Standing Paraplegic Omni-Directional Transport (SPOT)

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Abstract

Our client is a T12 paraplegic with no use of his limbs from the waist down. This has prevented him from continuing his work as an orthopedic surgeon. In order to return to orthopedic surgery, our client would need to be standing and capable of moving normally throughout the operating room. Therefore, the goal of this project is to design a device which can support our client in a standing position for around two hours and also quickly move him in all directions.

Introduction

Our client, Dr. Garret Cuppels, is an orthopedic surgeon who specializes in both lower and upper extremity surgeries. However, 18 months ago Dr. Cuppels sustained a serious injury to his spine following an accidental fall, causing an injury to the T-12 vertebrae in his spine; the location of the T-12 vertebrae can be seen in Figure 1. An injury to this area of the spine caused our client to lose all voluntary control of movement in his lower limbs and trunk, removing our client's ability to stand and walk. Following this, our client is out of work, as during as lower extremity orthopedic operations, such as hip replacements, our client would be required to remain in the standing position. While looking for possible job opportunity, our client contacted Dr. David Jones at Berlin Memorial Hospital in Oshkosh, Wisconsin. The hospital staff expressed interest in our client but also expressed the need for an additional device that would allow for Dr. Cuppels to perform the movements of a standing surgeon. As such, the basic premise of this project is to develop a device that will allow our client to perform lower extremity surgeries in the standing position. The creation of such a device to support our client in the operation room will need to rival the physical movements of a standing surgeon as well as replicate a surgeon's presence, and take into consideration the physical limitations of T-12 paraplegia. That is, our device must be able to support our client in a non-obstructive way as well as have to potential to move quickly and dynamically along an operation table as necessary, while addressing our client's needs. Therefore, upon considerations of designs to create a stable base that will support our client in the standing position in the operating room, we will need to examine and develop not only stability mechanisms, but also movement mechanisms and user interfaces that will allow Dr. Cuppels to mimic the movements of a standing surgeon.

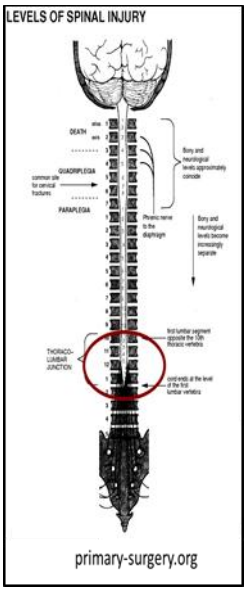

Figure 1: Human vertebral column illustrating levels of spinal cord injuries.

Background

A T-12 paraplegic refers to an individual that has sustained an injury to the T-12 vertebrae in the lower thoracic region of the spinal cord, in which voluntary nerves are either damaged or severed. Depending on the severity of trauma to the spinal nerves, an individual with a lower thoracic spinal injury may experience incomplete or complete paraplegia. Incomplete paraplegia refers to an individual that still experiences sensations and limited movement below the point of injury. Complete paraplegia refers to an individual that experiences a total loss of voluntary control and sensation below the point of injury. Our client can be classified as a complete T-12 paraplegic. This injury, however, does not compromise the use of Dr. Cuppels' hands, arms, abdominal muscles and trunk. Therefore, our client is still able to maintain a sitting balance in a wheel chair. The inability of our client to voluntarily move his legs causes a decrease in blood flow in his lower-extremities. To account for this, it is typically recommended that a T-12 paraplegic utilize electrodes to stimulate lower-leg muscle contractions to stimulate blood flow, or to massage the legs to prevent pooling of blood so that clots do not form. Therefore, In the development of our designs, this decreased blood circulation in our client's legs must be taken into consideration as a factor of patient safety.

Motivation

This project has the unique ability to directly make a difference in an individual's life. By successfully constructing a device that will allow our client to perform surgeries in the standing position we have the opportunity to greatly increase his ability to return to work. Such a device will serve as an example to all those individuals affected by disabilities that they are not defined by their conditions; that with determination everybody has the ability to lead a meaningful and productive life.

Client Requirements

The primary condition specified by our client is that our device must allow for him to perform surgeries within the operating room. The device must prove to be very safe and stable. Additionally, the device must have a minimum foot print within the OR so as to not obstruct surgeries. Since the device is in the hospital setting, it must comply with hospital, insurance, and FDA regulations, which will be examined further in a later section. The device must be easily cleanable and portable between surgery rooms. It

must be able to rotate clockwise and counterclockwise, allow for vertical, horizontal, and transverse translation and provide our client with the ability to lean over patients. Finally, our device must instill confidence in our client's patients; a device that is aesthetically pleasing and will provide Garret's patients greater assurance in his abilities.

Current Devices

Market Competitions

There are many products currently in production that assist individuals with paraplegia. The most common or frequently used item is the wheelchair. Although the wheelchair has been around since the 6th century, there have been many fascinating improvements over the years (BBC). Today, there are motorized wheelchairs, standing wheelchairs, and even commercial products that help transport non-handicapped people (ie. Segways). These products could be useful for our client in everyday use; however, a more specific design will need to be developed for his use in the operating room. The main goal of our research on current devices focuses on the mechanism that allows paraplegics to function in a standing position. Furthermore, there are devices known as *standing frames* that may be most useful to this particular project. Standing frames are currently used by patients who benefit from the freedom of standing. They do not have wheels for transportation, but rather remain stationary. Our device needs to incorporate this and serve a crucial functional role as well.

Regulations

Before consideration of design options and ideas, it is necessary to obtain a thorough understanding of the rules and regulations that govern this type of device. As one might imagine, guidelines in the healthcare field are strict. There are many layers of accountability that a device, its makers, and its users must face. First, and foremost the device must be safe for any patient in the operating room. Second, the device must insure client's own safety while he is performing the surgery. And thirdly, the device cannot inhibit or restrict the movement, function, or communication of any other person or machine in the operating room. There are three entities that help to insure that these parameters are met: (1) the United States Food and Drug Administration (FDA), (2) the insurance companies that protect the hospitals and surgeons, and (3) the hospital itself, in our case Berlin Memorial Hospital in Berlin, Wisconsin.

FDA

The first regulatory body that is a concern for us is the Food and Drug Administration. The FDA regulates what is considered a medical device, which by their definition is:

"an instrument, apparatus, implement, machine, contrivance, implant, in vitro reagent, or other similar or related article, including a component part, or accessory which is:

- recognized in the official National Formulary, or the United States Pharmacopoeia, or any supplement to them,
- intended for use in the diagnosis of disease or other conditions, or in the cure, mitigation, treatment, or prevention of disease, in man or other animals, or

• intended to affect the structure or any function of the body of man or other animals, and which does not achieve any of its primary intended purposes through chemical action within or on the body of man or other animals and which is not dependent upon being metabolized for the achievement of any of its primary intended purposes." [2]

Our device would likely fall under this definition as it could be seen as a way or mitigating our client's paralysis as well affecting the structure and function of his body. In order to determine the regulations, the next step would be classification. The classifications are as follows:

1. Class I General Controls
   - With Exemptions
   - Without Exemptions
2. Class II General Controls and Special Controls
   - With Exemptions
   - Without Exemptions
3. Class III General Controls and Premarket Approval [3]

Looking at similar devices, it is likely that our device would end up Class I if it is purely mechanical and Class II if it includes electronics. However, exact classification would be impossible without a final design. The likely outcome would be to submit a 510(k) for premarket approval as well as PMA approvals. Requiring clinical trials could be another possibility, as well as none of the previously mentioned regulations and only registration of the device.

After talking with Michael Courtney who is in charge of the FDA's Orthopedic Spine, Orthopedic Joint and Physical Medicine Rehabilitation Branch, it was determined that since we would be making an individual device that wouldn't be commercially sold that the FDA wouldn't not regulate our device in any way. This allows us much more freedom in our design, and allows us to avoid a lengthy process which would require many a resource. However, it is still important for our design to follow the standards that the FDA has put in place for medical devices. These standards, thing such as using certain materials and accounting for a certain degree of safety, will help ensure that the device is safe, reliable, and functional. It will also help instill confidence in our client as well as his patients which is very important as well.

Insurance

Insurance company compliance is necessary because without coverage it would be difficult for a surgeon to practice. Surgeons need malpractice insurance for protection in case something goes wrong during surgery. This issue is pertinent to our project, because our device directly affects our client's ability to perform a surgery. Jan Pankratz, an assigned risk consultant of the liability insurance company MMIC was able to shed some light on this area of concern. Moreover, MMIC is the company that insures Dr. David Jones, the surgeon who brought our client's situation to our attention. Jan assured us that as long as our client is competent, privileged by the hospital to practice, does not have a history of malpractice, or drug abuse he would be covered by their firm. Additionally, Jan said that the insurance company is not concerned with FDA approval of devices like ours.

