ME4001 - Mechanical Design Project

Project Report

Body Movement Wheelchair

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1 Introduction

Wheelchairs have been the source of mobility for people with difficulty in walking due to injury, illness or other due to other reasons. They help these people to overcome their physical limitations and go on about their daily life by helping them in locomoting between necessary places. To operate these traditional wheelchairs, a certain amount of physical strength and coordination is required. However there are a wide variety of physical limitations faced by specially challenged people and not all of them possess the abilities to operate traditional wheelchairs. Traditional wheelchairs also cannot be used for commuting long distances as the users will suffer from physical fatigue while manually driving these wheelchairs over a period of time. These difficulties have given rise to electric wheelchairs which do not require any physical efforts from the user.

Electric wheelchairs address most of these issues because to operate them physical endurance and strength is not the major requirement for using them. It helps in commuting long distances by making use of energy stored efficiently in batteries which are also usually rechargeable[1]. In recent years, the use of electric wheelchairs has increased tremendously due to the advantages provided by them. Their costs have also been decreasing due to technical advancements in battery and motor efficiency and costs. Electric wheelchairs have two motorized wheels powered using a battery. They are controlled using a small joystick placed on the armrest which is generally operated using the user's thumb. Figure 1 shows a typical electric wheelchair along with the joystick used. Depending on the user's abilities and comfort, they can also be controlled using the user's chin or foot.

(a) An electric wheelchair (b) A typical wheelchair joystick

Figure 1: An electric wheelchair with a joystick

The psychological impact that the use of an electric wheelchair has on specially challenged people is transcendental. It has a positive impact on the life of its users and improves their social participation. So it is very essential this is made accessible and usable to all specially challenged people who need them[2]. Electric wheelchairs require its users to control the joystick precisely using their body movements. Patients suffering from cerebral palsy or those who have suffered spinal injury accidents are not usually capable of this level of control and precise movement. This issue prevents these users from operating an electric wheelchair and hence require another person to help them to move from one place to another in a traditional wheelchair. Thus it is essential to develop a control system overcoming these limitations so that electric wheelchairs could become accessible and usable to these users.

2 Problems being addressed

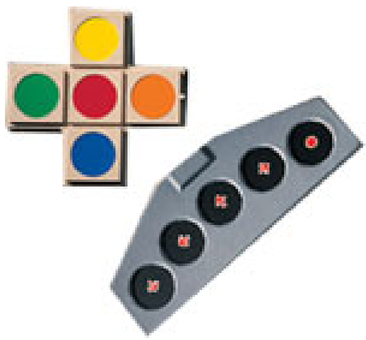
Cerebral palsy (CP) is a chronic condition where patients are unable to fully control muscles, body movement and coordination. The condition usually originates before birth or during infancy, often due to trauma or lack of oxygen to the brain. Cerebral palsy symptoms may include spasticity, muscle spasms, involuntary movements, seizures, disturbance in gait and mobility, as well as impairment of sight, speech and hearing. There are three different cerebral palsy types: spastic, ataxic, and athetoid or dyskinetic[3].

A spinal cord injury (SCI) is damage to the spinal cord that results in a loss of function, such as mobility and/or feeling. Frequent causes of spinal cord injuries are trauma (car accident, gunshot, falls, etc.) or disease (polio, spina bifida, Friedreich's ataxia, etc.). The level of injury to the spinal cord is helpful in predicting what parts of the body might be affected by paralysis and loss of function. Besides a loss of sensation or motor function, individuals with spinal cord injury also experience other changes[4].

The patients suffering from cerebral palsy or spinal cord injury in several cases do not have a lot of physical strength or coordination. These abilities are the very elementary requirements of operating the joystick of an electric wheelchair. Thus electric wheelchairs are not operable by many of these patients and therefore they are deprived of an opportunity to go about their daily life with its assistance. The people under this bracket can only perform gross body movements in a coordinated manner. These gross motions also differ a lot as some could do only upper body movements, some lower body movements, some only head movements and so on depending on their cases. Figure 2 shows the different control systems available other than the conventional joystick. Even these systems do not address the problems faced by cerebral palsy patients. Taking into account all these facts, the development of a solution to make electric wheelchairs usable to these patients is necessary.

