SENIOR DESIGN PROJECT:
ALCOA STAIR CLIMBING WALKER

GROUP MEMBERS:

EVAN GORDON (SUPERVISOR)

MARK MALLET

KUNKAI MA

DIJI TOKUNBO

HECTOR HERNANDEZ

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

The walker group consists of five members, who are Evan Gordon, Mark Mallet, Hector Hernandez, Kunkai Ma, and Diji Tokumbo. The project that was given to the group was of moderate complexity, challenging, and educational in the process. The objectives were to design and manufacture a walker that assisted a physically disabled person in climbing up stairs. All the walkers that have been known thus far were those that would assist a person in walking on level ground. Thus this seemed like a unique project.

In the first semester, all the design work was done. The greatest concern to keep in mind when designing the walker was functionality and stability. First, a patent search was done, and a couple of patents were found that had already existed for a walker that assisted a person in climbing up stairs. However, since such designs had already existed, our team tried to approach in new design direction which to include motorized wheels in the design. That would allow the user of the walker to travel along level ground with greater ease. As a result, the design would now have two functions; operation along level ground and operation along stairs. Research was done on regular walkers available on the market so that a “feel” of the possible dimensions that the walker would have. Next followed brainstorming with ideas and trying to stray away from the patent designs that existed so that the design would be unique. Several design concepts were developed which included a walker with a motorized track and a walker with a mechanism which consisted of three linked wheels. Solid modeling was done for each design concept so that a visualization of both could be seen. Small mock up models were also built so that a “feel” of the mechanics would be obtained for each. From these two designs one had to be chosen as the most viable design. The first design concept with the motorized track seemed to be a viable solution; however the track mechanism seemed would be too complex and costly. The second design concept with the mechanism of three linked wheels was chosen as the final design. The solid model of the final design was further detailed and FEA analysis was performed on the critical parts to insure it would work safely. The results of the FEA analysis showed that much of the design would work safely, with a few parts that would need modification to further insure that the design would not fail.

In the second semester, manufacturing of the final design would begin. However, it was realized that the final design from the previous semester had two huge drawbacks. First, the final design would be too costly if ever manufactured. Second, the functionality and stability seemed questionable. Due to these drawbacks, the final design was revised completely. Returning to one of the patents that already existed, it was realized that a similar design could be used with modifications. The patent that the final design was revised after had retractable front legs, which was controlled with a lever mechanism. The final design would include retractable front legs, which operated by a different mechanism other than the existing one from the patent. In addition, the revised design would have motorized front legs. A solid model was created and it was realized that this design was both simple and viable. This revised design would be the new final design and would be manufactured.

Before manufacturing could begin, appropriate materials had to be selected for each part. For the frame of the walker, aluminum and steel tubes were ordered. Two cordless hand drills were purchased, from which the motors, controller, and batteries would be utilized. For the mechanism that would provide the stair climbing assistance function, linear actuators would be used. Two lead screws, two sleeve nuts, and two motors were purchased and would serve as the linear actuators once they were assembled.

After all materials were ordered and purchased manufacturing began. Steel and aluminum tubes were bent appropriately to the dimensions of the frame that was desired. After disassembling the hand drills the motors were used to drive the front wheels, the controller would be used in conjunction with the motors, and the batteries would be used as the power source. The linear actuators were assembled with lead screws, sleeve nuts, and motors. Several small parts made from aluminum, steel, and plastic materials were manufactured, which served as fasteners, so that all the parts could be secured to one another. Milling, lathe, grinders, and other machining tools were used in this manufacturing process. Manufacturing became an iterative process when problems with the walker stability arose. Thus modifications were made to make the walker stable, such as reinforcement with PVC tubes. After the issue with stabilizing the walker was solved, electrical connections between the motors, controllers, and batteries were joined. Lastly, the walker was spray painted so that it had an aesthetically pleasing in appearance.

Once manufacturing was complete FEA analysis was done with CosmosWorks to insecure that the walker would not fail. The FEA analysis proved to be successful and the walker design was shown to be safe. Testing was done on the manufactured walker. Both functions of motorization on level ground and retractable legs to assist in stair climbing were successful.

2. INTRODUCTION

A walker is a simple device to assist the physically disabled in being more mobile. The walkers on today's market all have one function and that is to assist the user in mobility and with greater ease. These walkers are limited in that they do not make certain locations accessible to the user. For example, a physical disabled person cannot ascend or descend stairs with a walker on today's market. Thus there is a need for a walker to provide assistance in mobility on level ground and in ascending and descending stairs. A walker with such functions would be beneficial to the physically disabled.

The objective of this project is to design a motorized stair climbing walker that is both operational and safe. The design under consideration must possess stability under two functions. These functions include the ability to be motorized along level ground and stair climbing. Other requirements include lightweight system, maximum height of walker should be roughly 4ft, maximum weight capacity that can be carried is 250 lbs, and must be operational along steps no greater than 9 inches in height. Two designs were considered: a walker with a motorized belt mechanism and one with a motorized wheel frame assembly.

2.1 Project Description

The project consists of two parts, design and manufacturing. For the design part, there are several stages included which are literature search, developing several concepts, evaluating each concept based on advantages and disadvantages, approving the best concept, completing analysis, and assessing the final design. In order to accomplished the manufacturing of the chosen design the following was done, which are detail drawings, material selections, material orderings, manufacturing parts, parts assembly, and final analysis.

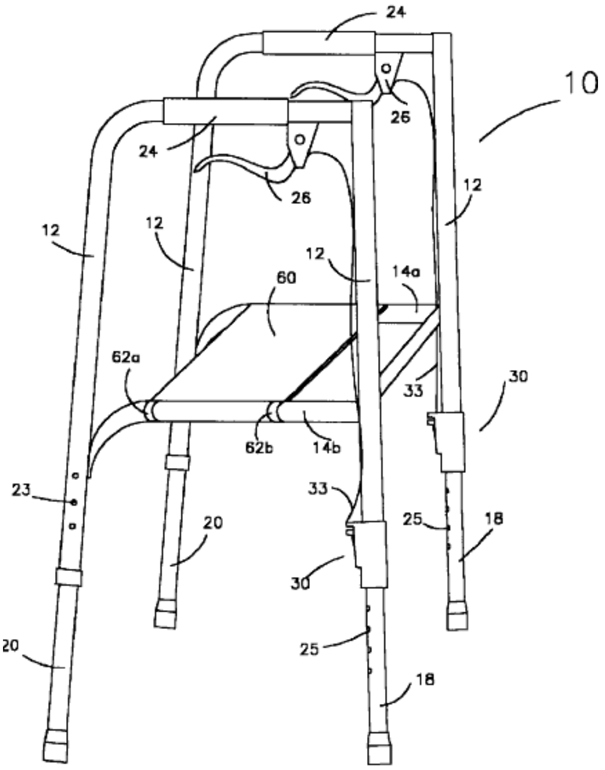
2.2 Motivation

A standard walker can not climb stairs. This comes at a disadvantage for physically impaired people. Thus it can be greatly beneficial if a walker was designed to climb stairs. Since a simple design for a stair climbing walker already exists, an additional feature for the walker design will be for it to be motorized on level ground.

2.3 Literature Search/Background

The first thing that was researched was existing patents of stair climbing walkers. A patent search was done through Google's own patent database. It was discovered that several patents for a stair climbing walker did exist and were of very simple design. This design of a stair climbing walker consisted of reversed U shaped handles with four legs that retracted and extended. These retractable and extendable legs served the function of ascending and descending stairs. The operation of the legs is through levers. The following figures illustrate the structure and function of the walker climbing stairs.

To obtain general dimensions of a standard walker several websites were visited including www.medicalproductsdirect.com/walkers.html. Wikipedia was used to obtain information on Gears and electronic controls.



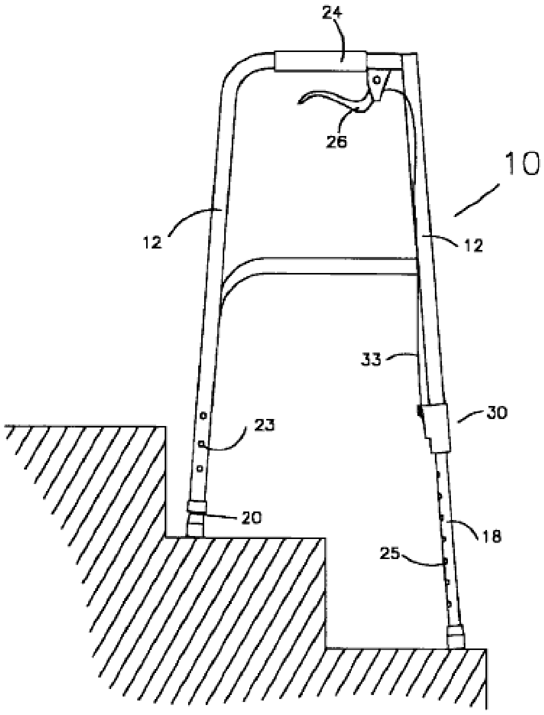


Figure 2.1 – Stair climbing walker

Figure 2.2 – Stair climbing walker descending

The second type of patent for the stair climbing walker is the one shown in **Fig.2.3**. It is a very simply design which utilizes adjustable handles to aid the person in climbing stairs while maintaining stability in the process. The major principle of the design is force equilibrium. The force concentration was change by using different handle positions. Having reactions from the stair and concentration of the person, the whole walker system was in equilibrium; therefore the person would able to climb stair safely by maintaining stability.

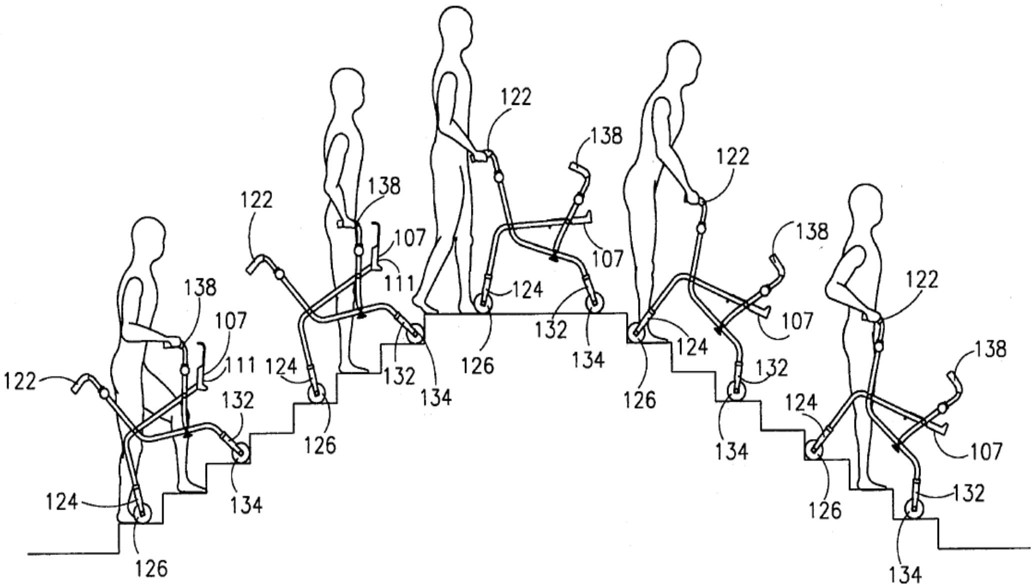


Figure 2.3: Second patent for stair climb walker

3. Problem Statement and Objectives

To design a walker that has the ability to climb and descend stairs while maintaining stability in the process.