Hospital

Though our group plans to visit Berlin Memorial to get a more realistic idea of the space constraints in the OR, we have spoken with the head of the OR at Berlin Memorial, Kathy Roehl. Ms. Roehl provided us with a basic idea of the regulations on our device set by the hospital. The device must fit through the

doors of the OR, which are 1.95 m tall and 1.52 m wide; the device must not be permanently attached the floor of the OR; and the device must be cleanable with Virex spray, a powerful disinfectant. Ms. Roehl also indicated that any device place in the OR must be FDA approved. As we have already spoken to the FDA and found that they are not set up to regulate devices like this, we must receive a commitment from Berlin Memorial to allow a non-FDA approved device in the OR.

Final Design

The Standing Paraplegic Omni-Directional Transport (SPOT) is an electronically controlled platform mounted on four mecanum wheels and is driven by a 4-axis motion controller with motors. The platform's movement is controlled by a joystick mounted on the support rails. It will have a desired speed of .25 m/s (slightly slower than walking speed) and will have a desired acceleration of .2 m/s^2 (it will reach top speed in approximately 1 second). By use of mecanum wheels this platform is omni-directional, meaning that it can move in any direction at any time. This includes translation perpendicular to the rolling direction of the wheels. The omni-directional nature of the mecanum wheels is due to the passive rollers tilted at a 45 degree angle mounted all around the wheel. These rollers change the direction of the movement vector by 45 degrees based on the direction of the rollers. Determining the direction of the entire four wheeled platform is based on adding the separate diagonal wheel vectors to form one large movement vector, Figure 2.

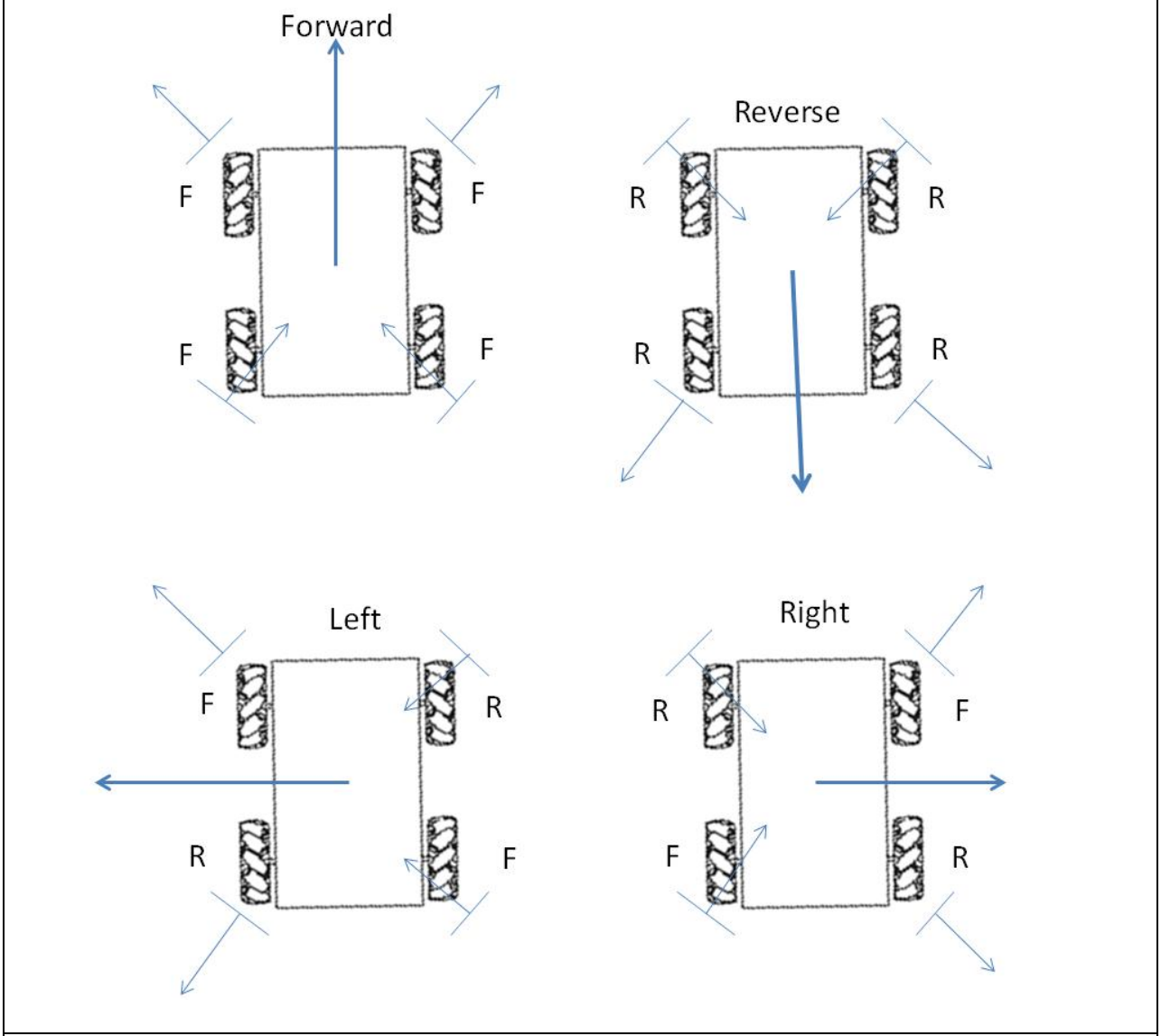

Figure 2. This figure shows how moving the mecanum wheels in different directions can create any direction of motion.

This platform is designed so that custom leg braces or a seating system could be mounted to the floor of the bot so that Dr. Cuppels could be secured in an upright position during surgery. Dr. Cuppels leg braces would be mounted approximately 6 inches from the front edge of the platform so that he will be able to be very close to the operating table. The base would have a low profile of approximately 2.5 feet by 3 feet and weigh approximately 250lbs. This will allow for a factor of safety of at least 2 to prevent tipping of the device.

Motor and Wheel Assembly

I. Introduction

This section illustrates a motor and wheel assembly that does not need gears, and utilizes a long steel axle for extra strength.

II. Discussion

After talking to AndyMark on 2/15/12, the representative, Andy B., recommended purchasing an empty Toughbox 31, and then inserting our own heavy-duty bearing. The representative also recommended not using 2 AndyMark Toughboxes, but instead just mounting a flush bearing to an outer square tube of aluminum. We will then be able to use a 7" long solid steel shaft for the axel between an outer flange bearing and inner linear bearing. To attach the motor to the axel shaft we will use a spider coupling. This will eliminate the problem of gear ratios and gear alignment. The linear ball bearing inside of the AndyMark Toughbox is 2.375" in length allowing this bearing to bolt to the inside edge of the outer portion of the Toughbox and then fit snuggly with the pre-cut .875" diameter hole on the opposite of the Toughbox. This design should create no stress on the motor shaft, and create a very strong axel to chassis configuration.

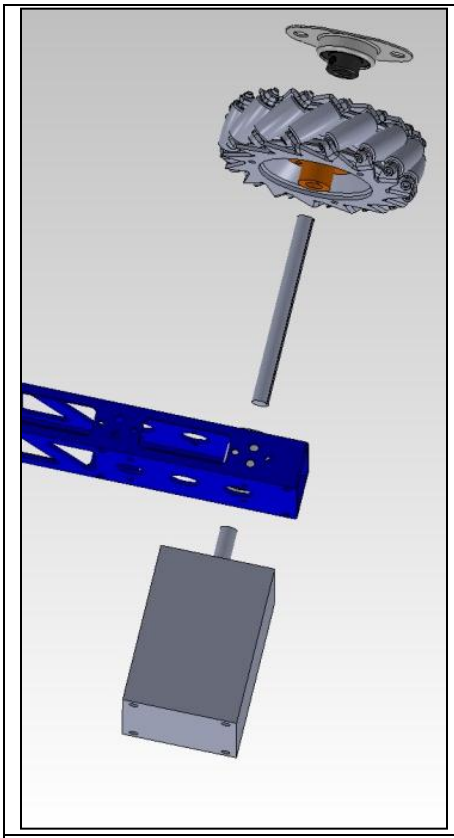

Figure 3. Picture shows TPP 34 electrocraft motor aligned with a linear shaft bearing mounted inside of the AndyMark Toughbox. The bearing is also lined up with a 7" long steel slotted axel, the wheel hubs, and a final flange bearing on the other side of the mecanum wheel.