(a) T shape joystick

(b) Head Controller



(c) Wafer Board Controller

(d) Chin Controller

Figure 2: Various Control Systems for Electric Wheelchairs

To avoid any sort of injury to these patients wheelchairs made for them should incorporate adjustable backrests, footrests, etc with ample cushioning and safety straps. These have to be necessarily implemented to specifically cater to these patients. The biomedical team of R2D2 lab have also been consulted for any such specific requirements and the problems to be addressed have been listed down based on their inputs.

3 Solutions

Developing a solution to make electric wheelchairs involves coming up with a solution to sense the gross body movements that these users can perform. We need to come up with a control scheme which defines what movements performed by the user lead to what actions of the wheelchair. Since different types of these users can perform only certain specific movements in a controlled manner, sensory apparatuses capable of specifically measuring them is one approach. For example for users capable of head movements distance sensors could be placed in different directions around the head to track its motion. For users capable of gross hand movements such as just lifting or lowering them, arm-bands with IMU's and other motion sensors can be used to track its motion. The issue at hand is that the diverse cases require a non-exhaustive list of sensors and thus we need to take a different approach which broadly captures these different motions in a single manner. We can observe that in all of these motions the centre of mass of the user changes in different degrees based on the mass of the part moved and the degree to which it is moved. So if we can capture the change in centre of mass for all these different movements using a single sensory apparatus and calibrate it to the degree to which it will vary for an individual user then that will serve as an universal system for these brackets of patients. The centre of mass position can be calculated by using a system of load cells with the number of load cells being 3 to determinately perform the calculation. It should be ensured that the entire weight of the user is directly transferred through the load cells directly.

To this end we have designed the Body Movement Wheelchair - an electric wheelchair which can be controlled using gross body movements without the need of a joystick.

These wheelchairs are equipped with load cells placed at strategic locations under the seat to determine the user's body posture by identifying their weight distribution and thereby the centre of mass. This is then used to calculate the direction and speed of the wheelchair. To control this wheelchair, the user simply has to lean in the direction they want to move. These wheelchairs can be calibrated for each user according to their range of body movements and body posture for accurate control. On top of being a mobility device, this can also be used as a therapeutic device for rehabilitation.

We have designēd two variants of the wheelchair - one suitable for adults and the other for children. The pediatric version has been designed to be modular ensuring adequate postural support. Both the wheelchairs have been designed keeping in mind the safety and comfort requirements of the users. In the following sections, the detailed design process for the development of the wheelchair has been discussed.

4 Control System

The wheelchair control system has been designed so that gross body movements can be used for specifying the direction and speed of the wheelchair. This system works by identifying the body posture of the user by measuring the position of their Centre of Mass (COM) and based on this position, the wheelchair moves accordingly. For example, if a person leans forward, their COM would move to the front and this difference in the COM's position is measured and the wheelchair is commanded to move forward. Similarly, if the user leans backward the wheelchair is commanded to move backward. If the user leans to their left or right the wheelchair rotates anticlockwise or clockwise respectively. For users who can only move certain specific body parts, the degrees of variation of centre of mass will be different and therefore the change of speed or direction based on centre of mass variations should be calibrated accordingly.

To measure the position of COM of the user, three load cells are placed under the seat of the wheelchair. These load cells are placed at specific locations and based on the weight distribution amongst the load cells the COM's position can be calculated.