1. Climbing stairs
2. Motorized on level ground

3.1 Objectives

The main objective of this project is to design a functional walker capable completing basic function such as; aiding a disable person navigate on a plain or ramped floor without any difficulty. Also the walker is design in a way that it can handle very complex task such as; aiding a disable person climb up and down the stairways. The walker for our senior design project is designed to meet the entire specification requirement by the professor, such as: fully functional, cost efficient, reliable and manufacturing

The objectives for the walker are as follows:

1. motorize along level ground
2. design stair climbing ability
3. keep safety, weight, and size in perspective

3.2 Design Gantt Chart

This is the design gantt chart from first semester of senior design project class. The design processes was basically done by following the procedures of the gantt chart. It helped the team organize the design process.

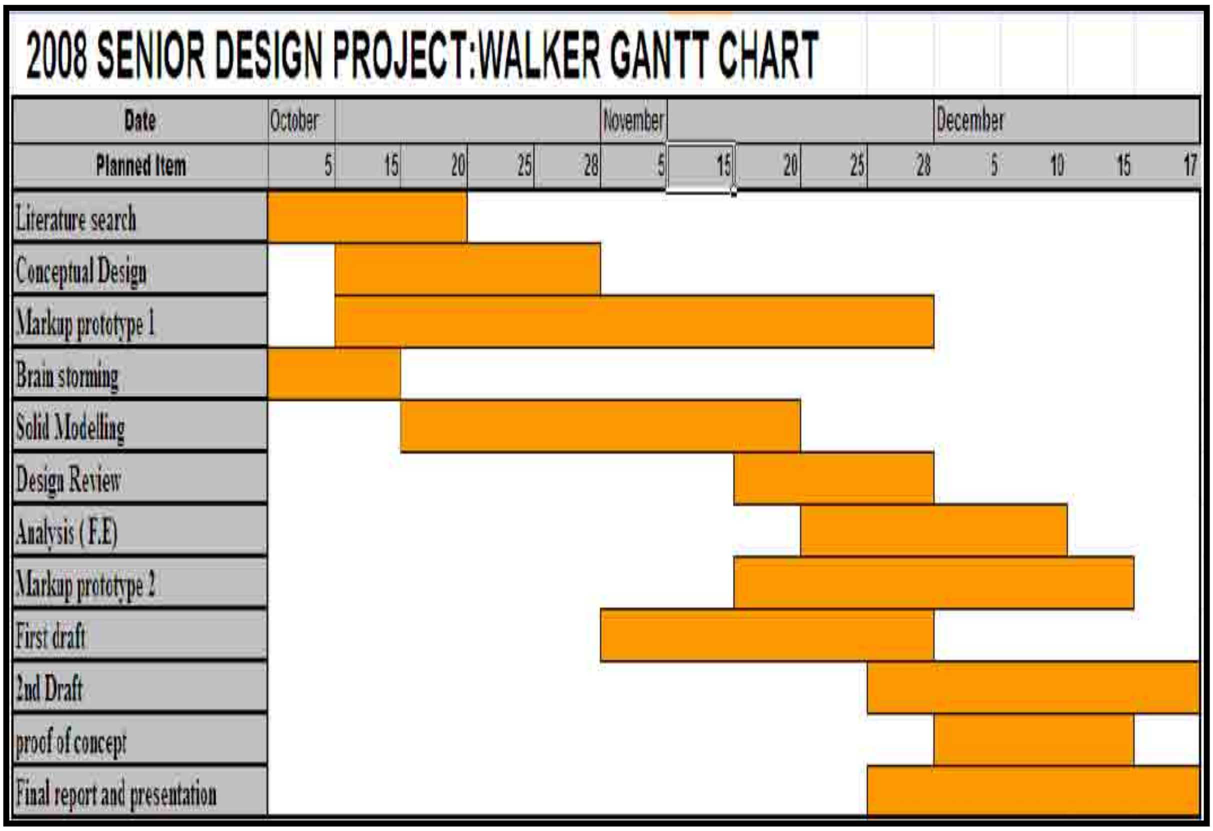


Table 3.1 – Gantt Chart

4. DIVISION OF LABOR

In order to make the design and manufacturing processes smooth, the work load was distributed based on each individual strength and weakness. Chart 4.1 shows how the labor was divided among group members.

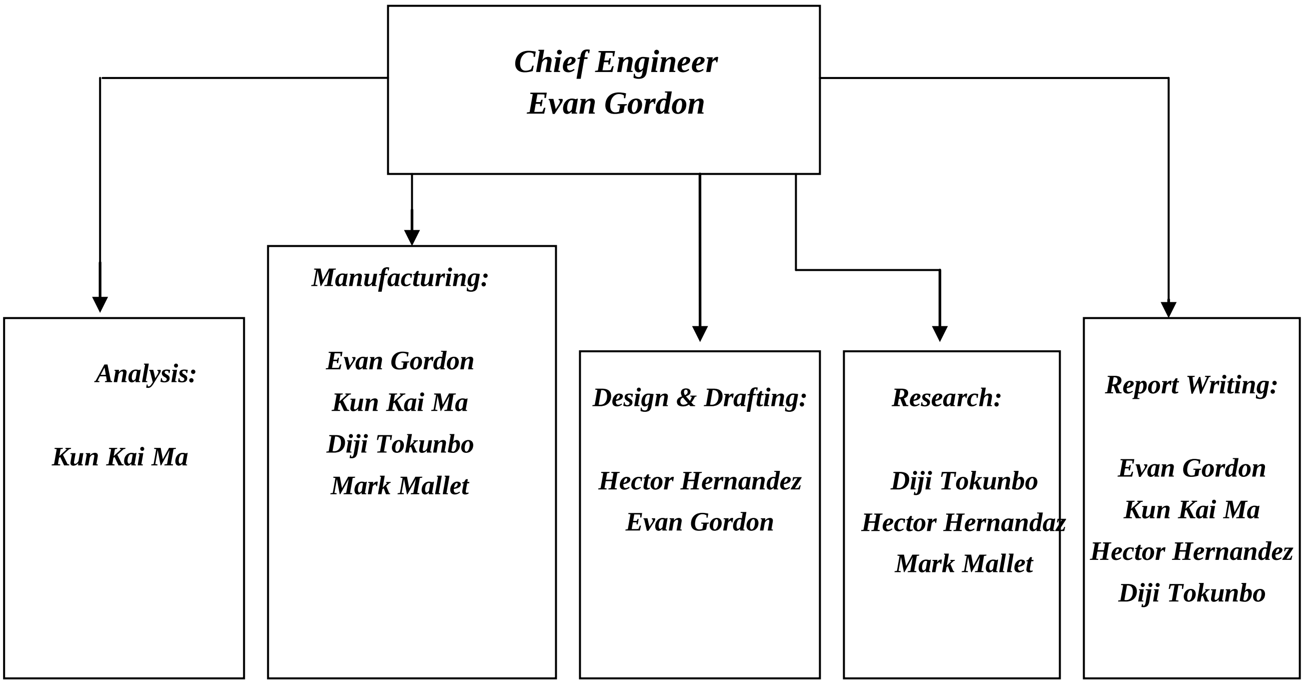


Chart 4.1- Division of Labor

4.1 Research, Drafting and Analysis:

The major tasks for this group were to determine the appropriate mechanism to be used in order to design a walker that can climb up a stairs without any major obstacle and at the same time can be used as a regular walker on a plain floor .We calculated and analyzed the amount of power that is needed to operate the motor that rotates the tires that enables the walker to climb up the stairs. The group responsible for the research also studies how a regular walker operates and how we can apply the pre existing technology of the design of regular walker into our design without infringing an existing patent. Patent infringe is a serious issue in the world of invention and if not properly considered it could cost the manufacturer a substantial cost as a result of law suit. In addition, we research on the manufacturing process needed for this project. There are several mechanical engineering equipments that can used to manufacture the parts of our walker. The main machines we would be using to manufacturing the major parts of our worker are the milling machine, and the lathe machine.

4.2 Structural Design, Drafting and Analysis:

This sub group is responsible for modeling and analyzing the necessary structural components of the walker. They create computer drawings, assemblies and produces solid model for the required structural analysis to ensure the proper use of materials and part dimensioning. Modeling is an essential part of this project and it is needed to coordinate a successful design. There are several applications that can be used to model a design. However, we used solid and cosmos works application to model our design. Also, a mini prototype of our design was created at the work shop for a more realistic look at the mechanism we created for the design.

4.3 Systems, Reporting, and Manufacturing:

System:

The systems group was responsible for determining the required electrical and power requirements for the walker, this also included determining the amount of power that can properly operation the motor needed to operate the walker. This group also determines the type of battery and circuitry design that would be needed for the walker. The system group conducted an extensive analysis on the kind of motor needed and the mechanism we would used to operate the walker.

Reporting:

This subgroup tracked the team’s progress, researched and kept a journal of modifications. They prepared and organized the written report as the project developed. Also, the report sub group collects information from all subgroups in this team on their contribution toward the project and they carefully draft them into the final report.

Manufacturing:

The manufacturing team will comprised of all the members of the group. The main task for this group was to translate designs into actual parts. This will be accomplished using several manufacturing techniques including Computer Aided design, manufacturing of parts, assembling and testing. The manufacturing team will face the most rigorous phase of this project because the manufacturing process for this project requires a lot of team work and hands on process.

5. DESIGN CONCEPTS

Three concepts considered were motorized walkers, which were; one that utilized a track, one that utilized a wheel frame assembly mechanism and the final one that utilized linear actuators to retract and extend front legs. After careful evaluation the motorized walker with the retractable front legs was chosen to be the final design.

5.1 Design Concept 1

This design utilized the motorized track, which sole purpose was to enable the walker to climb stairs. The major subsystems of this concept are a motorized track, adjustable handles, and a mechanism to control the position (angle) of track. The mechanism to control the position of track would be adjusted to match the slope of a specific stair while the teeth of the track maintain grip. This is to prevent slippage. The handles were used to provide stability and counter balance the moment that would cause an imbalance in the system.

The advantage of this design is that it provides a stable platform on the stairs while maintaining grip. The disadvantages are that it is difficult to manufacture, and when going downstairs it is unstable.

Figure 5.1 – Solid Model of Design Concept 1

5.2 Design Concept 2

The major subsystems consist of a driving mechanism, wheel frame assembly (WFA), the link mechanism to allow stair climbing, and adjustable handles.

The driving mechanism **(Figure 5.2)** to provide the functions of rectilinear motion on level ground and stair climbing will consist of two planetary gear set motors, a pinion gear, and a driver gear attached to the drive shaft. The reason for choosing the planetary gear motors is to provide high gear ratios for a relatively small size. In our case the high gear ratios is used to provide a high torque at a low rpm. The gear ratio is further increased with the driven shaft gear in order to produce the required torque. A large torque produced from the drive shaft will allow for the weight of the walker to be carried and allow the walker to climb stairs. The second function will become more apparent later in this discussion.

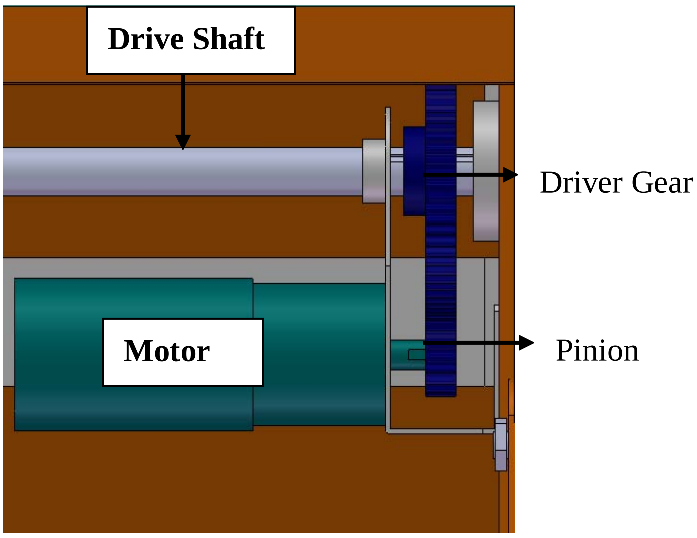


Figure 5.2 – Driving Mechanism

The WFA utilizes two sets of three wheels located at equidistant angles from each other and an arrangement of gears to provide an appropriate gear ratio. In our case we want to achieve a suitable rpm range that will comfortably allow the person to walk. Initially the WFA gear arrangement consisted of three gears, a Driver, Idler, and Driven. The Driver is the gear that is directly connected to the drive shaft, the idler is the intermediate gear, which sole purpose is to link the driver and driven gear without affecting the overall gear ratio, and the driven gear is that which is connected to the wheel via a rod. This assembly will increase the rpm and provide appropriate direction needed to use the walker on level ground. A disadvantage of this is that it requires a relatively large driver gear that will prevent the walker design from being compact.

