the DC motor which we will be controlling, and comes with plenty of supporting documentation, making the integration of the controller, and ultimately the DC motor a simple task for our team. The SHIELD-MD10 is shown in Figure 19 below.

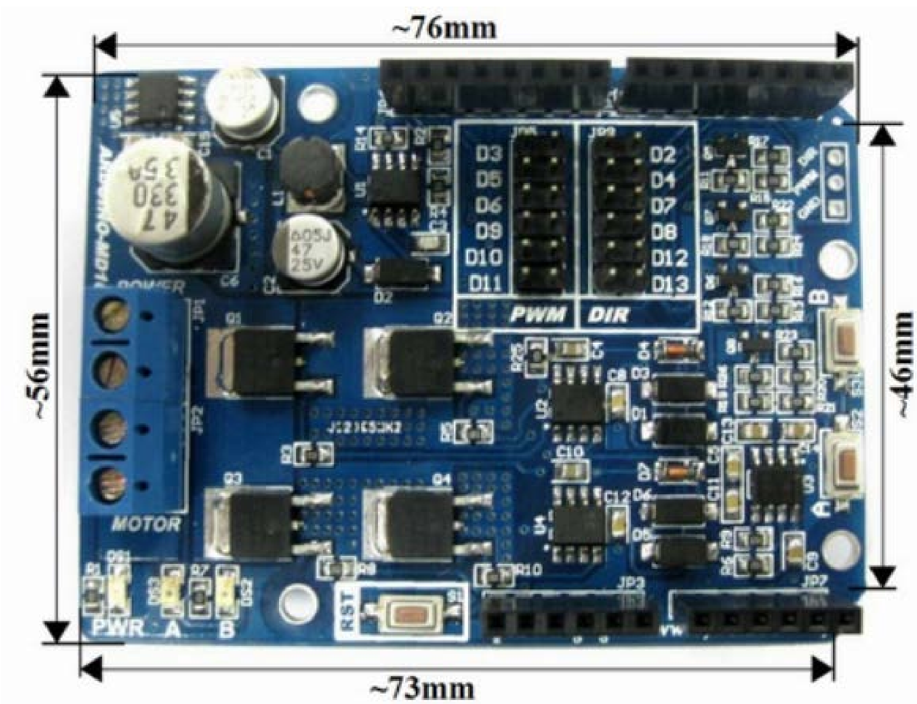

Figure 19: Cytron SHIELD-MD10 Motor Driver Shield [8]

7 SYSTEM TEST PLAN

7.1 Mechanical System Unit Test Plan

The goal of the Mechanical Test plan is to ensure correct functionality of all the moving parts associated with our braking system. That includes the mechanical relationship between the DC motor, the worm gearbox and the brake assembly. Careful thought and planning has to be taken into consideration with the speed of the motor, the speed at which the brakes are engaged and the force applied on the wheel by the brake pads.

1. Test if the brake pads touch the rims when brakes are engaged.
2. Test if the brakes lock the wheels when brakes are engaged.
3. Test if the brakes unlock the wheels when the brakes are disengaged.
4. Test if the brake pads contact the rims under one second from the moment the pads move.
5. Ensure that the stroller still rolls smoothly with brakes disengaged.
6. Ensure that the braking system does not affect the forward, backward and steered movements of the stroller.
7. Ensure there are no sudden or jerking movements present during the braking process.
8. Ensure that the addition of the braking system does not introduce any new pinch points to the user.
9. Ensure that all components of the braking system are securely fastened to the stroller.

7.2 Battery Unit Test Plan

The goal of the Battery Unit Test Plan is to ensure that the battery choice will be sufficient to satisfy all of the related function specifications. A number of tests will be executed in order to ensure that the battery will be powerful enough to drive the motor, as well as a large enough capacity to ensure the specified estimated life specified in the Standard Usage Policy. Tests will also be performed to ensure a high level of safety for the driver and passenger.

1. Test if the battery is supplying power to the system
2. Test if the battery terminals are well insulated.
3. Test if the battery is out of reach of the passenger.

7.3 Sensor Unit Test Plan

The goal of the Sensor Unit Test Plan is to confirm the functionality of the sensor unit as dictated in the Functional Specifications. These test cases were created to ensure that the sensors used are outputting the correct signal which will then be received by the microcontroller. Important test cases are created to verify that no false triggers will be detected to ensure the braking system cannot get unintentionally disengaged.

1. Ensure that the touch sensor outputs the correct signal when user touches it with one hand.
2. Ensure that the touch sensor outputs the correct signal when user touches it with one hand while wearing a glove.
3. Ensure that the touch sensors output the correct signal when user touches them with two hands.
4. Ensure that the touch sensors output the correct signal when user touches them with two hands while wearing gloves.
5. Ensure that the touch sensors output the correct signal when user is not touching them at all.
6. Ensure that the hand sensor does not harm the user when engaging or disengaging the brakes.
7. Ensure that all the sensors are impervious to false triggers (bumps, nudges, vibrations, triggers).

7.4 Electronics Unit Test Plan

In order to ensure the proper functionality of the Baby Guerrero smart stroller braking system, the software running on the Arduino must be thoroughly tested independently prior to integrating it with the various components that make up the smart stroller system. Testing and debugging will be done through the Arduino IDE. Unit and integration testing will be performed upon integrating each of the components with the Arduino. In each case, full code coverage will be ensured. This will be accomplished by setting up various test cases including:

1. Test interaction with the VCNL3020 IR sensors as expected:
    1. Ensure communication between the Arduino and the VCNL3020 working as expected as per I2C protocol
    2. Ensure interrupts for VCNL3020 being serviced appropriately
    3. Ensure interrupts are being triggered by the VCNL3020 chips at the appropriate proximity values
    4. Ensure Arduino differentiates between single and double handed user touch
2. Test interaction with SHIELD-MD10 as expected:
    1. Ensure Arduino is communicating with the SHIELD-MD10
    2. Ensure that the brakes are being applied to fully locked position when user lets go of the sensors.
    3. Ensure the motor being turned to the "Off" mode once the brakes reach the locked position.
    4. Ensure the brakes are being fully released when the user holds the touch sensors.
3. Ensure the algorithm laid out in the flow chart (Figure 18) is executed as expected by performing full code coverage testing.

7.5 Full System Test Plan

Speed of stroller at time of release (m/s)	Angle of Surface (Degrees | %Gradient)			
	0 | 0%		9 | 15.84%	
	Time to Stop (s)			
	Actual	Expected	Actual	Expected
0.0				
1.0				
3.0				

Figure 20: Full System Test Plan

8 CONCLUSION

In this document, we included in detail the technical aspects as well as the design methods used to design the mechanical, electronic and power units of the Smart Stroller Braking System. Also, it provides justification of each method by showing detailed analysis supported by calculations and simulations. Finally, test plans were designed to determine whether the design specifications meet the functionality and features that we intend to achieve by the end of this term.

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