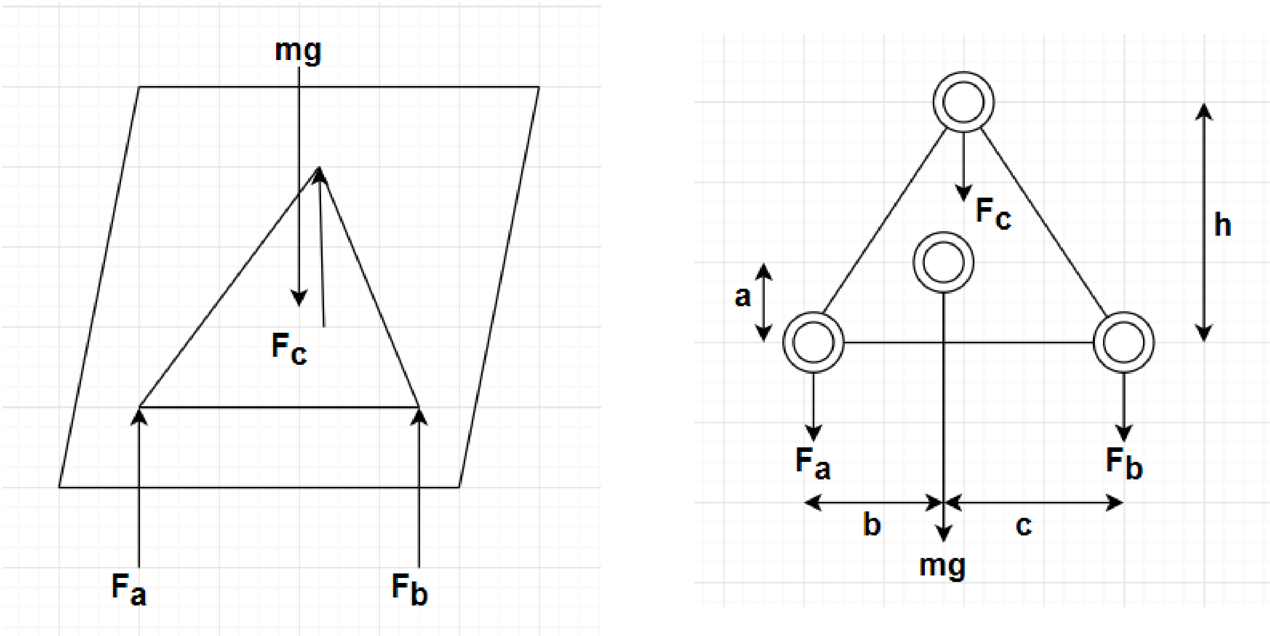


Figure 3: FBD for the wheelchair system

$$mg = F_a + F_b + F_c \tag{1}$$

$$mg * b = F_c * (b + c) \tag{2}$$

$$mg * a = F_c * h \tag{3}$$

There are 3 equations with 3 independent unknowns mg ,b and a. F_a, F_b and F_c are known from the load cell readings. h and $(b + c)$ are known from the CAD.

The above relations can be used to calculate the position of the COM. This system is sensitive to the body weight while determining the velocity of motion and hence needs to be calibrated for each user separately. This calibration also has to factor in the user's natural body posture and their range of body movements.

5 Mechanical Design

5.1 Adult Wheelchair

To ensure faster testing and ease of manufacturing, the adult version of the Body Movement Wheelchair has been designed using an existing Neofly wheelchair as the base. This ensured that we could develop and test the proof-of-concept prototype in a short time. The Neofly wheelchair is a manual wheelchair from Neomotion. To cater to the requirements of our device, we replaced the wheels with motorized hub wheels which could be powered using a 24 V battery. These wheels also have an electric braking system which ensures the safety of the user.

For load cell based control of the wheelchair, the entire weight of the user has to be transferred to the wheelchair frame through the load cells. This means that all the components that the user rests their weight on have to be coupled to the wheelchair frame entirely through the load cells. This is required to calculate the body posture accurately. To ensure this, we have designed the wheelchair such that the entire base of the wheelchair along with the backrest and footrest are fixed on top of the load cells. These load cells are then connected to the bottom of the wheelchair which also consists of a special electronic box which houses the battery and all the other electronic components. Suitable modifications to the Neofly wheelchair have been made to accommodate these changes. Figure 4 shows the 3D model of the wheelchair.