To remedy the space constraint and still achieve high rpm, a new design for the WFA consists of an arrangement of compound gears **(Figure 5.3).**

Figure 5.3 – Compound Gear

The three wheels of this assembly will all rotate about their own axis when the motors of the walker are active for the function of walking on level ground. The motor will be activated through a control that will be located at the top of the handles. This button must be held to produce a constant velocity of the walker. Upon release of the control, the motor is expected to stop instantaneously so that motion does not continue due to inertia. The wheels will work at a tangential velocity of 1-3 miles per hour. Such a speed is chosen because this is the average walking speed of a person. If the speed is exceeded beyond this range injury may occur.

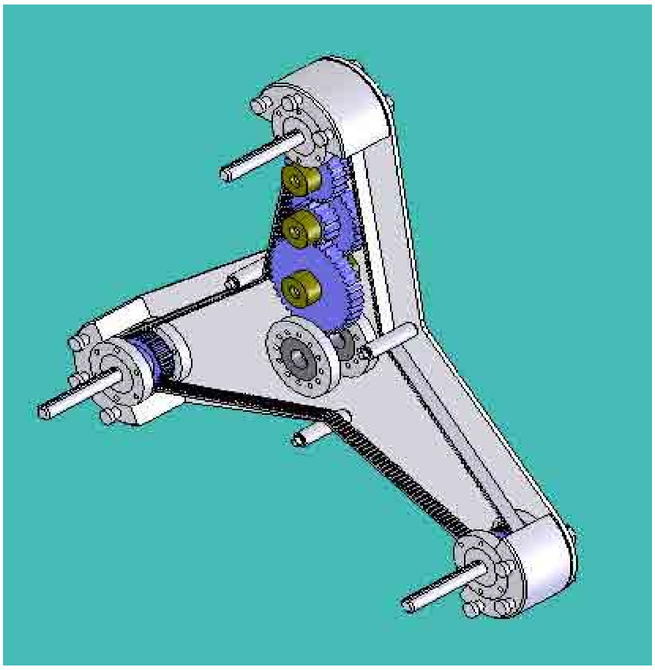


Figure 5.4 – Wheel Frame Assembly

When the walker is to climb stairs, the WFA must rotate about an axis through its center with all three wheels fixed. To provide this function a link mechanism **(Figure 5.5 & Figure 5.6)** to engage the drive shaft to both WFA, must be created. This engagement must be such that the motion from the drive shaft is transferred to the entire WFA and not to the compound gears, themselves. This link mechanism will consist of two cylindrical plates with teeth and a derailleur. The cylindrical plates are kept separated by a spring when inactive and when active will interlock. The teeth of the cylindrical plates will be cut at an angle at two faces to increase the probability of the plates interlocking.

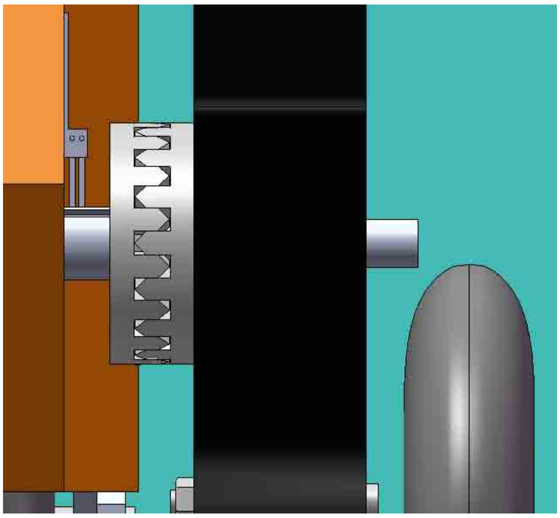


Figure 5.5 – Link Mechanism Engaged

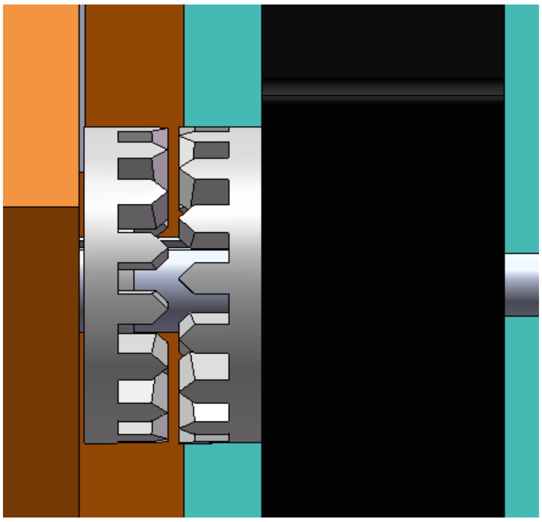


Figure 5.6 – Link Mechanism Disengaged

The adjustable handles are convenient for the user in that they provide an incline that is suitable for pushing the walker.

The body plate links the WFA to the back swivel wheels. These swivel wheels allow the walker to turn. The body plate in conjunction with the swivel wheels counters the moment that results every time the WFA rotates on the stairs.

The materials to be used for the walker include alloy steel, aluminum, and acetal/nylon. The advantages of this design is that it is stable going upstairs and downstairs, can be used as a motorized walker, and fairly simple to manufacture. The disadvantages are that the design consists of a reasonable amount of parts/mechanisms that require higher maintenance and cost.

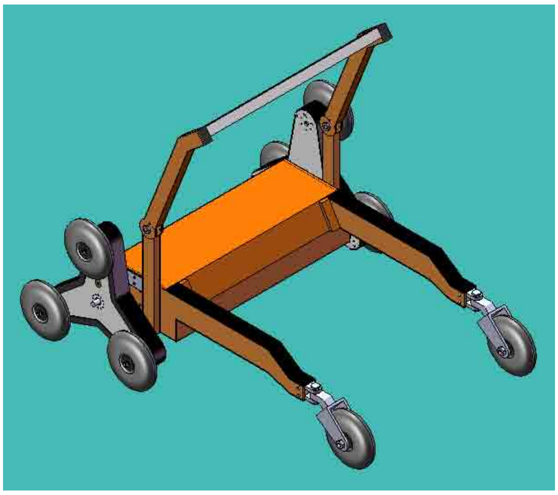


Figure 5.7 – Design Concept 2

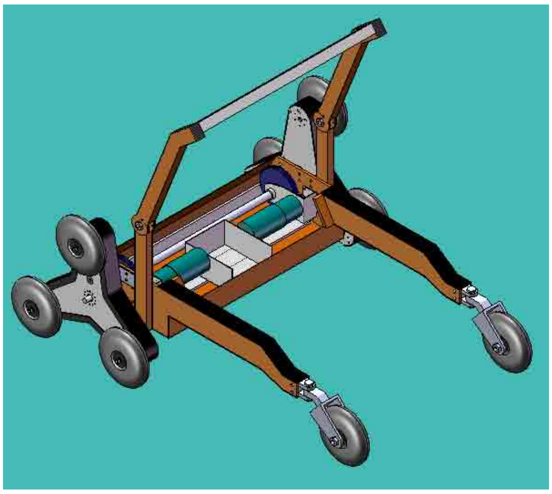


Figure 5.8 – Design Concept 2 w/ open cover

5.3 Design Concept 3 (Final Design)

The third design concept (final design), instead of using a track or a rotating wheel assembly, utilizes automated front legs. The legs retract and extend in order to match the height of the steps being climbed, see **Fig. 5.10**. The retraction and extension of the front legs are achieved by using a set of linear actuators placed inside of the moveable sections of the legs. Along with having a stair climbing function, the walker is also able to be motorized along a leveled surface. This is achieved by placing a set of motorized drive wheels at the base of each front leg (**Fig. 9**).

Fig. 5.9- Final Design

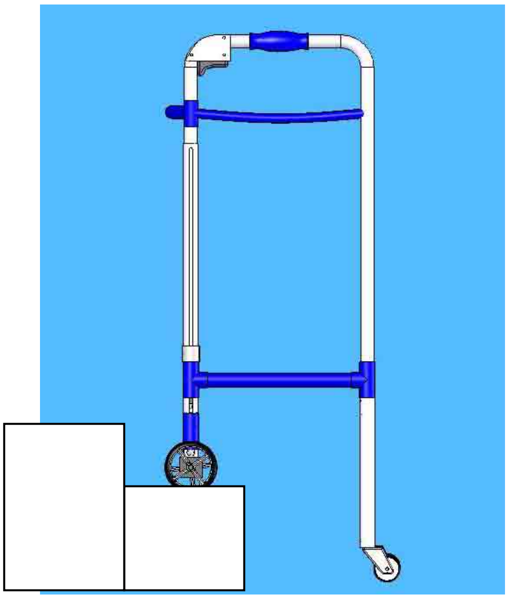


Fig. 5.10- Legs Retracted

5.3.1 Linear Actuators:

The major components of the linear actuators are: i) Lead screw ii) Sleeve nut iii) Planetary gear box motor iv)Ball bearing v) Motor holder. The planetary gear box motor is constrained by the motor holder, which prevents it from rotating when a reaction torque occurs. The motor holder also serves the purpose of restraining the entire linear actuator assembly within the moveable section of the front legs by means of two holes located on its outer periphery. Power is transmitted from the motor to the lead screw by means of a coupling with a set screw. The sleeve nut, which is retained in a holder, is held fixed in the stationary potion of the front legs; therefore, allowing the lead screw to travel along it, which in turn makes the entire moveable section of the front leg retract and extend.

