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OPTIMIZED DESIGN OF STAIR CLIMBING WHELLCHAIR: A REVIEW

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Abstract

Wheelchairs are used by people for whom walking is difficult or impossible to due to disability. In overall world population about 7.3% of people are disable. It creates number of problems for them overcoming various obstacles like Stairs etc. Conventional wheel chairs are not self operated, they are manually operated, as they face problems while climbing Stairs. A concept of stair climbing wheel chair capable of moving on flat road automatically, as well as Climbing Stairs with special geometry is briefly explained in this paper. Main goal is to provide information to reader how the technology and science can be used for betterment of society.

Index Terms: Wheelchair, Spider, shaft, gear, cradle mechanism, coupling etc.

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1. INTRODUCTION:

In day to day life man is been improving himself in fields of science and technology. This is to overcome his problems and improve comfort levels. Mobility is the most frequently problem faced by physically disabled people. The people with physical disability not only have less living space, but also the quality of life is seriously affected and it also brings big burden to their family. Wheelchair as a means of transport tool plays an important role in the life of those people who are old and disable.
After the PWD act in 1995, number of building are developed keeping in mid disabilities of people though there are many building designed without considering mobility of physically challenged people. This provides a scope of development for disabled people.

On observing the few prototypes that have been made to serve similar purposes, we observed that the designs were very complicated and robust and thus could be optimized by modifying the mechanism and materials of components that was employed.

There are many attempts made since 20th century to reduce the human efforts by introducing a power wheelchair. Power wheelchairs are useless when they face obstacle like stairs. This gives another chance of development in areas of stair climbing wheelchairs for Engineers. Several attempts are made in developing stair climbing wheelchairs. Some of the wheelchairs uses tracks, which requires high energy resulting high power input and they are also robust in construction due to material used for chassis as well as components. Other solutions like iBot adopt hybrid locomotive systems, which is efficient. Major drawback of these iBots is, it’s excessive cost to achieve safety standards.

2. WORKING PRINCIPLE:

Design and Analysis:

The wheelchair that we have designed operates primarily in two modes namely:

1) Flat Ground Mode
2) Staircase Climbing Mode

It was necessary to design the mechanism of the wheelchair to achieve the motion associated with both these modes of operation.

The design that we chose uses the two degrees of freedom available in an epicyclic gear train to perform the required task. The components of the wheelchair can broadly be classified into the following sub-assemblies.

1) Drive Train
2) Seat tilting mechanism
3) Chassis
4) Motor and Gearbox assembly

The design of each of these sub-assemblies and their constituent components is given below.

2.1 Drive Train:

The drive train is the most critical sub-assembly of the entire machine. The drive train consists of the following components:

1) Gear Train

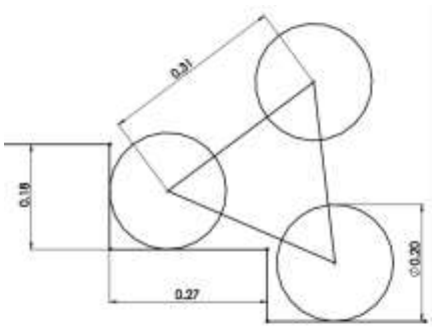

Fig No.1 Configuration of Wheels

It is observed that the straight line distance between the two wheels must be less that the hypotenuse of the stair.

Hypotenuse = 324.5 mm

From the triangle it is observed that the length of the arm

OA = OB = OC = r

r = 180 mm

In order to calculate the gear dimensions we must make the following assumptions.

Module, **m = 2 mm**

Gear Ratio i = 4

Number of teeth on Planet Gear (pinion) **Zp = 18** (taken as minimum teeth to avoid interference)

Diameter of Planet Gear (pinion) Dp = m * Zp = 18 * 2 ; **Dp = 36 mm**

Therefore Number of Teeth on Sun Gear Zg = 18 * 4 ; **Zg = 72**

Diameter of Sun Gear Ds = m * Zg = 2 * 72 ; **Ds = 144 mm**

Hence Diameter of Intermediate Gear,

Di = r – (Rg + Rp) = 180 - (72 + 18) ; **Di = 90 mm**

Therefore Zi = Di / m = 90 / 2; **Zi = 45**

Now we calculate the stresses on the gear pair to ensure safety for beam and wear strength.

To calculate we make the following assumptions,

Speed of the wheelchair on flat ground V = 4 Km/h.

Bending Stress = 146.67 N/mm^2

Beam Strength Fb = σ_b * b * m * Yp

= 951.87 N

Wear Strength Fw = Dp * Q * K * b

= 829.44 N.