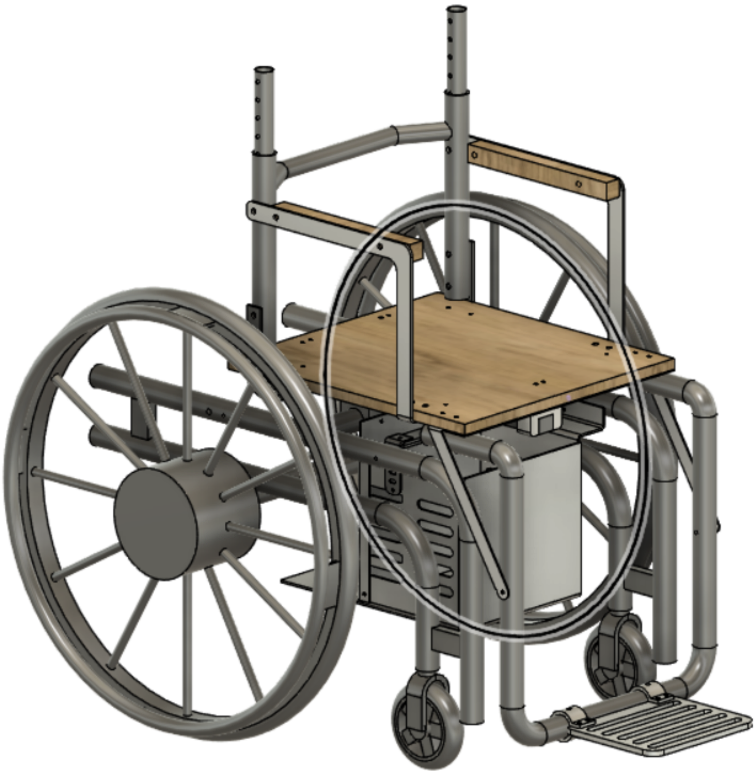


Figure 4: CAD model of the adult version of the wheelchair

5.2 Pediatric Wheelchair

The pediatric version of the wheelchair has been designed as a completely standalone version without using any old wheelchair as a base. The major aim of this version of the wheelchair was modularity, postural support and comfort for children along with the novel control system. This wheelchair is also meant to be used as a rehabilitation device for children. Keeping these objectives in mind, we have developed a modular electric wheelchair suitable for children between the ages of 6 - 18.

For this wheelchair, instead of using hub motorized wheels, we have used a pair of 250 W and 75 rpm rated 12V DC motors. This was due to the fact that hub motorized wheels were not available in smaller dimensions and also for economical reasons as the long term goal is to develop this as an affordable product. Modularity was ensured in the design. The backrest height and angle, footrest height, position of the headrest can be changed easily according to the user's comfort. These have been incorporated to aid the physical safety of the user while operating the wheelchair. Additional adjustable chest support plates have been included for postural support. Straps have been placed on the footrest and backrest to provide additional support to the user. Adequate cushioning has been added in the seat, under the thigh, arm rest, backrest and headrest.

The frame of the wheelchair is made of 18 mm OD, 14 mm ID mild steel bent pipes which are welded together to form the frame of the wheelchair. A 15 cm dia castor wheel has been identified for this and its bearing coupling is custom designed with the connector to the frame made of mild steel to facilitate welding to the frame. Motorised back wheels have been identified from Callidai vendor and the coupling to the frame has been designed based on the CAD details shared by them. An electronics mount is designed in this frame below the seat using CNC bent sheet metal plates to house the electronics of the wheelchair. A special casing has been designed using a thermoforming process to give the wheelchair a car like appearance to enhance the appeal to pediatric users. The parts have been designed for a 2.5 mm thickness with necessary drafts and clearances . Connectors to assemble them to the mainframe have also been custom designed. Figure 5 shows the 3D model of the wheelchair