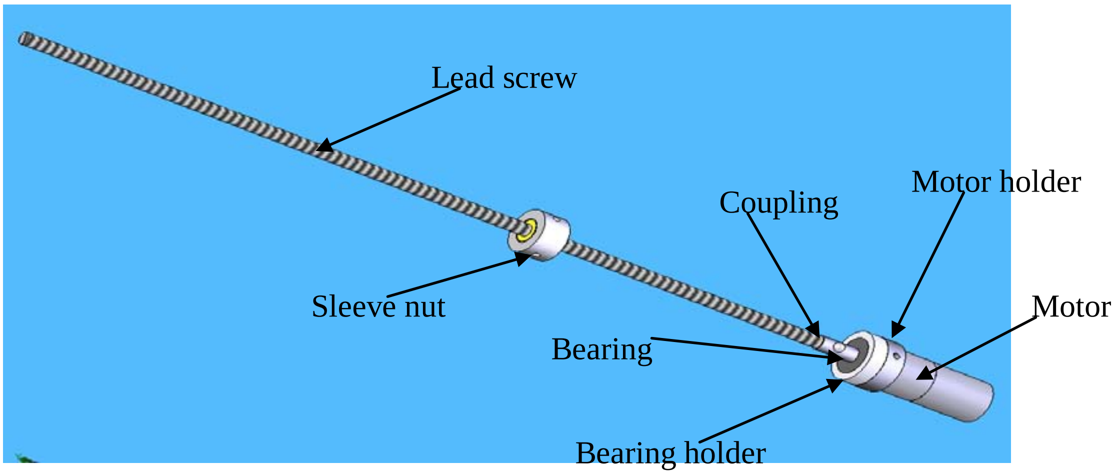


Fig. 5.11– Linear Actuator

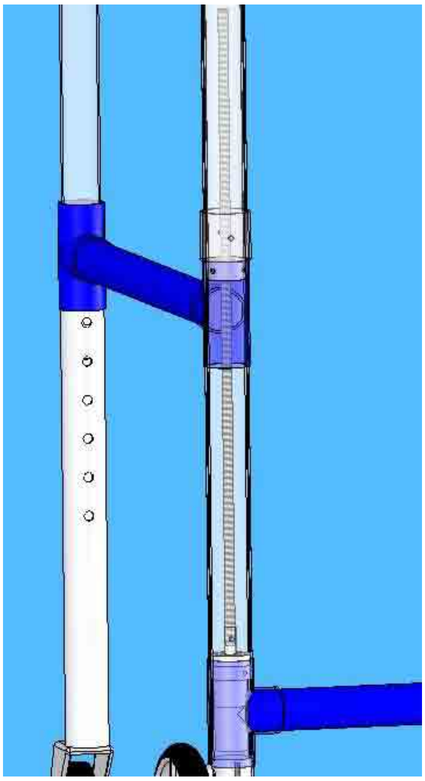


Fig. 5.12 –Close up of Linear Actuator in front leg

5.3.2 Moveable section of Front Legs:

Slots are placed on opposite sides of the moveable section of the front legs. The slots serve two purposes, which are: i) to act as a guide when the legs retract and extend ii) to prevent the legs from rotating due to the incurred reaction torque from the linear actuator motors. **Fig. 5.13** shows the position of the slots on the front legs.

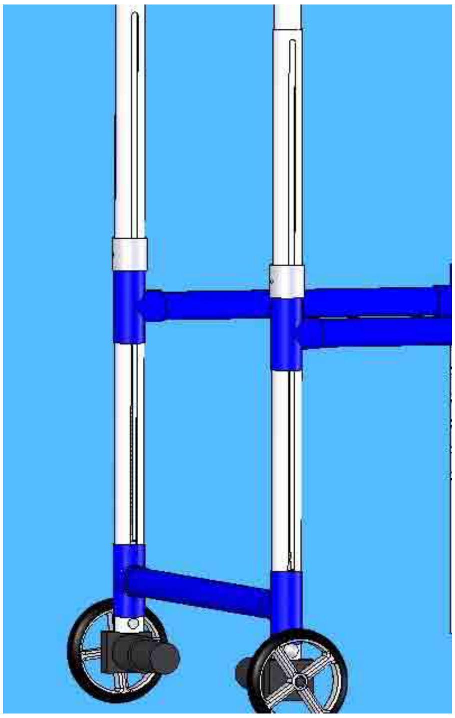


Fig. 5.13 – Slots in Front Legs

5.3.3 Speed Controllers:

Both sets of drive wheel motors and linear actuator motors are controlled by electronic speed controllers (esc's). The controllers serve two purposes, which are: i) vary the speed of the motors ii) used for electromagnetic breaking. **Fig. 5.14** shows the esc used for the purpose of this project.

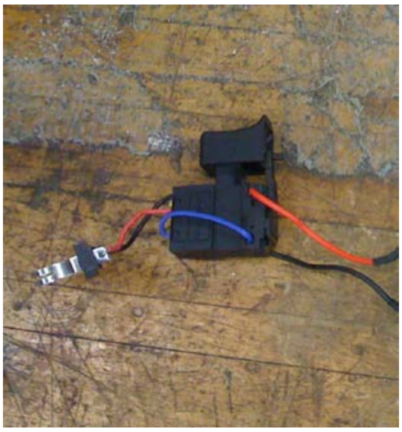


Fig. 5.14- Electronic speed controller (ESC)

5.3.4 Drive Wheels:

The purpose of the drive wheels is to enable the walker to be motorized when being used on a leveled surface. The wheels are powered by a set of planetary gear box motors. A major concern with using these wheels is the issue of stability when the walker is being used to climb stairs. This problem is averted by means of allowing the motors to act as generators when they are off; doing this provided enough resistance to prevent the wheels from rolling too easily when on the steps, thus increasing the overall stability of the walker.

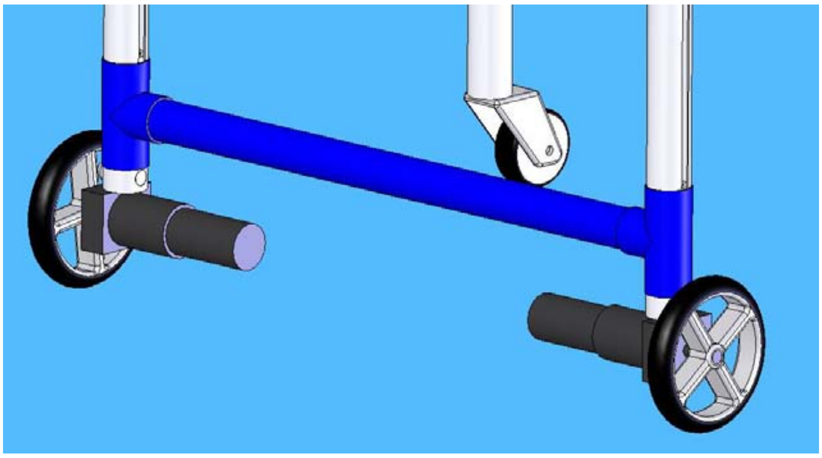


Fig. 5.15- Drive Wheels

5.3.5 Swivel Wheels:

The purpose of the swivel wheels is to allow the walker to turn easily when used in the motorized function (**Fig. 5.16**).

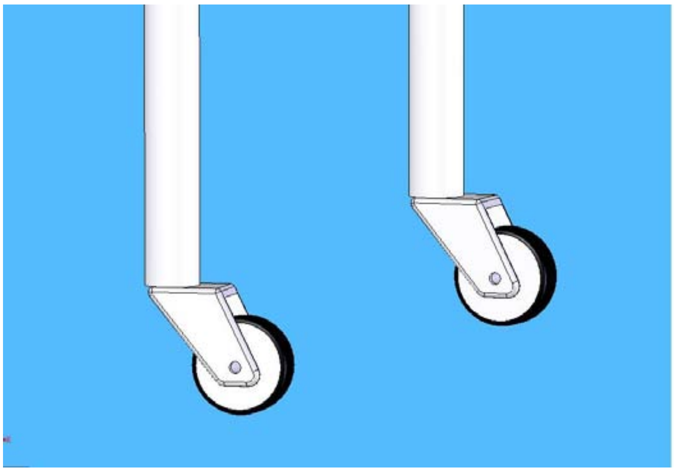


Fig. 5.16 - Swivel Wheels

5.4 Evaluation of Concepts

An evaluation was done for concept 2 and concept 3 to see which one is the most viable design. This evaluation was done based on weight factor, rating, and score shown in **Table 5.2**.

Evaluation for concept 1 and concept 2 in first semester

Design Attribute	Design 1			Design 2	
	Weight factor	Rating	Score	Rating	Score
Operation and safety	5	1	5	5	25
Size and Weight	4	3	12	3	12
Cost	5	4	20	5	25
Reliability	4	2	8	4	16
Manufacturability	4	2	8	3	12
Durability	3	2	6	3	9
Maintenance and Service	2	2	4	2	4
Power Needed	2	3	6	3	6
Speed of Operation	4	4	16	3	12
Total			85		121

Table 5.1: Comparison of Concepts 1 and 2

Evaluation for concept 2 and concept 3 in second semester.

Design Attribute	Design 2			Design 3	
	Weight factor	Rating	Score	Rating	Score
Operation and safety	5	1	5	5	25
Size and Weight	4	3	12	3	12
Cost	5	4	20	5	25
Reliability	4	2	8	4	16
Manufacturability	4	2	8	3	12
Durability	3	2	6	3	9
Maintenance and Service	2	2	4	2	4
Power Needed	2	3	6	3	6
Speed of Operation	4	4	16	3	12
Total			85		121

Table 5.2 – Comparison of Designs 2 and 3

6. ANALYSIS OF DESIGN AND RESULTS

Based on the final design concept of our project, the analysis for the walker is mainly focused on two type of analysis: i) kinematic analysis ii) finite element Analysis. For each analysis, appropriate assumptions and constraints were made. For kinematic analysis, the movable leg and drive wheel motor would be analyzed. For finite element analysis, the support screw and walker frame would be analyzed. In addition, in order to verify the results, other calculation approaches were used. In order to validate our results, they were compared we standardized material properties. These results were reasonable compared with specification of components. Therefore, the analysis demonstrates that the design is safe.

6.1 Kinematic Analysis

For kinematic analysis, the major components are the movable legs (see **Fig. 6.1**) and drive wheel motors (see figure 3). They are the most essential parts of this project. Without them, the walker would not be able to climb or descend stairs. To do the analysis, some assumptions were made and some operation constraints were considered.

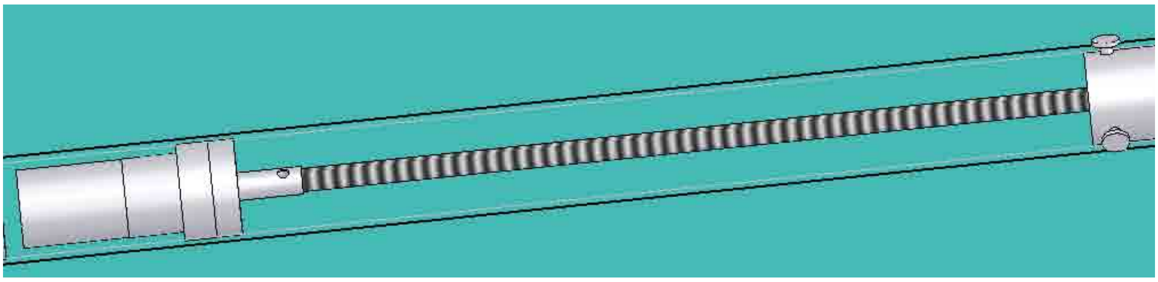


Fig. 6.1: Solid Model of Movable Leg.

6.1.1Movable Leg

Constraints:

There were several constraints in this project. These constraints limited the design flexibility. It is very important to understand what the constraints are. They were concluded as following:

1. The speed of the two movable legs have to be synchronized meaning both legs have to move at approximately same speed.
2. The two movable legs have to be able to move up or down by 9 inches from the equilibrium position.
3. The weight of each movable leg has to be about 5 to 6 lbf so the overall weight of the walker would not exceed 20 lbf.

Assumptions:

There were some assumptions made for this analysis. With these assumptions, the overall calculations were simplified while maintaining reasonable results for analysis.

1. Assumed the time required for the movable leg to move up or down for 9 inches is 15 second.
2. Assumed there was no friction involved during the motion of the legs.