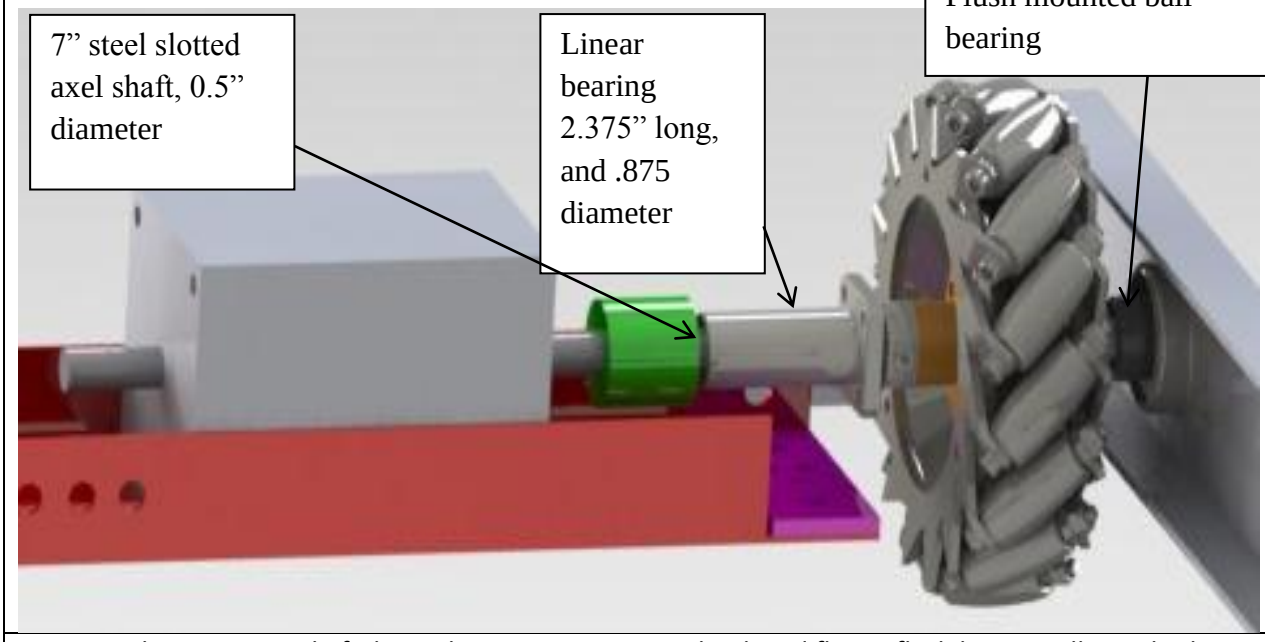

Figure 4. Shows motor, shaft, linear bearing, mecanum wheel, and flange flush bearing all attached into a single assembly. The Toughbox has been omitted from the figure, but will surround the linear bearing. The motor will be attached to the shaft by a flexible coupling.

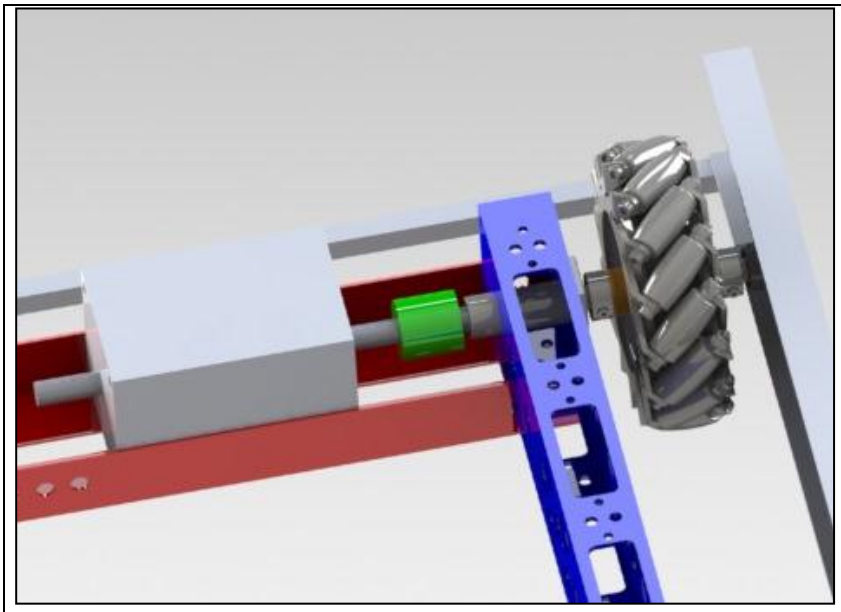

Figure 5. Shows full assembly of motor, Toughbox, linear bearing, wheel hubs, mecanum wheels, steel shaft, and flush flange bearing.

III. Conclusion

This type of construction of the wheel assembly will allow for a 1:1 power ratio from the motor to the mecanum wheel. It also enables the team to use a solid 7" steel shaft as the axle, and mount it between two bearings. This will result in a very strong axle configuration, and also allow for minimal force upon the motor shaft. One item not shown in the figures is the flexible coupling, which will be used to connect the motor shaft and the steel axle shaft. Finally, this solution may be cheaper and stronger than purchasing and modifying the full Toughbox assembly from AndyMark.

Theoretical Base Testing

I. Introduction

This section describes the front-to-back tipping analysis as it relates to the total weight and length of the omni-directional operating room device.

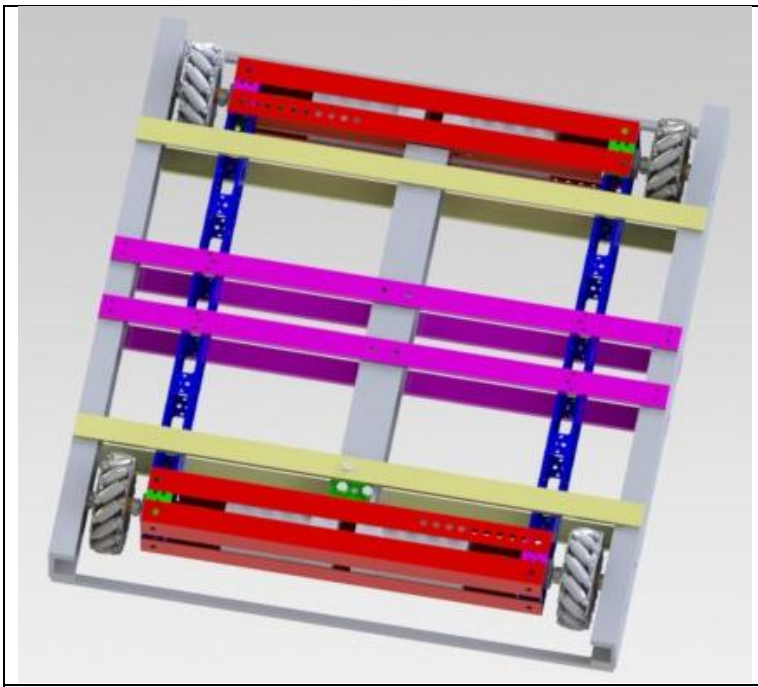

Figure 6. This figure shows the SolidWorks drawing of current base design.

II. Discussion

Free Body Diagram:

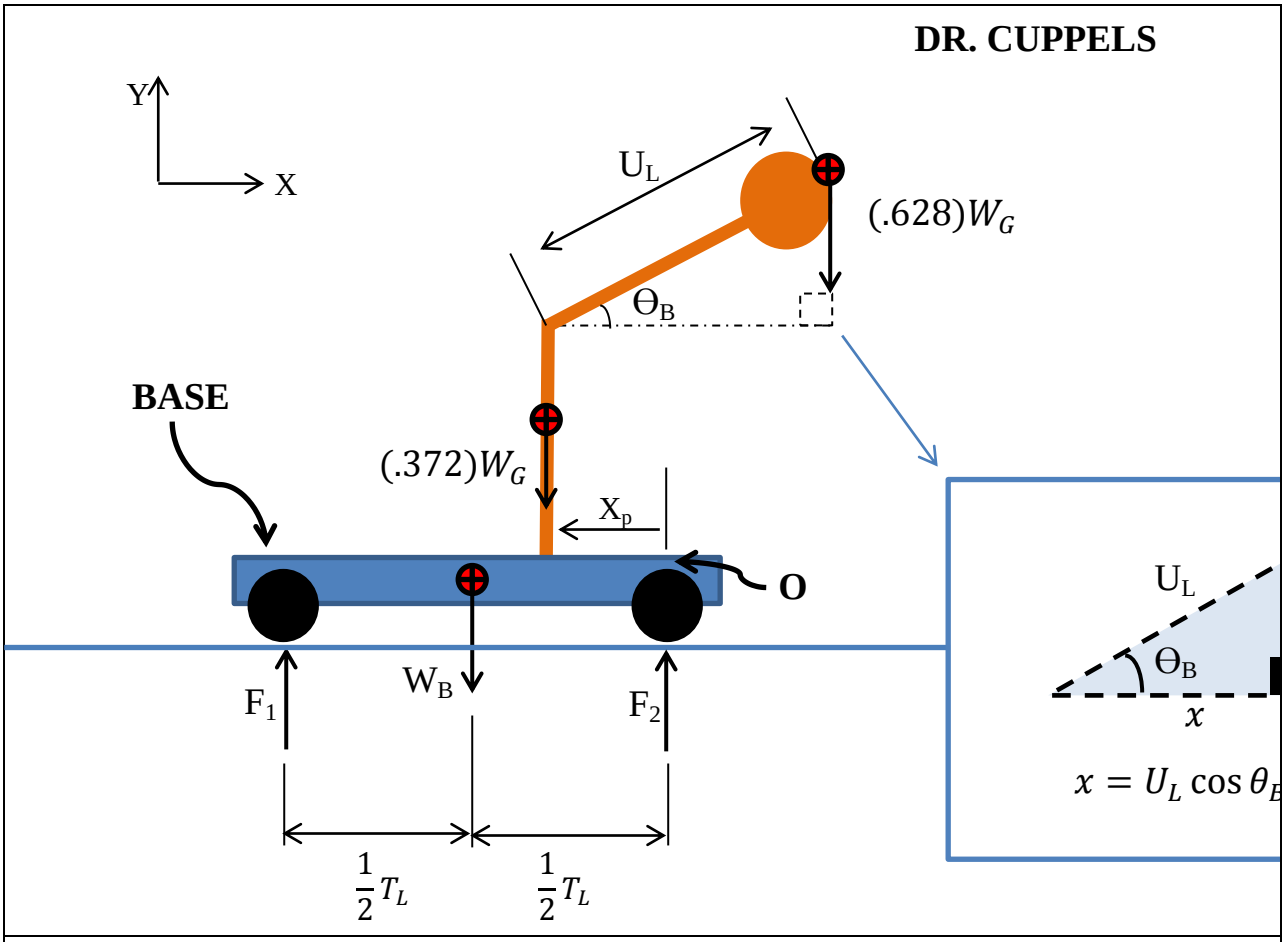

Figure 7: Illustration of the free body diagram for the omni-directional device when it is being using in the operating room.

Labels:
F_1 = Friction force on both of the back wheels
W_B = Total weight of the base
F_2 = Friction force on both of the front wheels
T_L = Length of the base from the center of the back wheels to the center of the front wheels
U_L = Distance from Dr. Cuppels' hips to his upper-body center-of-mass
Θ_B = Dr. Cuppel's angle of inclination
W_G = Dr. Cuppel's total weight
X = Horizontal distance from Dr. Cuppels' waist to his upper-body center-of-mass
O = Position directly below Dr. Cuppels' feet

Assumptions:
U_L = 2ft. 10in. (0.8595m). This distance is 47% of Dr. Cuppels' total height which is representative of the total length of his upper body (Herman). Placing Dr. Cuppels' upper body center-of-mass at the top of his head will account for at situation in which he has his hands fully extended with heavy tools in grip.
Θ_B = 20° (0.35rad.). This is the smallest angle of inclination that will be allowed by the device.
W_G = 823 N. This weight in Newtons corresponds to 185 lbs. (83.9kg), which is Dr. Cuppels' current weight.

Position 1: Dr. Cuppels standing directly over the front wheels, $X_p = 0$

The moment that the base begins to tip the F_1 force will become zero, effectively removing the back wheel from the operating room floor. In the static situation, we can sum the moments about point O (eqn. 1), and find an equation (eqn. 2) describing W_B, or Dr. Cuppel's weight.

$$\sum M_O = 0 \rightarrow -F_1(T_L) + W_B(0.5 \times T_L) - (0.628 \times W_G)x = 0 \quad \text{(eqn. 1)}$$

Solve for W_B

$$W_B = 2F_1 + \frac{(1.256)W_G x}{T_L} \quad \text{(eqn. 2)}$$

Choosing various T_L values allows for a comparison between the total weight and total length of the base, Figure 8.

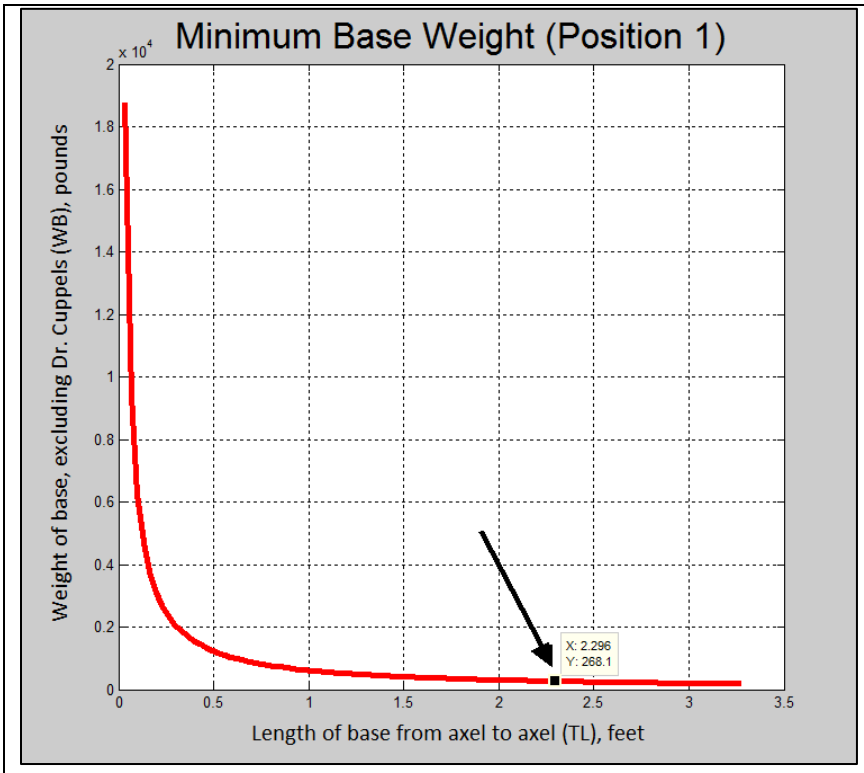

Figure 8: Graphical illustration of the relationship between total base weight and length with respect to the tipping point.

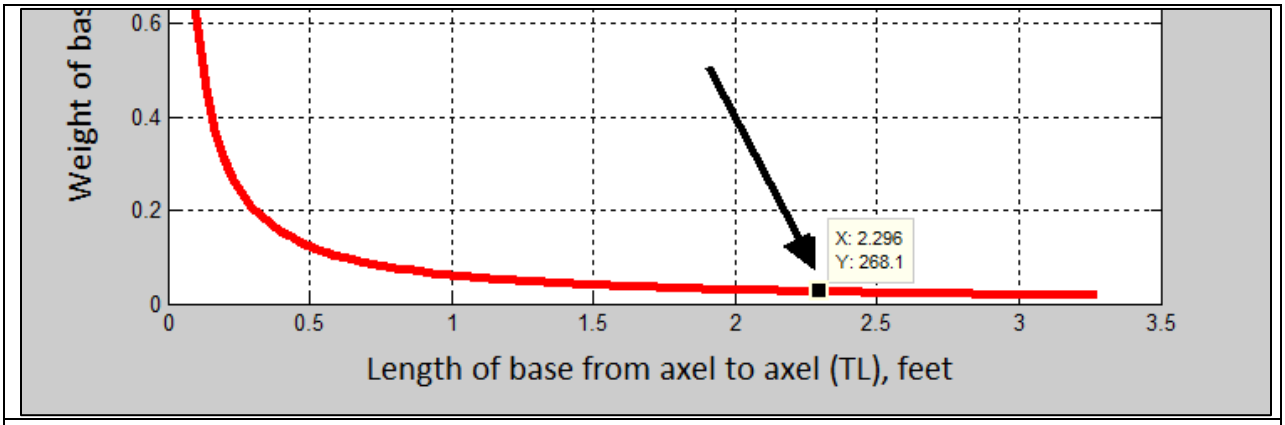

Figure 9. A closer look at the graph in Figure 8.

In conclusion, at a base length of 2.296 ft. (27.5 in.) the base would begin to tip at 269 lbs. The design that we plan to build will measure 27.5 in. from axel to axel, so if the stability mechanism that will hold Dr. Cuppels is located directly over the front wheels the base will need to weight a minimum of 269 lbs. Also, note the assumptions taken while making this calculation.