Since the pinion is weaker in wear than in bending we design for wear failure.

Therefore Wear Strength = FOS * Effective force (dynamic and tangential)

Effective force, Feff = Ka * Km * Ft / (Kv)

Feff = 1.1 * 1.3 * 209.67 / 0.7735 = 387.62 N

FOS = Fw / Feff = 829.44 / 387.62 = 2.14

Since **FOS** > **2** the design is safe.

Analysis Results of Gears in Ansys:

1. Sun Gear:

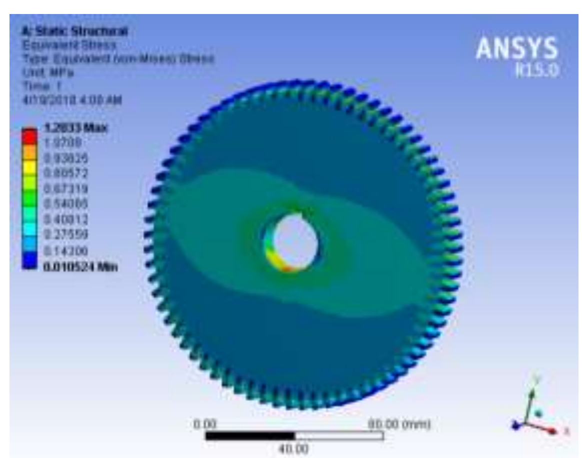

Fig No.2 Equivalent Stress

1. Intermediate Gear:

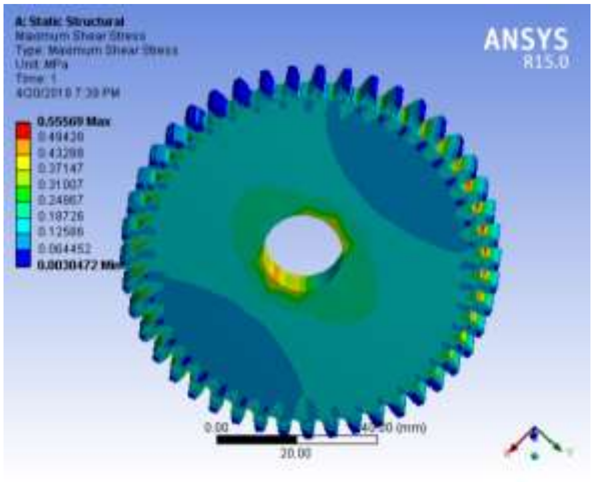

Fig No.3 Maximum Shear Stress

2. Pinion Gear:

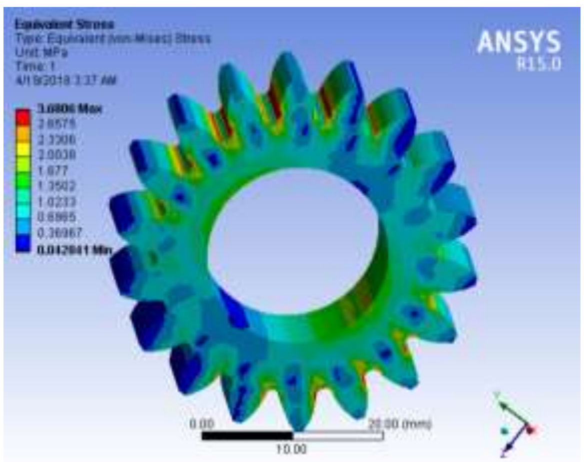

Fig No.4 Equivalent (Von-Mises) Stress

2) Spyder:

The spyder has been mounted on it and coupling which is used to transmit the motor torque and creates the epicyclic motion of the cluster of wheels required to climb the staircase.

Material EN8/AISI 1040

Ultimate Tensile Strength Sut = 700 N / mm^2

Required FOS = 2

Thickness of plate = 10 mm.