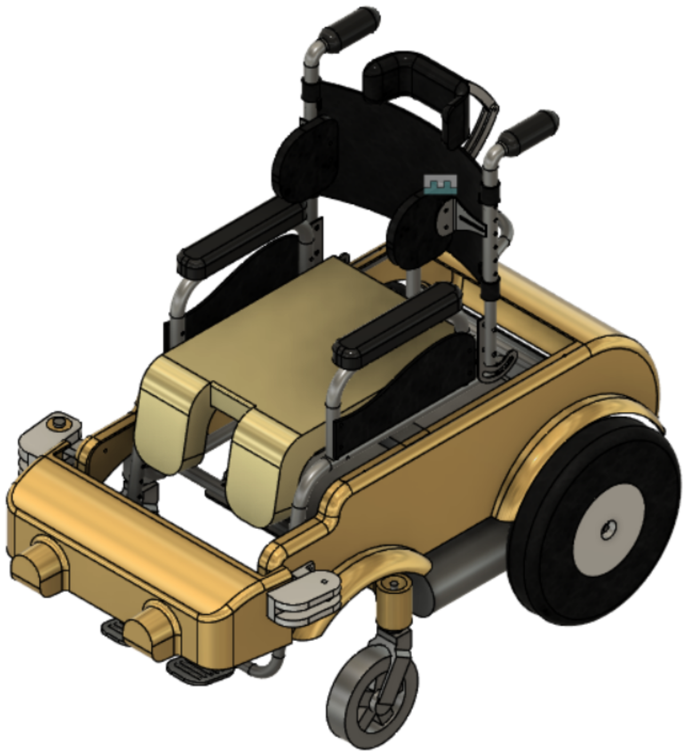


Figure 5: CAD model of the pediatric version of the wheelchair

The entire top portion of the wheelchair which includes the seat, armrest, backrest and footrest is attached to the bottom frame through 3 load cells placed under the seat. Most of the above components are made of 18mm OD, 14mm ID mild steel bent pipes. The seat is provided with a cushion made from PU foam and wire-cut to the required dimension providing support to the legs as well. The arm rest is welded to the base of the seat. The back rest is fixed to the base using a custom connector which enables angle adjustment of the backrest from -15° to +15°. The height of the back rest can also be set at multiple heights over a range of 100mm. The design ensures that the adjustments can be done in a hassle free manner. The back rest is covered using a fabric which provides additional support to the user and is provided with multiple straps to fully secure the user to the wheelchair. The chest support plates are also attached to the back rest. The head rest is connected to the back frame of the wheelchair through a 4 bar linkage. This enables the head rest to adjust along 2 DOF enhancing the comfort of the user. The foot rest is also made adjustable in a similar fashion. .

6 Simulation Studies

Simulation studies have been performed on both the wheelchairs to ensure structural stability and safety for both static and dynamic loads. Based on the results of these studies, appropriate modifications have been made to the designs ensuring safety and integrity of the wheelchairs. The final results have shown that the wheelchairs have an adequate minimum factor of safety of 3.034 under static load conditions. Impact studies have also been performed on both the wheelchairs. Figure 6 shows these results.