Computation:

Since the moving distance of 9 inches and the required time of 15 second are known, the speed of the movable leg can be found as:

Speed of the leg: $V = \frac{d}{t} = \frac{9in}{15s} = 0.6in/s$

By finding the moving speed of the leg, the power required for the leg also was found as:
$P = FV$
Where F is the weight of the movable leg about 6lbs

$$P = 6lbf \times \frac{0.6}{12} ft/s = 0.3lbf \cdot ft/s = 0.00055hp = 0.0004kW$$

$$737.56lbf - ft/s = 1.34hp = 1kW$$

Due to the limitation of constraints and design concept, we need to have a very precise manufactured lead screw in order to achieve the synchronization of the two legs. Therefore, we selected a very precise one online. Pitch of the lead screw is about 0.05 inches per revolution. By knowing the pitch and the moving distance, the total number of revolution was calculated as:

$$n = \frac{9in}{0.05in/rev} = 180rev$$

Therefore, the following parameters also were able to calculate as:

$$\omega = \frac{2\pi n}{t} = \frac{2 \times \pi \times 180rev}{15s} = 75rad/s$$

$$N = \frac{60\omega}{2\pi} = \frac{60 \times 75rad/s}{2 \times \pi} = 716rpm$$

$$F_t = \frac{33000H}{\pi dN/12} = \frac{33000 \times 0.00055hp}{\pi \times 0.25in \times 716rpm/12} = 0.4lbf$$

$$T = d/2F_t = \frac{0.25in}{2} \times 0.39lbf = 0.05lbf - in$$

$$P = \omega T = 75rad/s \times 0.05lbf - in \times 4.45/39.37 = 0.42W$$

Comparing the results for the obtained power by using $P = FV$ and $P = \omega T$ methods, they are relatively close. That demonstrates that the calculations were correct. However, the result for power was too small for a motor required to use in this operation. Therefore, we went back to the assumptions and concluded these results were reasonable. The reason for that is these results were calculated base on no friction involved. In reality, we cannot avoid friction. Especially, for our project, the friction was very high. This friction included mechanical friction between the lead screw and sleeve nut, and surface friction between inner and outer tube. Therefore, the efficiency of the overall mechanical system of the movable leg should be

very low. Since the friction was very difficult to calculate in this mechanism, we decided to estimate the efficiency of the mechanical system.
Estimating the efficiency for the movable leg system 20%, that gives,

$$P_{actual} = \frac{P}{0.2} = \frac{0.42W}{0.2} = 2.1W$$

$$T_{actual} = \frac{P_{actual}}{\omega} = \frac{2.1W \times 39.37/4.45}{75rad/s} = 0.25lbf - in$$

By searching on the internet, we selected a motor (see **Fig. 6.2**) for the movable leg that matched our design needed with the following specifications.

Specifications
Speed: 950 RPM
Torque: 45 oz – in
Gear Ratio: 16 : 1
Power: 0.004hp
Voltage: 10 V
Current: 0.5A
Weight: 2.3 oz
Diameter: 0.86 in

Figure 6.2: Selected Motor from Internet

$$V = \frac{P_{actual}}{I_{selected}} = \frac{2.1W}{0.5A} = 4.2Volt$$

Results Summary:

Table 6.1: Summary of Analysis Results for Lead Screw System

Motor	RPM	Torque (lbf-in)	Power (W)	Voltage (V)
Analysis	**716**	**0.25**	**2.1**	**4.2**
Selected	**950**	**2.8**	**6**	**10**

6.1.2 Drive Wheel Motor

The kinematic analysis for this part was similar to movable leg. Similar equations were used to analyze this part.

<u>*Constraints:*</u>

1. Total weight of the walker is about 20 lbf.
2. Average walking speed for elders is about 10 inches per second.
3. The wheel of walker is 2 inches from material selection.

<u>*Assumptions:*</u>

1. Maximum weight applied on the walker when walking is about 40 lbf.
2. Friction coefficient between the wheel and floor is about 0.3.

<u>*Computation:*</u>

Using the average walking speed 10 inches per second for elders, we calculated the angular velocity and RPM for the drive wheel motor.

$$V = \frac{\omega r}{2\pi}$$

$$\omega = \frac{2\pi V}{r} = \frac{2 \times \pi \times 10 in/s}{2in} = 31.4 rad/s$$

$$\omega = 2\pi N/60$$

$$N = \frac{60\omega}{2\pi} = \frac{60 \times 31.4}{2 \times \pi} = 300 rpm$$

The total weight support by the drive wheel motor was 60 lbf. The frictional force between the wheel and the floor was found as:

$$F_f = \mu N = 0.3 \times 60 lbf = 18 lbf$$

In order to move the walker, the required force had to be bigger than the frictional force. To find out the required force, Newton's second law was applied.

$$\sum F_i = ma$$

$$F_f + F_{rotation} + F_{tranlation} = ma$$

However, the acceleration and translational force were unknown. This equation could not be solved. The best way to do this was to make an estimation again.

Estimating the required force to move the walker at speed 10 – 12 inches per second was about 25 lbf, we obtained

$$P = FV = 25 lbf \times \frac{10}{12} ft/s = 20.8 lbf \cdot ft/s = 0.038 hp = 0.028 kW$$

$$F_t = \frac{33000H}{\pi dN/12} = \frac{33000 \times 0.038 hp}{\pi \times 4in \times 300 rpm/12} = 4 lbf$$

$$T = d/2F_t = \frac{4in}{2} \times 4lbf = 8lbf - in$$

$$V = \frac{P}{I} = \frac{28W}{2A} = 14Volt$$

<u>Specifications</u>
Speed: 420 RPM
Torque: 12 lbf-in
Power: 0.04hp
Voltage: 16 V
Current: 2A
Weight: 2 lbf
Diameter: 2.8 in

Fig. 6.3: Drive wheel Motor from Hand Drill

<u>Results Summary:</u>

Table 6.2: Results Summary of Drive Wheel Motor

Motor	RPM	Torque (lbf-in)	Power (W)	Voltage (V)
Analysis	**300**	**8**	**28**	**14**
Selected	**420**	**12**	**32**	**16**

6.2 Finite Element Analysis

In this analysis, SolidWorks program was used to model and analyzed the parts for the walker. These parts included the support screw and frame of walker. The procedures in this finite element analysis included: boundary condition, meshing, and result plots.

6.2.1 Support Screw

The location of the support screws are shown on **Fig. 6.4** below. They were used to support the whole lead screw system of the walker. When maximum weight 250lbf is applied on the walker, each leg carried about 60lbf. The 60lbf weight was directly applied on the support screws. This weight created a direct shearing force at the cross section of the support screw. If the support screw fails, the whole walker would collapse. Therefore, the support screw has to be analyzed thoroughly using finite element analysis. Also, the FEA result would be compared with the mathematical calculation in order to achieve the accuracy.

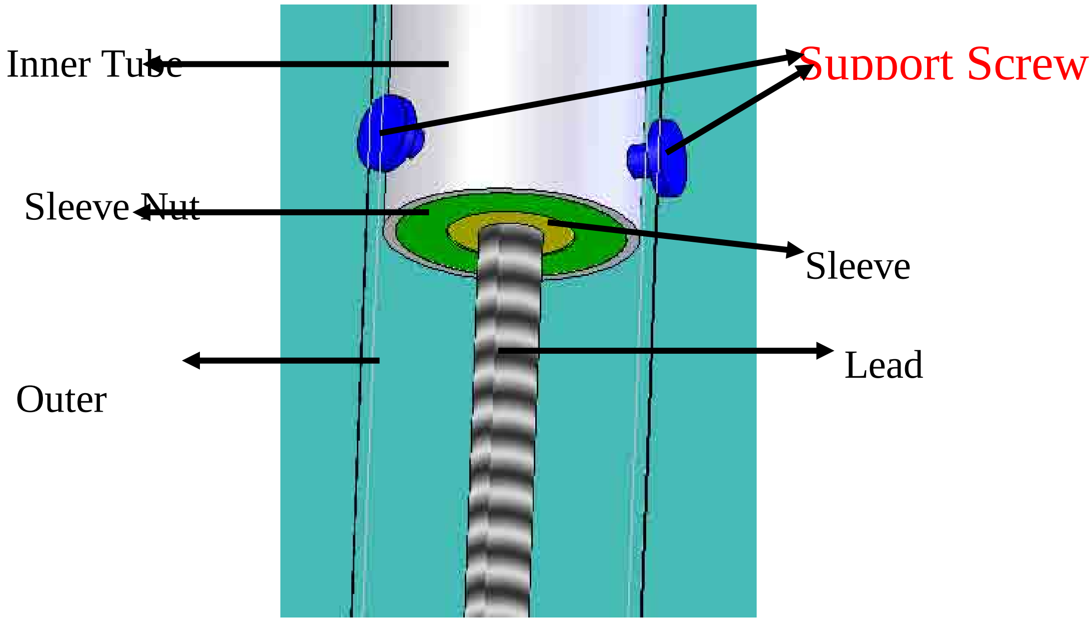


Fig. 6.4: Location of the support screws

<u>*Boundary Condition, Meshing and Result Plots:*</u>

Based on the location and operating condition of the support screws, the boundary condition was applied as shown in **Fig. 6.5**. When the screw is driven through the tube and then goes into the sleeve nut, the part that went into the nut was fixed, and the part that was driven through the tube was under shear force directly from the tube. Therefore, a fixed restraint was used at the end part of support screw, and vertical normal force was applied at the part that was near the head of the screw. Meshing was used to refine the elements of screw model. Finally, running the FEA, shear stress plot was obtained (**Fig. 6.6**). Also, the von Mises stress plot (see figure 7) was obtained in order to check for the failure of the screw.

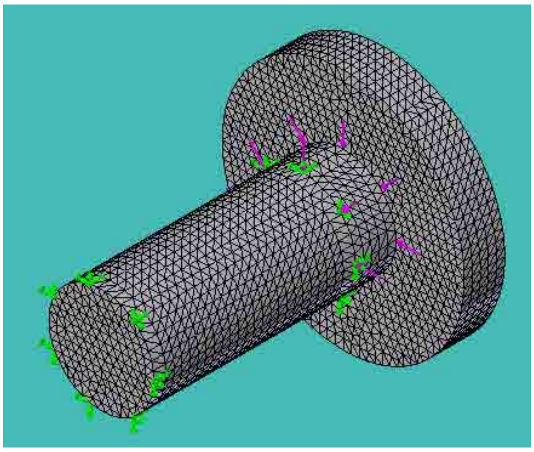


Fig. 6.5: Boundary Condition and Meshing of screw

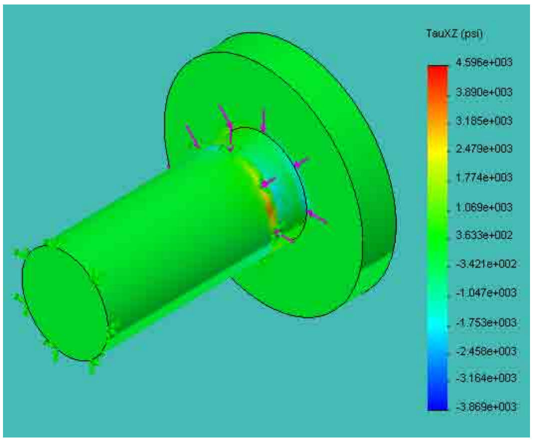


Fig. 6.6: Contour Plot for Direct Shearing Stress

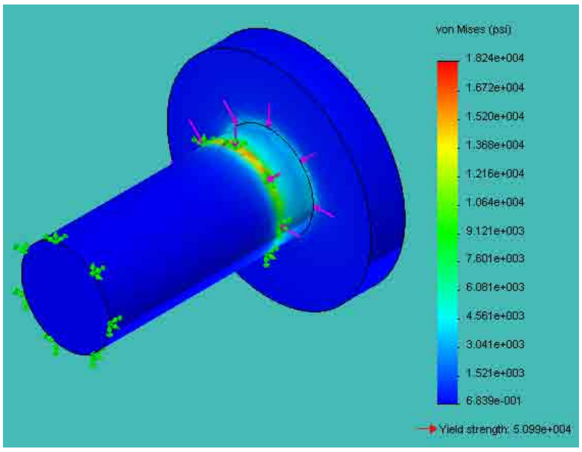


Fig. 6.7: Contour Plot for von Mises Stress

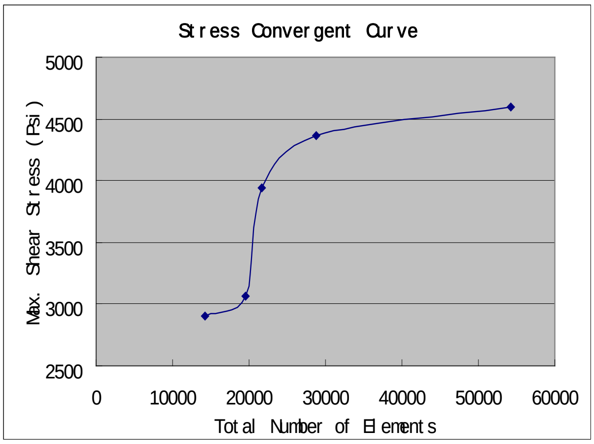


Fig. 6.8: Stress Convergent Curve for Shear Stress

Mathematical Calculation and Discrepancy

Direction shear

$$\tau = \frac{V}{A} = \frac{60lbs}{\pi \times 0.065^2 in^2} = 4520.4lbs/in^2$$

$$\%Error = \frac{(4596\,psi - 4520.4\,psi)}{\frac{(4596\,psi + 4520.4\,psi)}{2}} \times 100 = 1.66\%$$

Failure Criteria

Safety Factor: 2

$$\sigma_{\max} \leq \frac{\sigma_Y}{n}$$

$$18240\,psi \leq \frac{50990\,psi}{2} = 25495\,psi$$

After the performed failure criteria test, the support screw was confirmed safe.