Position 2: Dr. Cuppels' standing over the center of the base, $X_p = \frac{T_L}{2}$

Again, the moment that the base begins to tip the F_1 force will become zero, effectively removing the back wheel from the operating room floor. In the static situation, we can sum the moments about point O (eqn. 3), and find an equation (eqn. 4) describing W_B, or Dr. Cuppel's weight.

$$\sum M_O = 0 \rightarrow -F_1(T_L) + W_B \cdot \left(\frac{T_L}{2}\right) + (0.372)W_G \cdot \left(\frac{T_L}{2}\right) - (0.628 \cdot W_G) \cdot (x - X_p) = 0 \quad \text{(eqn. 3)}$$

Solve for W_B

$$W_B = 2F_1 + W_G \left[\frac{(X_p(1.256) - x(1.256)}{T_L} - (0.372)\right] \quad \text{(eqn. 4)}$$

Solving this equation for any value of T_L always gives a negative base weight. This means that tipping cannot happen in this situation unless the base is being pushed upward from below. In other words, with the current assumptions, if Dr. Cuppels is positioned in the center of the base, there is no chance it will tip.

Position 3: Dr. Cuppels standing halfway between the front wheels and the center of the base, $X_p = \frac{T_L}{4}$

Again, the moment that the base begins to tip the F_1 force will become zero, effectively removing the back wheel from the operating room floor. In the static situation, we can sum the moments about point O (eqn. 5), and find an equation (eqn. 6) describing W_B, or Dr. Cuppel's weight.

$$\sum M_O = 0 \rightarrow -F_1(T_L) + W_B \left(\frac{T_L}{2}\right) + (0.372)W_G \cdot \left(\frac{T_L}{4}\right) - (0.628 \cdot W_G) \cdot (x - X_p) = 0 \quad \text{(eqn. 5)}$$

Solve for W_B

$$W_B = 2F_1 + W_G\left[\frac{(X_p(1.256) - x(1.256)}{T_L} - (0.186)\right] \text{ (eqn. 6)}$$

Choosing various T_L values allows for a comparison between the total weight and total length of the base, Figure 10.

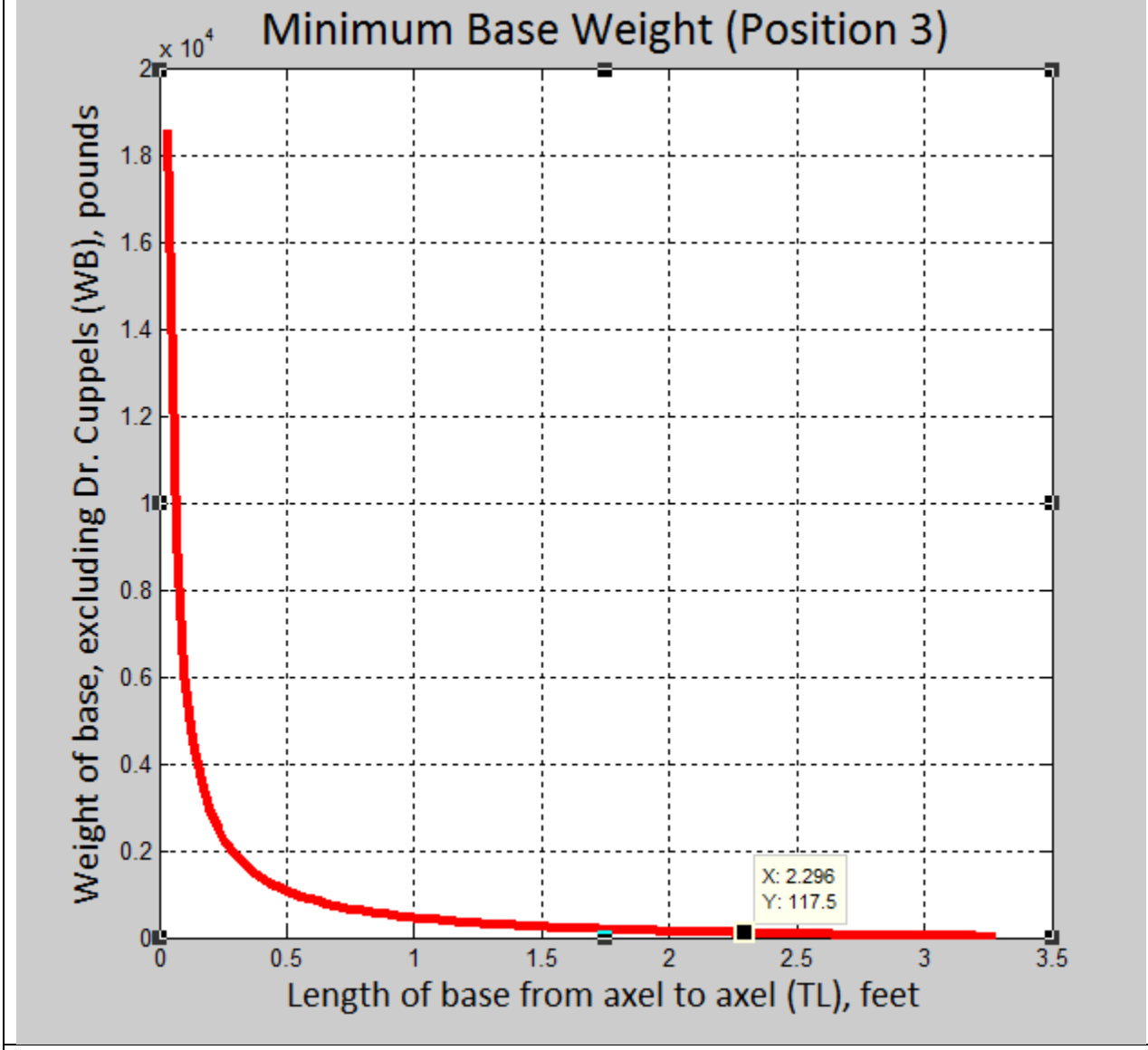

Figure 10. Graphical illustration of the relationship between total base weight and length with respect to the tipping point

In conclusion, at a base length of 2.296 ft. (27.5 in.) the base would begin to tip at 118 lbs. The design that we plan to build will measure 27.5 in. from axel to axel, so if the stability mechanism that will hold

Dr. Cuppels is located half way between the center of the base and the front wheels, then the base will need to weight a minimum of 118 lbs. Also, note the assumptions taken while making this calculation.

III. Conclusion

Minimum Base Weight for Various Positions		
Front	*Middle*	*Halfway Forward*
269 lbs.	No Tipping	118 lbs.

Figure 11. Base weight summary table.

In a static situation, using Dr. Cuppels' current height and weight, minimum tipping weights can be determined by taking moments about point O in figure 1. Using some reasonable assumptions stated above, the minimum weight of the base when Dr. Cuppels is standing directly over the front wheels is 269lbs. When Dr. Cuppels is in position two, directly over the center of the base, the base cannot tip, and when Dr. Cuppels is halfway between the front wheels and the middle of the base, it must weigh 118 lbs.

Circuit Diagram

I. Introduction

The purpose of documentation is to record the mechanism by which circuitry integrates brakes, motors, and the user-interface of the joystick into workable, coherent device. A diagram of the circuit is shown in Figure 12. A key for this diagram is found in Figure 13.

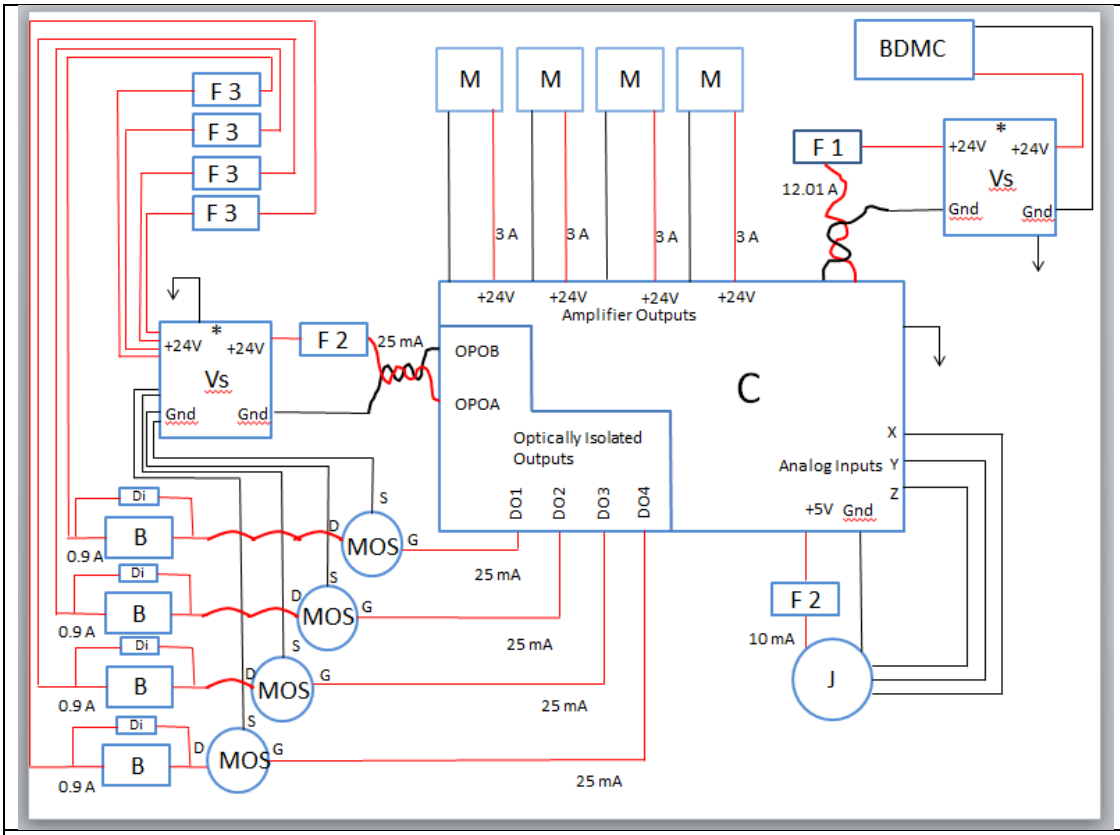

Figure 12. Circuit diagram for entire electrical system.