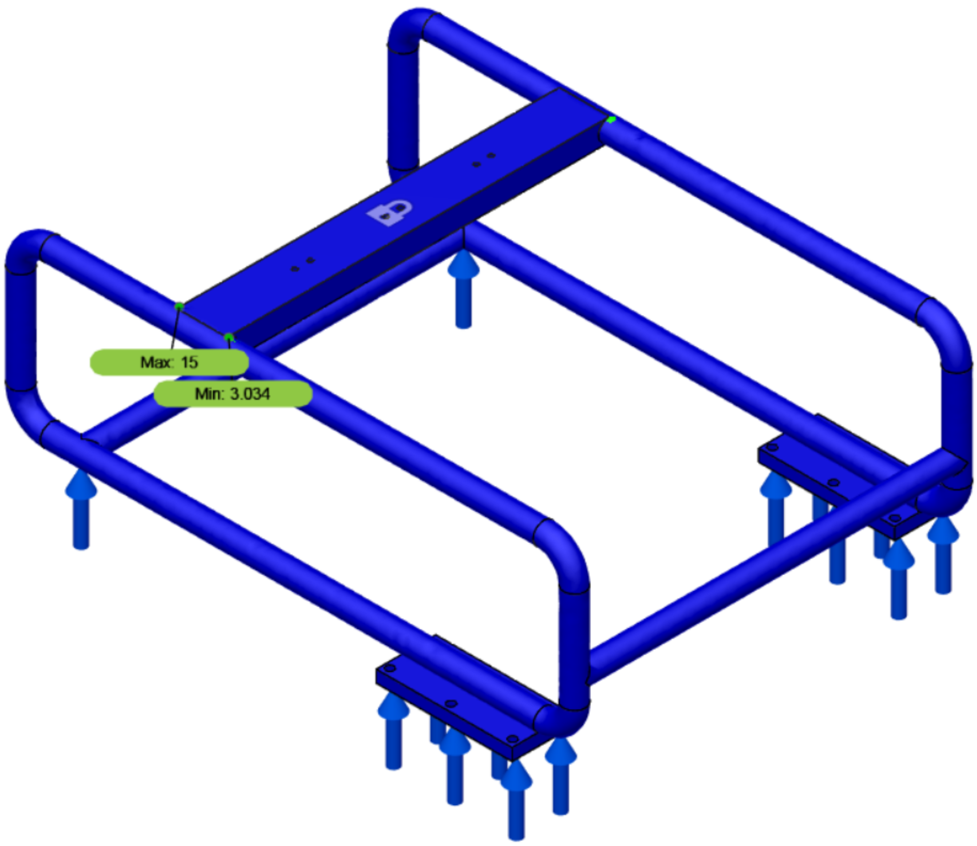


Figure 6: Simulation results on the wheelchair frame

7 Electronics

The electronic architecture has been developed for robust control and safety. The architecture is common for both the adult and pediatric case except for the choice of motors. The entire system is powered using a AMARON Quanta SMF 42AH/12V Battery. The motors are controlled using Cytron MDD20A motor drivers. A Raspberry Pi is used as the CPU for the entire control system which requires a 5V power supply. To meet these different requirements, buck converters have been used to power all the devices using the single battery. The load cells and the motor drivers are connected to the RPi. The load cells provide the load weight readings to the RPi which then calculates the position of the COM and gives appropriate signals to the motor drivers which then run the motors. Thus the wheelchair moves in the specified direction. All the electronics are housed in a special electronic box for easy access and debugging. Modular connectors are also used for all motor connections. Additionally, a kill switch is used to cut off the power supply entirely to stop the wheelchair in case of emergencies.

The motors are the primary difference between the adult wheelchair and pediatric wheelchair. In the adult wheelchair 24 V DC Hub motors controlled by a joystick had to be used as it was what was already available in the R2D2 lab for the purpose of a prototype of our load requirements. It was quite a challenge running them directly using a raspberry pi as it was designed to be operated using the joystick provided. As there was no direct documentation available online on what input to feed directly to the motors terminals to run them, the joystick had to be operated and the voltage differences between the different terminals had to be measured using a multimeter while connected to the joystick for different directions of movement.

This was noted down and the same input was replicated by the raspberry pi using SMPS for commanding the system to move in a specific direction. For the pediatric version the motors used are rated 250 W and 75 rpm rated 12V DC and can be controlled in a straightforward manner by using the motor drivers. Figure 7 shows the electronics setup.