6.2.2 Walker Frame

Another stress concern of this project was the overall strength of the walker frame. Assumptions had been made for the case of when the walker hits a large object. Is the walker frame strong enough to resist the impact created from this accident? Therefore, an FEA was run for the walker frame. The results are presented below.

Boundary Condition, Meshing and Result Plots:

A fixed restraint was applied at the handles of the walker frame. We assumed the frame was stable when a person was holding on the handles. Also, a 20lbf normal force was applied at the front cross bar by assuming something hit at the front of the walker. Meshing was used to refine the elements of walker model after the boundary condition was applied (**Fig. 6.9**). Finally, running the FEA, von Mises stress plot (**Fig. 6.10**) was obtained.

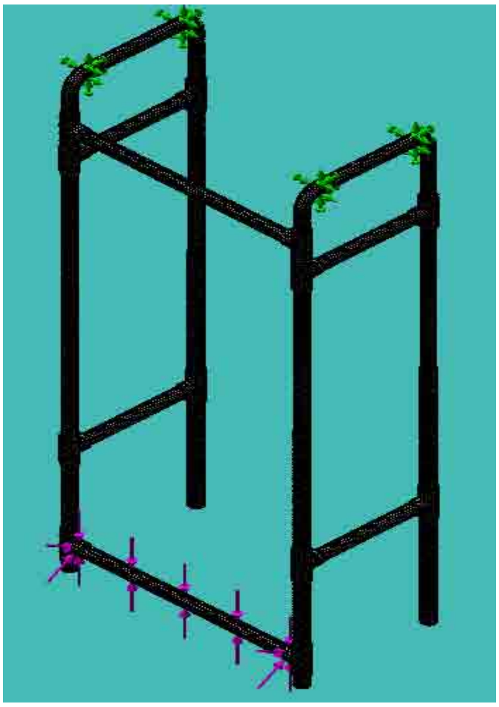


Fig. 6.9: Boundary Condition and Meshing.

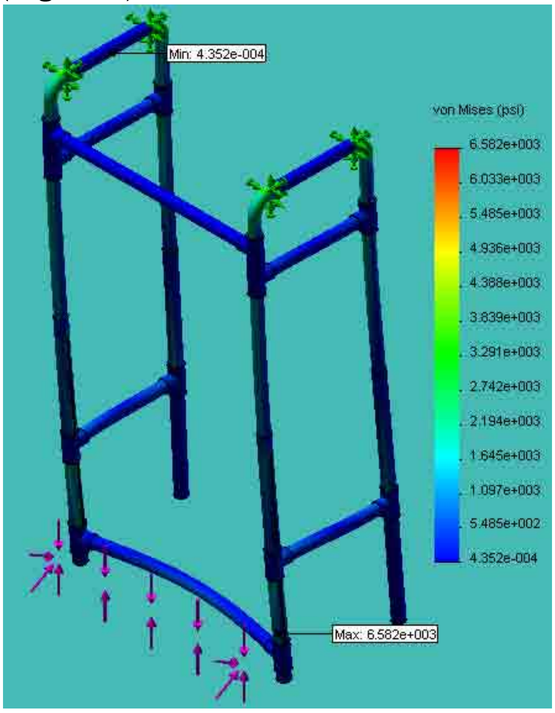
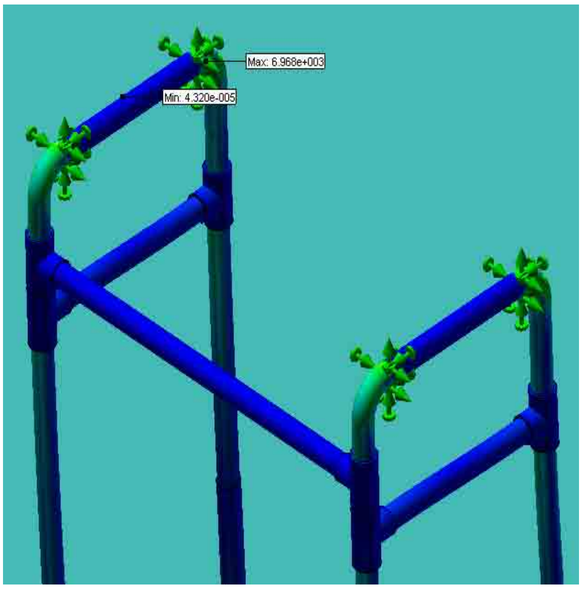


Fig. 6.10: Contour Plot for von Mises Stress.



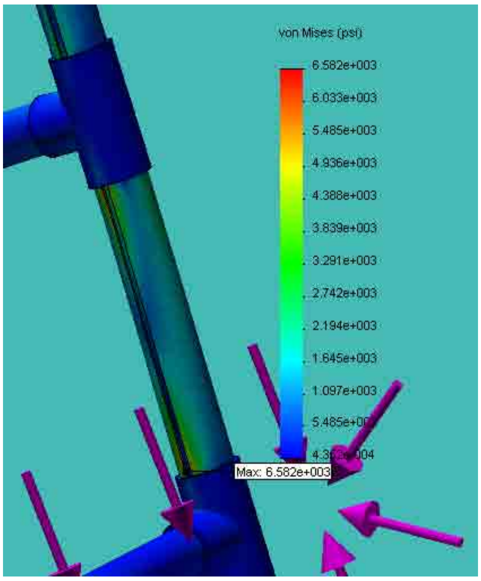


Fig. 6.11: Zooming on the Stress Concern Area.

Failure Criteria

Material: Aluminum 6064

Safety Factor: 2

$$\sigma_{\max} \leq \frac{\sigma_Y}{n}$$

$$6582\,psi \leq \frac{39885.4\,psi}{2} = 19942.7\,psi$$

From failure criteria test, we confirmed the walker frame also safe.

7. MANUFACTURING

In this portion of the project the necessary steps and procedures used in the manufacturing of the alpha prototype will be outlined. In order to ascertain that the manufacturing procedure would go smoothly, it was ensured that the dimensions and tolerances were correctly within the allocated design parameters. Material selection was done based on the task attributed to each component/part of the design. Another critical factor of the manufacturing process is the cost. It was ensured that the cost of the materials did not exceed the project's budget. The steps taken and the equipments used to manufacture various parts/components will be detailed in this portion of the project.

7.1 Manufacturing Gantt Chart

To ensure that the manufacturing process was efficient the tasks shown in **Chart 7.1** were executed according to time table.

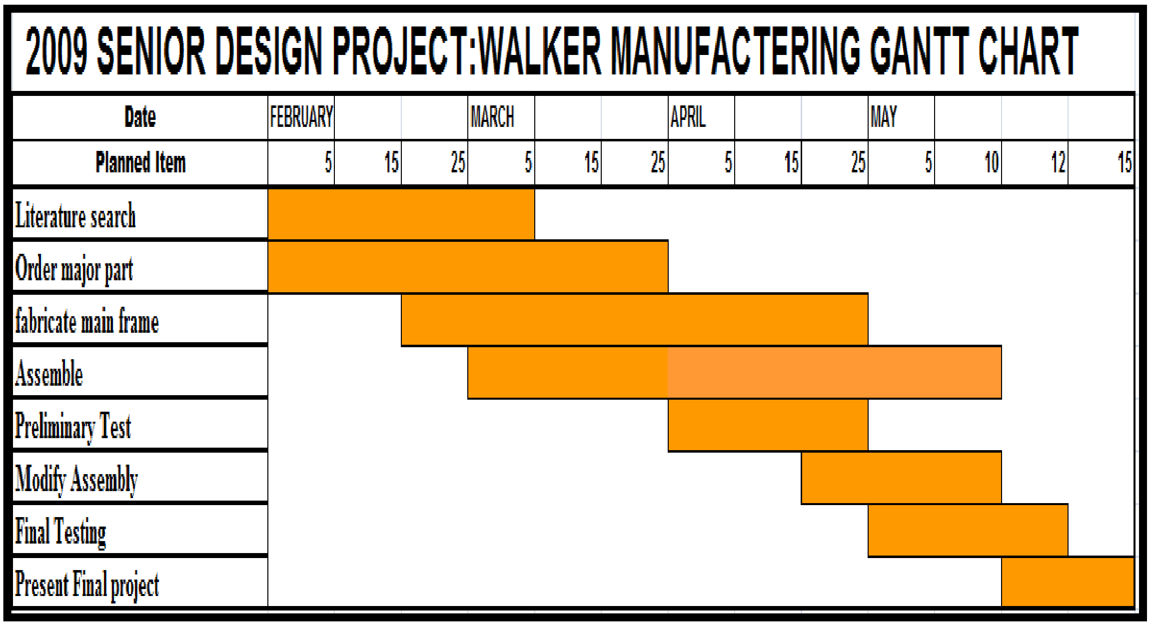


Chart 7.1: Manufacturing Gantt Chart

7.2 Material Selection:

Materials were chosen for each specific parts based on the requirements that needed to be fulfilled. Example, the overall frame of the walker was constructed from aluminum because the requirements for the design were to be lightweight and have relatively high structural rigidity.

Part	**Material**
Legs	6061 Aluminum
Structural Frame	1020 Steel
Reinforcements	PVC
Lead Screw	Steel
Bearing Holder	Porous PVC
Sleeve Nut	Bronze
Bearings	Ball
Speed Controller	ESC
Drive Wheels	Plastic/ Hard Rubber
Back Swivel Wheels	Plastic/ Hard Rubber
Drive Motor	Planetary Gear Box Motor
Linear Actuator Motor	Planetary Gear Box Motor
Motor Holder	Porous PVC
Lead Screw Couple	6061 Aluminum
Controller Holder	Porous PVC
Screws	Hardened Carbon Steel
Power Supply	16v Nicad Batteries

Table 7.1- Material Selection

7.3 Material Cost:

In order to ensure that the design was within budget, a cost estimate was done for the design based on the cost of materials and individual components, which are needed to complete the alpha prototype.

Material/Component	**Quantity**	**Cost**
1’’ OD x 0.035’’ Wall x 72’’ Long 6061 Aluminum Tube	1	$16.25
1.125’’ OD x 0.035’’ Wall x 72’’ Long 6061 Aluminum Tube	1	$20.38
0.75’’ OD x 0.035’’ Wall x 48’’ Long 1018 Steel Tube	1	$17.05
0.75’’ OD x 0.125’’ Wall x 120’’ Long PVC Pipe	1	$20.00
Drive Wheels	2	$20.00
Swivel Wheels	2	$10.95
Lead Screws	2	$35.00
Sleeve Nuts	2	$40.00
Cordless Drills (drive wheel motor, speed controller, batteries)	2	$50.00
Total		**$229.63**

Table 7.2 – Material Cost

7.4 Manufacturing of Parts:

In order to manufacture different components of the design, certain steps were followed and various equipments were used. These equipments are Vertical Milling Machine, Drill Press, Band Saw, Caliper, Measuring Tape, Rule, Lathe, Punch, Scriber, Metal Bender, and Sander.