Circuit Diagram Key:	Vs – Power Supply
M – Motor	DO$_n$ – Optically Isolated Digital Outputs
F$_n$ – Fuse$_{Type}$	OPOB and OPOA – 25mA Sourcing Optically
X, Y, Z – Axis	Isolated Ground and Supply Ports
C – Controller	—— Power
J – Joystick	____ Ground or Feedback
B – Brake	* Same Power Supply
Di – Dissipation Diodes	
IGBT – Isulated Gate Bipolar Transistor	Notes
D – Drain	The motor wiring is simplified to only one
S – Source	power line and one ground line, but in reality
G – Gate	each motor will have four to six leads. The
Gnd – Ground	BDMC has not been designed yet; its diagram is
	therefore inherently simplified as well.

Figure 13. Corresponding Key for Circuit Diagram.

There are four main sections to the Circuit: Braking system, motors, the joystick, and batteries. These sections are described below as well as how they are integrated into a single system.

II. Joystick

As shown in the bottom right portion of the Figure 12, the joystick has two leads, +5 V and relative ground, with an expected 10mA draw. A fuse is included in F2 for protection. Depending on the position of the joystick, in the x, y, or z directions, there will be a different voltage output corresponding to the angle of displacement from O°. An example for the change of voltage outputs a change in angle deflection for the x-axis is shown below in Figure 14.

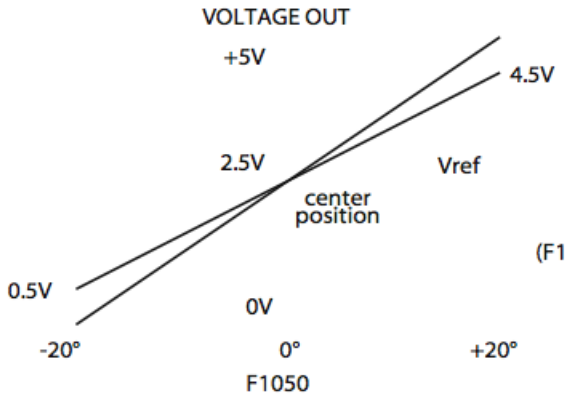

Figure 14. Voltage output and angle deflection graph for joystick [3].

As can be seen in Figure 14, each axis can deflect from -20° to +20° causing a change in the output voltage of the axis terminal from 0.5 V to 4.5 V, respectively. The controller can read each output axis independently. Thus the controller can use this 3-axis joystick output to control the desired movement in the motors.

III. Motors

The motors are controlled directly by the controller as a result from the user-input in the three joystick axes. Upon being stimulated by the user-inputs the controller will send a 3A current at 24 V to each motor, eliciting the movement of the wheels and the desired directional control of SPOT. This portion of the circuit is fairly straightforward. Each motor has 4 wires that have 4 corresponding terminals on the controller. We will likely have to crimp longer wires as a go between from the motor location and the circuit box, which will be discussed later.

IV. Braking System

In this portion of the circuit, which is in the right portion of Figure 12, a 24 volt battery will be used to power the entire system. Here, current will pass from the battery through a 1.5A fuse, F3, and will follow to a brake in parallel with a diode, or protection. After this, the current will reach an insulated gate bipolar transistor (IGBT). The IGBT serves as a gate to control the current through the brake system. When a voltage is applied to the gate terminal, the IGBT acts as a short and allows current to pass through the brake, releasing the brake's resistance and allowing the wheels to turn. The IGBT is controlled through the optically isolated terminal of the controller, which in turn is powered through the same type of fuse, F2, mentioned in the joystick section.

V. Batteries

The entire system will be powered from two 24 V batteries in parallel with one another. If we use lead-acid batteries, we will not need a battery drainage management circuit (BDMC) to monitor the drainage between the two batters. This, however, will be needed with other batteries such as lithium-ion batteries. The batteries will power the optically isolated terminals with + 24 in OPOB and relative ground in OPOA. The motor and joystick portion of the controller will be powered through a direct connection with 6 terminals in the controller, after passing through a 15 A fuse, F1.

Testing Voltage Protection in Brake Circuit

I. Introduction

Here, protection elements and subsequent testing for the brake circuit for the purposes of eliminating voltage spikes is documented. As the brakes are quickly powered on and off by activation of the gate terminal of the IGBT, there is a need to protect the system from any violent voltage spikes that may damage circuit components such as the IGBT relays. As such, diodes (1N4004-E3/54) are used in parallel to eliminate any voltage spikes.

II. Diode Protection Mechanism

In the Brake circuit, the brake acts as an inductor. As an inductor, V = L(di/dt). Thus, as the current in the system is quickly turned off or on (like a step function), the voltage in the brake circuit can theoretically increase to infinity. While this is not possible in reality, there is nonetheless the possibility of a large voltage spike in the brake due to a near instantaneous control of current flow in the circuit, possibly damaging equipment. With the integration of a diode in parallel with the brake, the residual current and subsequent increase in voltage in the brake will be routed through the diode instead of through other circuit elements. As such, the increased voltage and current will loop between the brake and the diode until it is dissipated, greatly decreasing the incidence and magnitude of voltage spikes seen as an output of this circuit.

III. Experimental Results

The voltage spikes of the brake circuit with and without protection diodes in parallel are illustrated below.

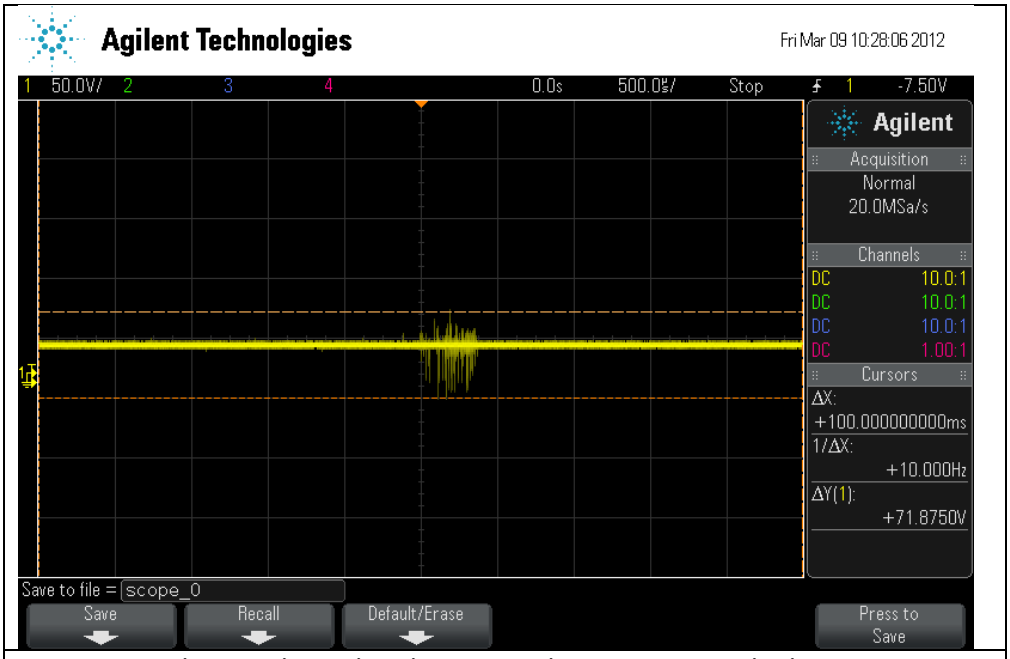

Figure 15. Voltage spikes in break circuit without protection diodes.