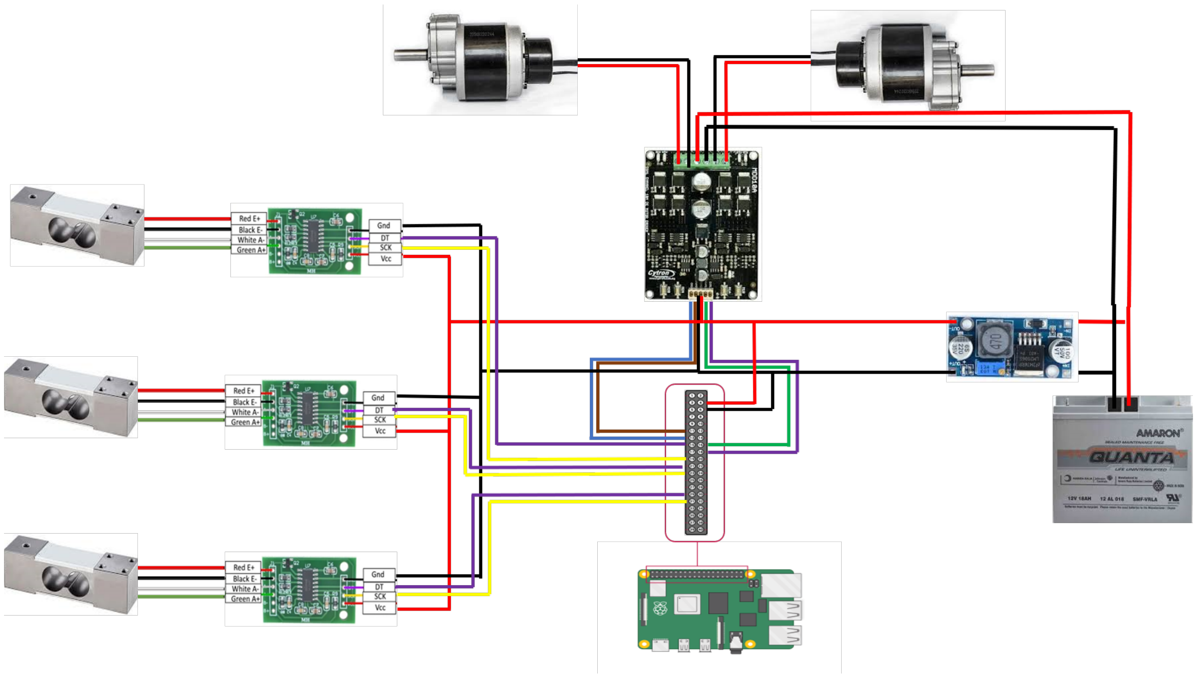


Figure 7: Electronics Layout

8 Conclusions and Future Work

The CAD design for the adult wheelchair was completed with constant feedback from design experts and simulations. Based on their feedback changes were incorporated in the design. Anthropometric Data was used to decide several crucial design dimensions. They were manufactured and assembled together using the manufacturing resources from the institute and also with the help of vendors outside. The electronics framework was set up on the adult wheelchair version and was kept ready to start testing. Due to the onset of the pandemic the testing could not be taken forward and hence the focus was redirected to making design improvements in the meantime.

After these improvements were made the focus was reoriented to developing a pediatric version targeted at pediatric users falling under the same umbrella and also in a complete product development approach with a goal to make more units of the same after testing. Along with taking inputs from design experts, simulations and anthropometric data design inputs were further made using the consultation of biomedical experts and physiotherapists. The complete design has been manufactured and assembled together.

Full scale testing of the pediatric wheelchair has to be taken forward with the help of volunteers and the different aspects of the wheelchair have to be redone based on their feedback and new solutions should also be considered based on this. After this has been done the next focus of the project should be on cost cutting to reproduce many units of the wheelchair at an affordable cost to make it accessible to many users. Modifications have to be made in parallel to give a full product look. Versions of this product version have to be beta tested with users and a final version is to be hence built and made available to the consumers.

9 Acknowledgements

We would like to thank Dr Sujatha Srinivasan for graciously giving us the opportunity to work on this project and guiding us through the journey with her inputs and the resources of the R2D2 Lab. We would like to thank Mr Vivek Sarda for teaching several product design inputs and guiding us besides also setting the foundation for this project through his Bachelor's Project. We would like to thank Mr Swastik and Neomotion for providing a Neofly wheelchair during our initial phase when we were working on our first prototype. We would like to thank Dr Javeed for helping us to refine our approach through several meetings during the project. We would like to thank Ms Mounika and Mr Vignesh for helping us with the manufacturing face of the project when we couldn't be in the institute to directly work on it due to the ongoing COVID pandemic. We would like to thank Mr Praveen for facilitating the project related expenses. We would like to thank Mr Samson and the Lab's biomedical team for providing us with inputs when we had certain queries regarding the project. We would like to thank all the members of the R2D2 Lab for helping us in many ways while we had the chance to work in the Lab before the pandemic. Lastly we would like to thank our Institute, Indian Institute of Technology Madras for making this all possible.

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