7.4.1 Walker Frame and Components:

Legs and frame support constructed from 1''OD x 0.035'' Wall Aluminum Tubes and 0.75''OD x 0.035'' Wall Steel tubes respectively.

Walker Frame and Components:

Fig 7.1: Walker Frame Assembly

The legs (**Fig 7.2**) were made by bending the aluminum tubes with a metal bender. Steel tubes were cut, bent, and welded in order to construct the frame support shown in **Fig 7.3**.

Fig 7.2: Legs

Fig 7.3: Frame Support

7.4.2 Planetary Gear Motors:

Both motor utilizes a planetary gearbox for the purpose of gear reduction. The specifications for the drive wheel motor (**Fig 7.4**) are: i) Speed-600rpm ii) Weight-2lbs iii) Overall diameter-1.45in iv) Overall length-4in. The specifications for the linear actuator motor (**Fig 7.5**) are: i) speed- 950rpm ii) stall torque-45ozin iii) gear ratio- 16:1 iv) Weight-2.29oz v) Diameter-0.86in

Fig 7.4: Drive Wheel Motor

Fig 7.5: Linear Actuator Motor

7.4.3 Linear Actuator:

The linear actuators were constructed from 24 in long by ¼ in diameter lead screws with 1/20 inch pitches. The sleeve nuts, made from bronze, were ½ inch by ½ inch with inner diameters of ¼ inch. The motor holders were constructed from aluminum discs. Slots were milled in the center of each of them in order to constrain the motors. $^{3}/_{32}$ inches holes were drilled on the sides of each motor holder for the purpose of constraining the linear actuators in the moveable sections of the front legs. ¼ inch thick ¼ inch bore ball bearings were held in position by means of porous PVC plastic rings. Aluminum couplings were used to connect the output shaft from the planetary gear motor to the lead screws; they were held in position by means of set screws. Drilled aluminum discs and PVC discs were used to retain the sleeve nuts. **Fig 7.6** shows the assembly linear actuator, while **Fig 7.7** shows a close up of the motor assembly.

Fig 7.6: Linear Actuator Assembly

Fig 7.7: Close-up of Motor Assembly

7.4.4 Motor Holder:

The purpose of motor Bracket is to secure the drive wheel motors in the moveable sections of the front legs. It constructed from 1/8 inch thick aluminum plate. A slot was milled in the center of the bracket (**Fig 7.9)**, where in the planetary gear box motor will be constrained. The shape of the outer periphery of the bracket was obtained by means of cutting with a bandsaw.

Fig 7.8: Drafting of Motor Bracket

Fig 7.9: Milling Slot in Bracket

7.4.5 Drive Motor Assembly:

Along with the motor bracket, slotted porous PVC slabs were sandwiched between the bracket and an aluminum plate in order to ensure the rigidity of the assembly, **Fig 7.10**. A hole was drilled in the motor bracket so that the assembly could be bolted into the moveable section of the front leg **(Fig 7.11).**

Fig 7.10: Drive Motor Assembly

Fig 7.11: Attaching Motor Assembly to Leg

7.3.6 Moveable Section of Front Leg:

Two $^{3}/_{32}$ inch wide by 20 inch long slots were cut into a 1.125" OD × 24" Long Aluminum Tube.

The slots were milled on opposite sides of the tube. The purpose of the slots is to prevent the leg from rotating and to act as a guide as the leg travels up and down. **Fig 7.12** shows the slotted front leg alongside the linear actuator assembly. The motor end of the linear actuator will be secured in the lower end of the moveable leg and the sleeve nut end of it will be retained in the stationary section of the front leg (not shown).

Fig 7.12: Slotted Front Leg

7.4.6 Reinforced Assembly of Prototype:

After the first assembly was tested, it was discovered that it was too unstable. In order rectify that problem ¾ inch diameter PVC pipes were used to reinforce the structure of the walker, which ensured that the safety factor was at a desired level, see **Fig 7.13**. The reinforcement was done so that the walker would retain its fold ability function. This was accomplished by fixing one end of the PVC pipe to the back leg of the walker while the other end allowed the moveable section of the front leg to have three degrees of freedom-rotation around the Z axis and translation in positive and negative directions on the Z axis.

Fig13: Reinforced Assembly of Prototype

7.4.7 Refined Assembly of Prototype:

The prototype was refined by completing the electrical wiring, the drive motors were connected to one of the speed controllers while the linear actuator motors were connected to the other. The speed controllers were used to independently control the speed and directions of the motors. The batteries were secured to back legs of the walker while the speed controllers were placed on the handles. Swivel wheels were inserted in the back legs. Fig **7.14** and **Fig 7.15** shows the walker folded and opened respectively.

Fig 7.14: Walker Folded

Fig 7.15: Walker Opened

8. DISCUSSION

After careful evaluation, Design Concept 3- walker with motorized retractable and extendable front legs-was chosen as the final design. It is a plausible design on the basis that it fulfilled the requirements previously mentioned in the problem statement.

In order to ensure the optimal performance of the design necessary analysis were undertaken, which are static and kinematic analysis of key components. Pertaining to static analysis, the critical parts under consideration were the support screw and walker frame. Static analysis was done by means of utilizing two methods, which are analytical and numerical .The numerical method (F.E.M) used the Cosmosworks software to obtain solutions. Both methods were used to ensure the accuracy of results by means of comparing them. The percent errors obtained from the comparison were within the range of 5%-20%, which indicates that the results were fairly accurate based on the assumptions made. Kinematic analysis was done on the drive wheel system in order to obtain walking speeds.

Before doing any analysis, reasonable dimensions for the walker design were chosen. We used the dimensions of a standard walker as a reference the design. For other some parts, judgment was used to choose these dimensions.

Various problems arouse during the manufacturing process of the walker, which are: i) instability of the overall frame of the walker ii) slots in the moveable sections of the front resulted in a degradation in the structural strength of the tubes iii) difficulty in positioning linear actuators in the front legs. Instability of the overall structural frame of the walker was solved by means of implementing PVC pipe reinforcements. The reinforcements were done in such a way that enabled the walker to maintain its fold ability function. The reduction in structural strength of the front legs due to the slots was solved by placing PVC coupling concentrically around each leg; they were placed in such a way that prevented the tubes from bulging while allowing them slide.

9. SUMMARY AND FUTURE PLAN

9.1 Summary

In Summary, a plausible design (concept 3) was achieved that fulfilled the objectives in the problem statement. The final concept was selected, by means of an appropriate selection process, from series of three concepts: i) concept 1-utilzed a track to climb stairs ii) concept 2-utilized a rotating wheel assembly iii) concept 3- utilized adjustable front legs. Kinematic and static analysis was done on the final concept in order to attain a safe and optimal design. After the design phase, the alpha prototype for the final concept was manufactured and tested.

9.2 Future Plan

In order to further refine the final deign the following will be done in the future: i) Replace drive wheel planetary gear motors with suitable power and lower speed motors ii) Replace power cords with flat retractable tape wire iii) Replace Nicad batteries with Nimh or Lithium ion batteries.

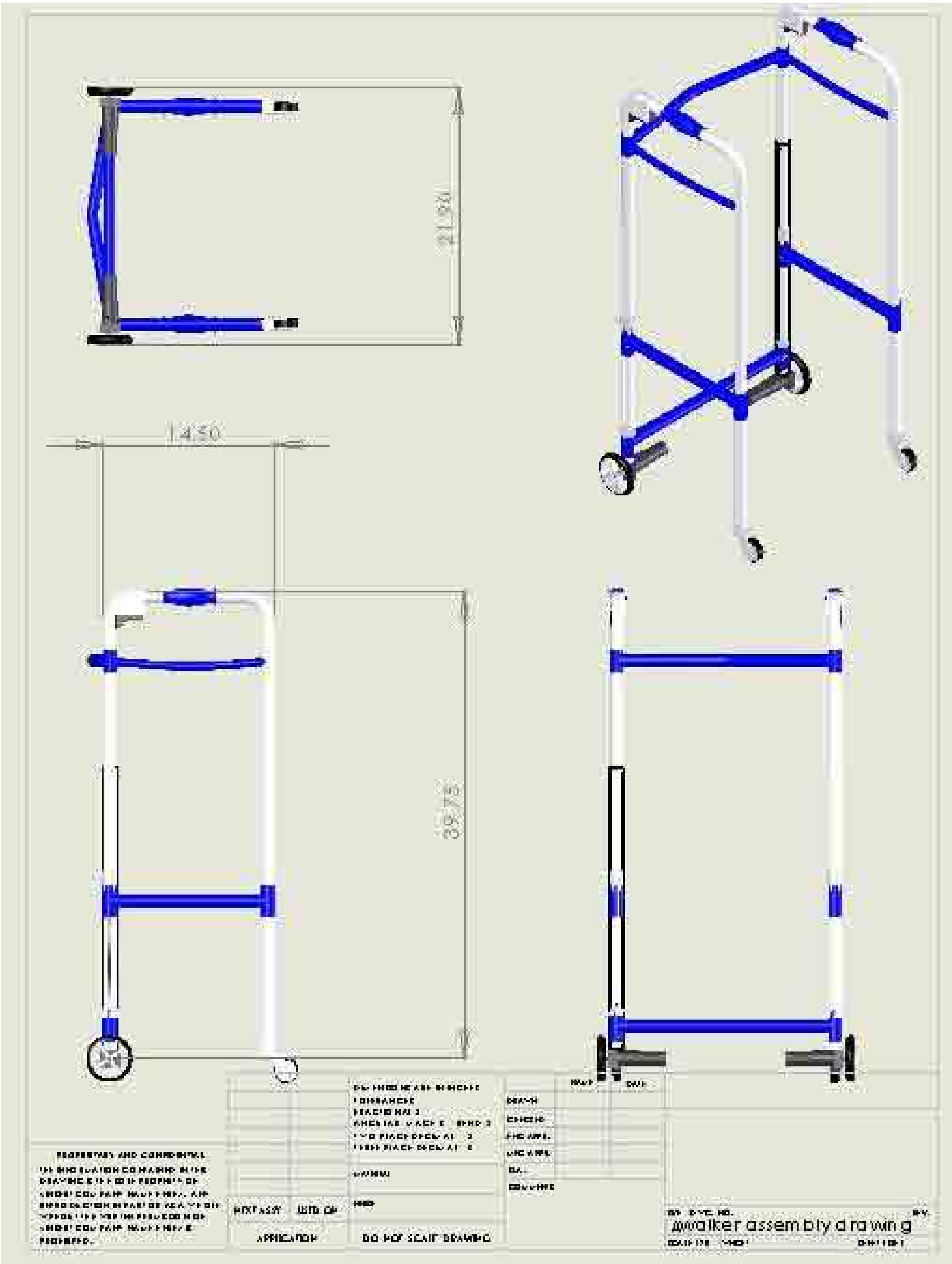
10. REFERENCE

1. Mechanics of Materials, Sixth Edition, R.C. Hibbeler, Pearson Prentice Hall, 2005.
2. Mechanical Engineering Design, Eighth Edition, Richard G. Budynas and J. Keith Nisbett.
3. www.medicalproductsdirect.com/walkers.html
4. www.robotmarketplace.com
5. www.onlinemetals.com