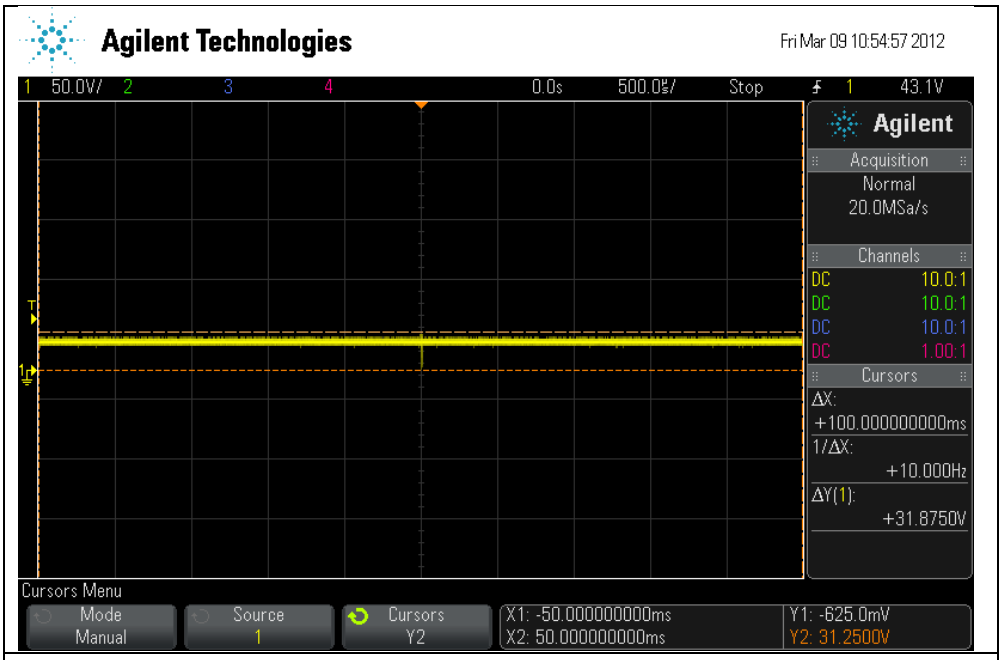

Figure 16. Voltage spikes in brake circuit with protection diode in parallel.

As can be seen in Figures 15 and 16, the integration of the diode into the brake circuit not only significantly decreases the incidence of voltage spikes, but also reduces the magnitude of these spikes from around 70 V to 31 V.

IV. Conclusion

The integration of diodes into the brake circuit greatly reduces voltage spike magnitude and occurrence, due to the diodes ability to loop current through the brake/inductor element from its parallel placement and directional current flow. This greatly reduces the risk of voltage spikes that have the potential to harm equipment from reaching more fragile, expensive elements.

Sourcing Brake System

I. Opto-Isolated Output and Brake

The 41×3 motion controller from Galil Motion Control contains an opto-isolated output, allow for electronic control of the brakes on the wheels. The sourcing opto-isolated output is shown below in Figure 17.

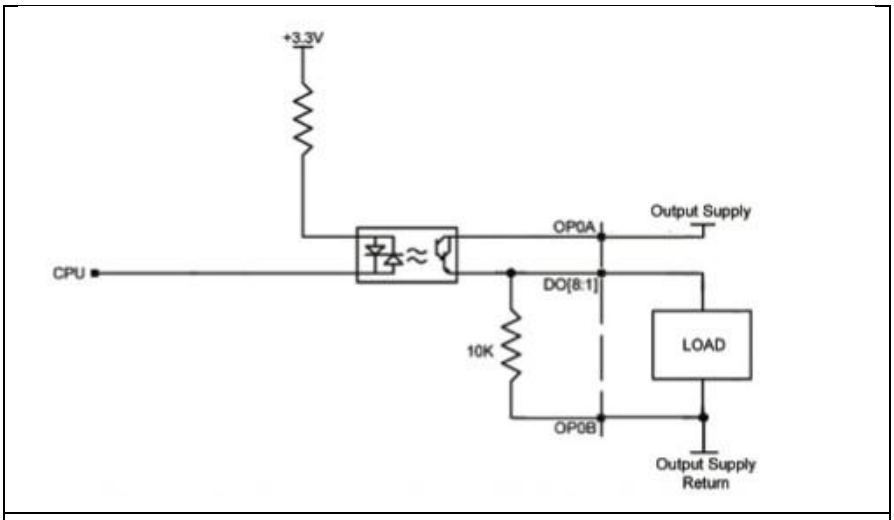

Figure 17. Sourcing opto-isolated terminal from Galil.

The left portion of this circuit in Figure 17 contains the actual optical component of the entire system. When a specific voltage is applied within the motion controller, the two diodes will emit light to a bipolar junction transistor (BJT) transistor, essentially changing the transistor from an open to a short circuit, allowing for current to flow. The right portion of figure one shows a vertical dotted line with three specific markings on the line. This is the right-most edge of the internal components of the motion controller with the three markings: OP0A, DO (8:1), and OP08 being three ports on the controller. The "Load" of this entire system will comprise the actual braking system, shown below in Figure 18.

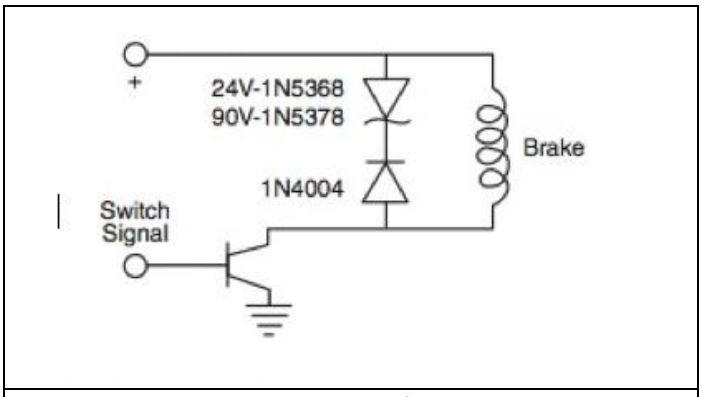

Figure 18. Braking circuit layout for series.

Here in Figure 18, the brake is noted by the inductor symbol. The two diodes in parallel with the brake serve to protect the brake from a large spike in voltage when this circuit is powered, given that in an inductor V=L(di/dt). For this brake to operate properly, it needs to be supplied with +24 V at the positive terminal, while maintaining a +24 V at the "switch signal." If the +24 V is removed from the "switch signal," the transistor will act as an open circuit and causing the brake to engage. When the +24 V is applied to the "switch signal," the transistor will act as a short circuit, allowing the brake to disengage.

Placement of this brake into the sourcing component of the 41×3 Galil Motion Controller can be seen below in Figure 19

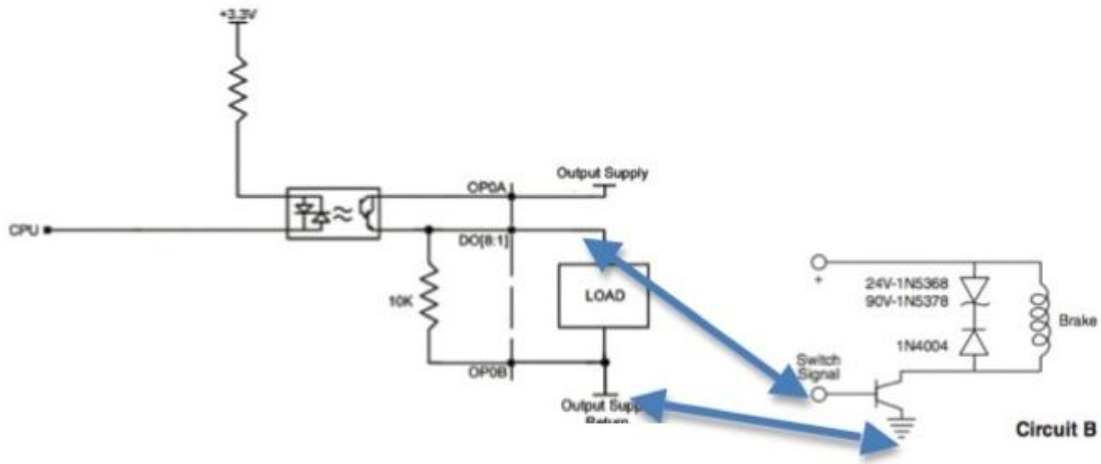

Figure 19. Connection of the sourcing opto-isolated output of the motion controller with the braking system.

.

The "switch signal" terminal of the motor is attached to DO[8:1] and the ground terminal of the motor is attached to the OP0B terminal from the controller (both relative grounds).