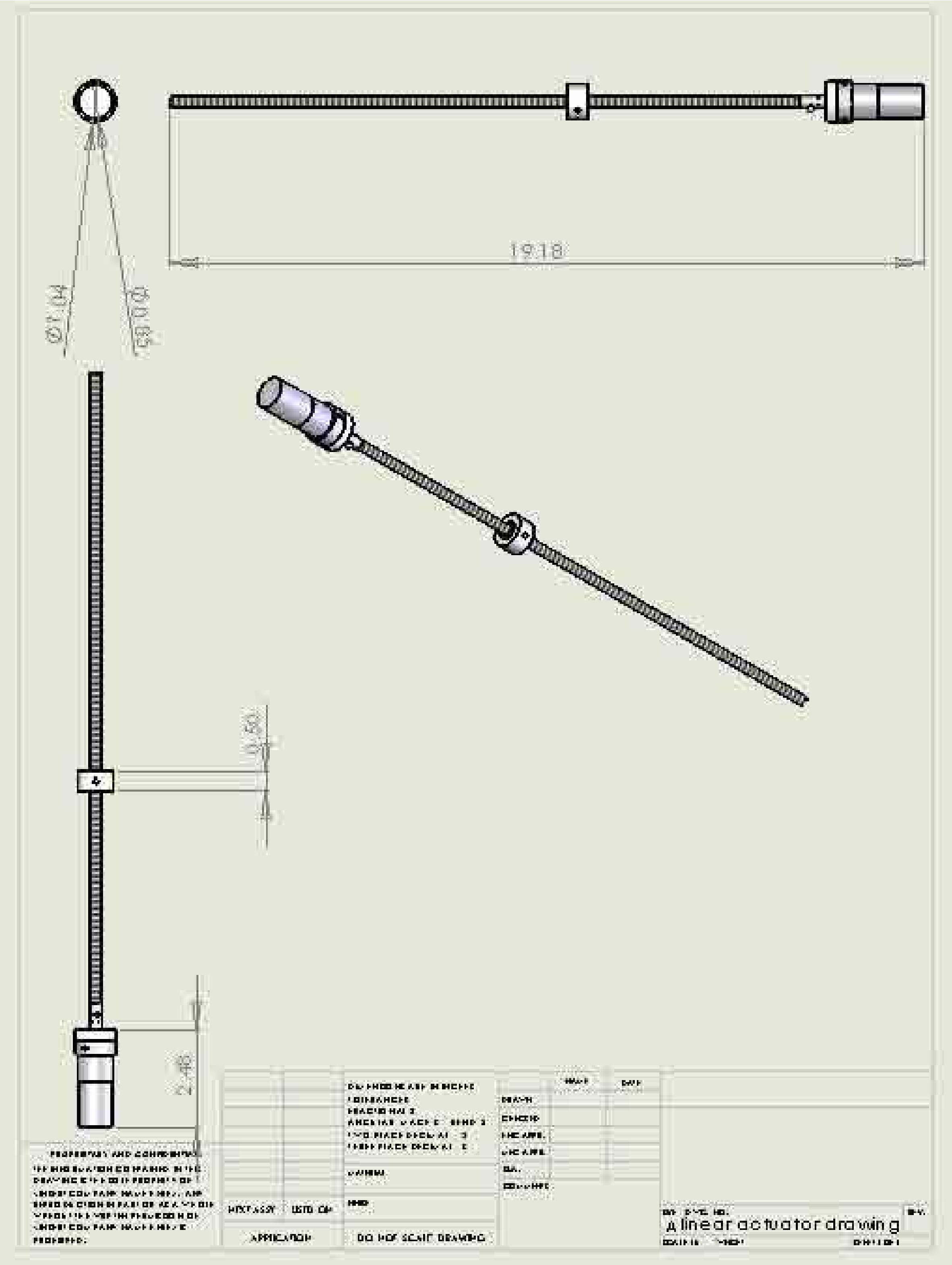
11. APPENDIX

Drawings:

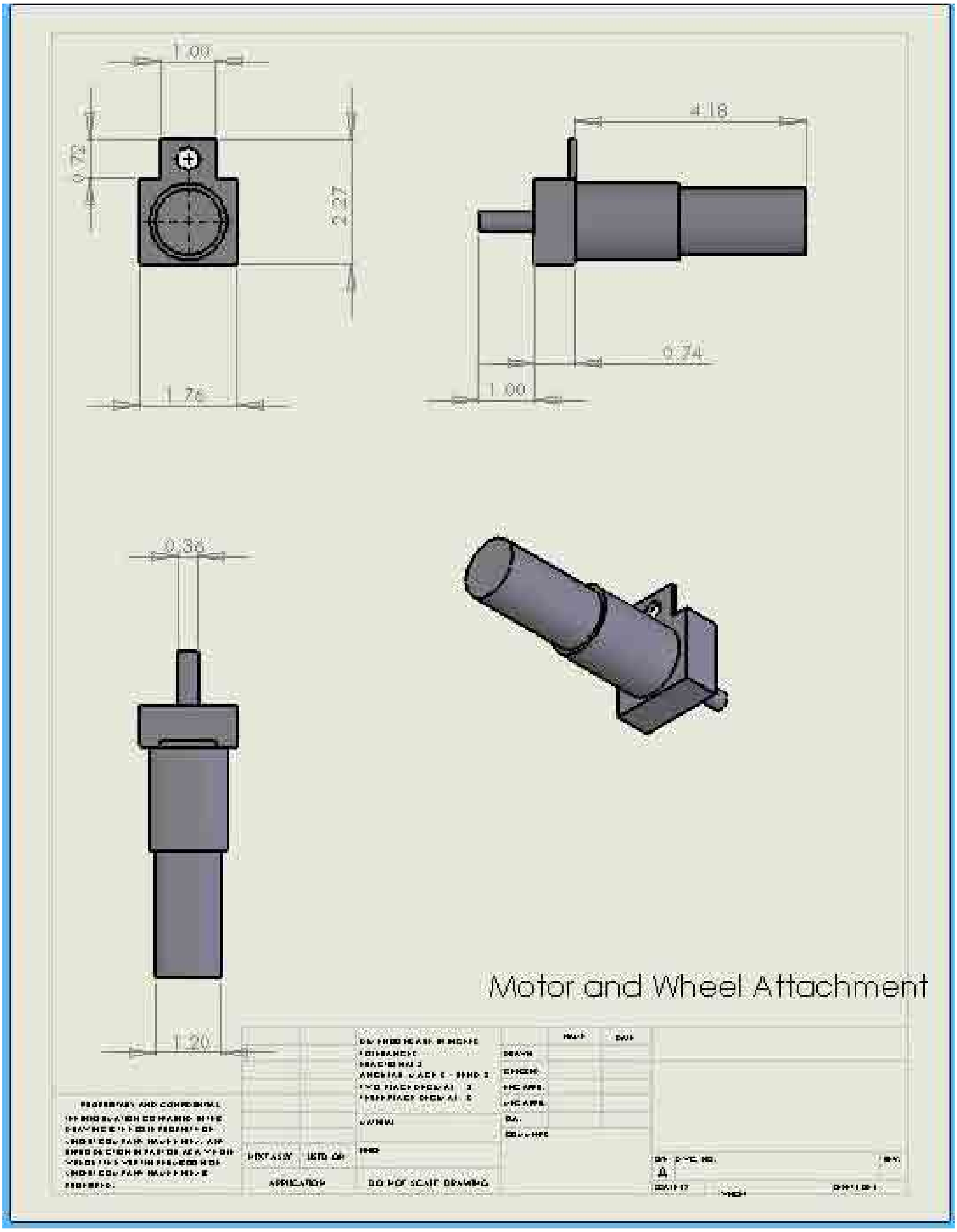
The manufacturing was done based on the dimensions represented in technical drawings.



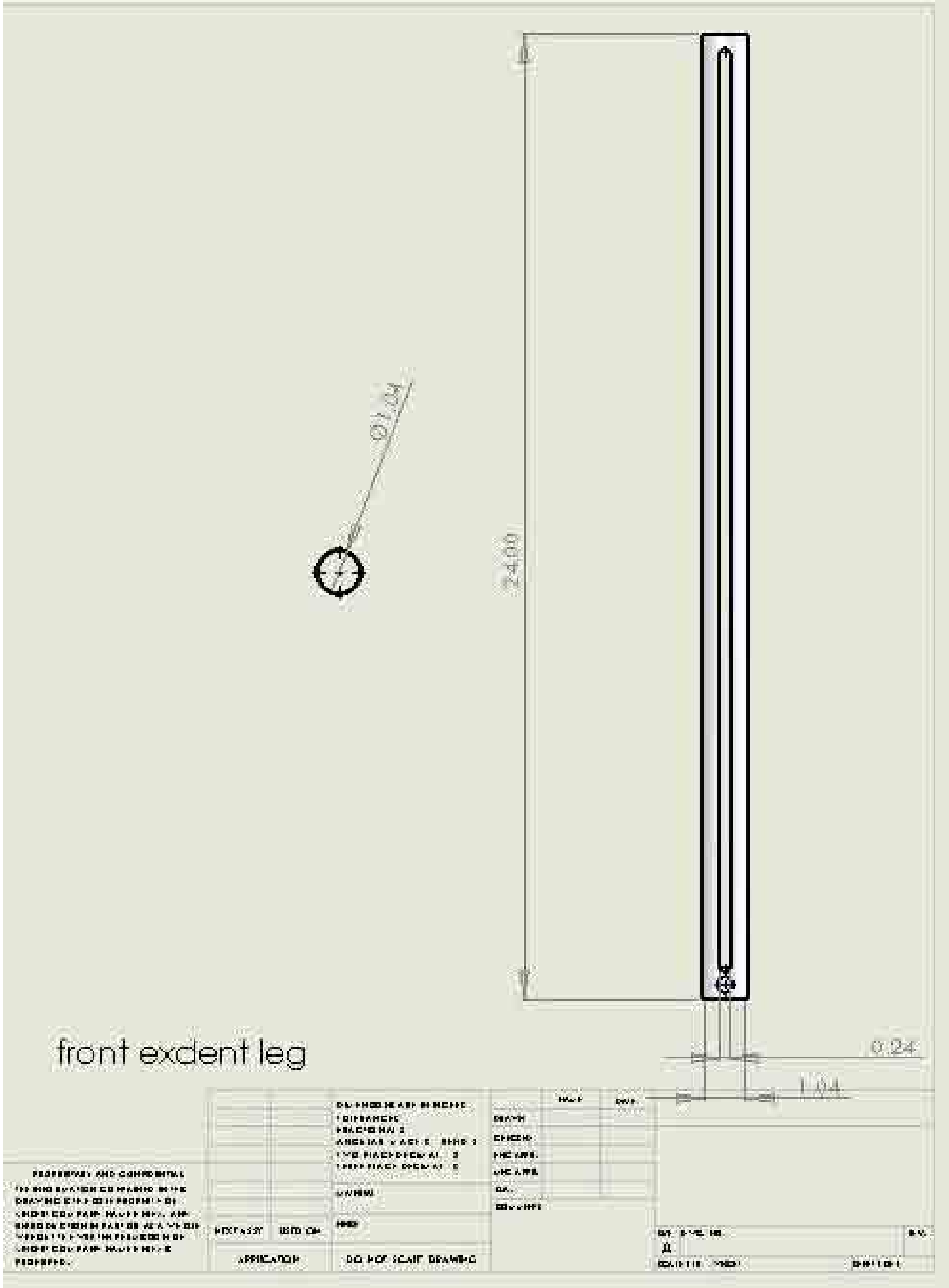
A-1: Drawing of overall walker



A-2: Linear Actuator



A – 3: Drive Wheel Motor


Ø1.04
24.00
0.24
1.04
front exdent leg
DO NOT SCALE DRAWING
APPLICATION

A – 4: Front Leg