II. Operation

Release of Brake

The motion controller would have the "output supply" set to 24 V external to the motion controller and the positive terminal of the motor would also be set to 24 V. Upon an internal signal from the motion controller, current is to be passed between the +3.3 V and CPU terminals, emitting light from the diodes. This light from the diodes causes the transistor to change from an open circuit to a short circuit. In doing so, the 24 V from the "output supply" terminal will connect to the "switch signal" of the brake. By exposing the "switch signal" to 24 V, the transistor acts as a short circuit and allow current to flow through the brake, thus deactivating the brake.

Initiation of Brake

When the user desires to stop, an internal signal will current flow through the diodes in the motion controller, stopping the generation of light. In the absence of light, the internal transistor in the motion controller will become an open circuit, preventing the 24V of the "output supply" from reaching the "switch signal" of the brake. Without this 24V supply the transistor in the brake will act as an open, preventing current flow through it. Here, the current in the brake will loop through the portion of the circuit containing the inductor and the two diodes (as a property of the zener diode, not mentioned here) until the energy dissipates through internal resistance. At this point, the brakes will reengage.

Programming

I. Introduction

The SPOT design utilizes a Galil motion controller which needs to be custom programmed. This program needs the following functions: read the position of the joystick, set speed of each motor independently, engage/disengage the brakes, and shutdown at the push of a kill switch. The Galil controller needs to be programmed in Galil's DMX code.

II. Discussion

Currently, code has been written which meets two of the four basic functions, reading the joystick position, and independently adjusting the motor speeds. While this code has yet to be testing, it passes the proof-reading provided by the GalilTools software. The first major round of testing will be done with a test circuit containing the joystick, Galil controller, one wheel, and one brake. It should prove to disengage the brake when the joystick is moved from the neutral position and adjust the speed of the motor. It should also re-engage the brake when the joystick is in the neutral position. Once the base is completed, heavy testing must be done with the program. The appropriate maximum motor speed (dependent on the weight of base and safety of use) will be determined and adjusted within the code. The accuracy of the motion compared to the intended motion must also be tested.

III. Programming code:

```
'Third version (1.0.2 pre-alpha) of SPOT code without brake or kill switch
'This version of the code was written without the Galil controller
'13Mar2012 Blake Marzella
#AUTO
#A
ST;                                          'Stops any current motion
'NEED CODE TO ENGAGE BRAKES HERE
JS#B,(@an[2]<>2.5);                          'Jump to label #B when joystick is not in the
neutralz
JS#C,(@an[3]<>2.5)|(@an[4]<>2.5);            'Jump to label #C when joysitck not neutxy
JP#A;                                        'Jump back to label #A if joystick is neutral
#B
JS#A,(@an[2]=2.5);                           'Jump back to label #A if joystick is returned to
neut
z=@an[2]
'NEED CODE TO RELEASE BRAKES HERE
JG 7000*(z-2.5)/2.5,-7000*(z-2.5)/2.5,7000*(z-2.5)/2.5,-7000*(z-2.5)/2.5;          'Rota
JS#B;
#C
JS#A,(@an[3]=2.5)&(@an[4]=2.5);              'Jump back to label #A if joystick is neut
xpos=@an[3]
ypos=@an[4]
p13=((xpos-2.5)/2.5)+((ypos-2.5)/2.5)
p24=((ypos-2.5)/2.5)-((xpos-2.5)/2.5)
'NEED CODE TO RELEASE BRAKES HERE
JG 7000*p13,7000*p24,7000*p13,7000*p24;
JS#C;
```

Ethical Considerations

All engineers, especially biomedical engineers, must take into consideration the ethical aspects of their designs. The first fundamental canon in the NSPE Code of Ethics for Engineers is “Hold paramount the safety, health, and welfare of the public” [7]. If our device were to fail, it could lead to injury not only to our client, but his patients as well. Normally devices like ours would be regulated by the FDA to help ensure safety and reliability. Since the only regulation our device would need to meet is hospital approval, the burden of proving the safety of our devices is shifted more on to us. This makes it very important for us to take the necessary steps and precautions to produce a safe and reliable device. This will be done primarily through testing, but also by choosing high quality materials, being careful during building, and meeting OR standards. These steps will need to be taken regardless of whether or not the hospital approves our device without them. This is necessary to ensure the level of quality needed.

Quality of our device doesn’t solely depend on preventing failure but also on its ability to enable our client to adequately perform surgery. It wouldn’t be ethically sound for us to produce a device which would hinder our client’s surgical skills. If our client isn’t able to perform at a level comparable to before

his accident, it may endanger his patients. In order to ensure this, our client will need to practice thoroughly with the device and possible be recertified using it. Only then will we satisfy the ethical requirements of an engineer.

Future Work

With the bulk of the base, circuit, and programming design work completed, the design team's primary goal moving forward the integration of all of these independent elements. Upon completion of the physical circuit, the electronics need to be combined with the base, utilizing water-tight seals. The completion of the physical circuit will also enable for testing of the programming. That is, by having the motors, joystick, and brakes all correctly interfaced with the controller, the programming can be more efficiently tested and further improved. With the integration of the mechanical, electrical and programming features of SPOT, the design team will begin user testing.

In performing user testing with the initial constructed device, the design team will be testing the capabilities of SPOT as would be required in the OR setting. In order to test the stability of the base, the user of the device will be placed in a number of positions and the risk of failure of the system will be measured at each position. In order to test the durability and capabilities of the design, the design team will have SPOT perform specific maneuvers that would be expected in the OR. As such, the velocity of SPOT will be measured as well as its effectiveness in instantaneously changing directions. Following this, the design team will focus on testing and improving the safety of the device's human interface. Finally, the design team intends to perform testing with Dr. Cuppel s in an OR setting to understand how the device can be improved to more specifically assist Dr. Cuppels' surgical performance.

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Appendix

PDS

Standing Paraplegic O.R. Device

Updated: October 11, 2011

Justin Cacciatore, Michael Konrath, James Madsen, Blake Marzella, Bret Olson

Advisor: Amit Nimunkar

Function/Problem Statement:

To design and construct a device that will enable our client, a T-12 paraplegic, to perform standing orthopedic surgeries in the O.R. for up to three hours. The device should allow the client to cover a range of motions including: clockwise and counterclockwise rotation, as well as vertical and horizontal translation. It must be stable, serviceable, compact, cleanable, portable, safe, comfortable, affordable, and comply with hospital standards. Our intention is to design and construct a device for our client over the timeline of two semesters.

Client Requirements:

- Must allow for standing O.R. procedures
- Be able to rotate clockwise and counterclockwise
- Must support vertical and horizontal translation
- Stable, compact, portable, cleanable, safe, comfortable, affordable
- Comply with hospital standards
- Be in use for up to 3 hours
- Support client build of 6’1’’ 215 lbs, safety factor of 2
- Device must leave small footprint in O.R
- Less than $10,000
- Materials capable of being autoclaved
- 10 years of device use
- Make of simple, easily fixed parts
- Easily disassembled – easier portability, cleanability

Design Requirements:

Our final constructed device will be designed and constructed for intended used by our client within a hospital O.R. setting. As such, all appropriate hospital standards as well as the functional standards of the device must be considered.

1. Physical and Operational Characteristics

A. Performance Requirements:

- Support a 6'1'' individual weighing 215 lbs in a standing position for up to three hours
- Able to support clockwise and counterclockwise rotation, and vertical and horizontal translation.

B. Safety

- Must not harm the client during periods of use lasting up to 3 hours
- Pose no risk to contamination of O.R. environment – easily cleanable and stable

C. Reliability

- Able to withstand a service life of 10 years
- Be composed of materials that can take consistent cleaning (possibly in an autoclave)
- Made out of easily serviceable parts
- Disassembles easily for cleaning

D. Life of Service

- Consistent use within O.R. hospital setting for 10 years.
- Must be easily cleanable for O.R. setting
- Portable device within minimum footprint

E. Operating Environment

- Must comply with hospital and O.R. standards

F. Ergonomics

- Device must be comfortable for client during periods of extended use
- Small footprint so as to not interrupt the environment/work space of others in the O.R.

G. Size

- Small footprint in the O.R. as to not be obstructive

H. Weight

- As minimum a weight as possible for easier portability

J. Materials

- Common materials and components that could be easily serviceable incase of breakdown
- Materials that are easily to clean up to O.R. standards
- Possible consideration of autoclavable materials
- Easily disassembled parts

K. Aesthetics, Appearance, Finish:

- Minimum O.R. footprint
- Device that instills confidence in potential patients of our client

2. Production Characteristics:

A. Quantity: 1 Deliverable

B. Target Product Cost: Less than $10,000

3. Miscellaneous

A. Standards and Specifications

- We must adhere to O.R. and hospital standards for use.

B. Customer/Patent Related Concerns

- None identified through current research

C. Competition

- While there are standing wheel chair devices on the market, none of these devices specifically relate to our client's needs. That is, a device that can be used within an O.R. setting. As such, competition, through the current research, is not a primary concern.