Calculations:

Force acting at end of each arm = M * g = 1569.6 N

= 0.18 * 1569.6 = 282.53 Nm

Maximum Bending Moment;

σ_b= Sut / 3 = 700 / 3 = 23.333 N/mm^2

σ_b/ (FOS * Y) = BM / I

23.33 *2 / (2* w) = 282.53 / (0.416 * w^3)

Therefore, **w = 38 mm.**

Analysis of Spyder in Ansys:

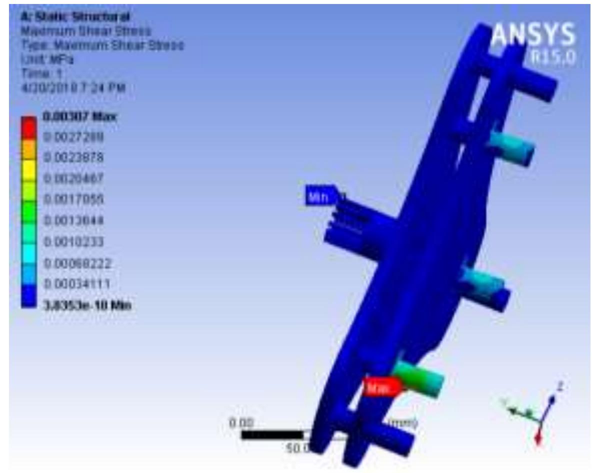

Fig No.5 Maximum Shear Stress

3) Shaft:

The shaft is responsible for transmitting the motion from the motor and gears to the gear train. Material used for shaft is EN8/AISI 1040.

Torque Calculations:

Torque at Shaft , T = (M * g * r) = (160 * 9.81 * 0.18)

= 282.53 Nm

Therefore per motor T = 282.53 / 2 = 141.265 Nm

Equivalent Torque considering combined bending and torsion;

$$Te = \sqrt{(Kt \cdot T)^2 + (Kb \cdot BM)^2}$$

Te = 160.65 Nm

According to the Torsional Equation

$$\tau = \frac{16T_e}{\pi d^3}$$

τ = 94.5 N/mm^2

$$\mathbf{d_{shaft} = 25.4\ mm}$$

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Analysis of Shaft in Ansys:

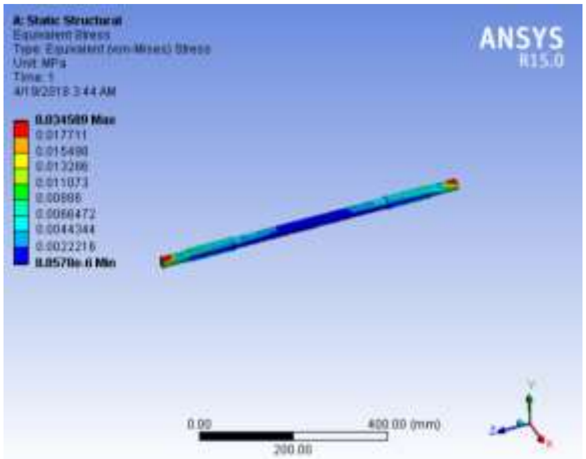

Fig No.6 Equivalent (Von-Mises) Stress

4) Coupling:

The coupling is internally splined and has relative axial motion with the shaft. It mates with the external splines of that shaft and this mate is used to transmit the force from the motor to the arm. The engagement and disengagement of the coupling is used to shift between the flat ground and stair climbing mode. Its movement is controlled manually using a fork to move it. Material used for coupling is EN8/ AISI 1040.

Design of shaft splines:

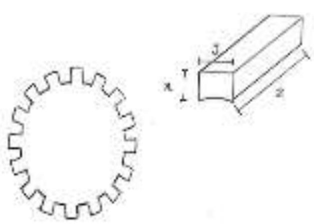

Fig No.8 Cross Section of Shaft and Spline

x = 2mm

y = 3mm

Inner dia. of couple $\mathbf{d_{ci}}$ = d_{shaft} + (2 * x) = **29.4 mm**

$$\frac{\tau_s}{FOS} = \frac{T\frac{d_{ci}}{2}}{\frac{\pi}{32}\left(d_{co}^4 - d_{ci}^4\right)}$$

Therefore with FOS = 2

d_{co}= 34mm

Design of coupling teeth and spyder teeth

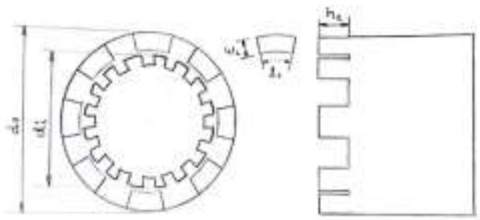

Fig No.7 Front and Side Views of Coupling

Assuming width of teeth to be 4 mm

Thus the outer dia. Of the coupling increases to 40mm

Considering Crushing failure of tooth

When the entire load is taken by one tooth and Crushing Strength = Tensile Strength

$$\frac{\frac{2T}{d_{coupling}}}{w_c h_c} = \frac{S_{ys}}{FOS}$$

Therefore with FOS = 2

h_c= 5.5 mm

For ease of manufacturing we assume h_c to be 10 mm

Considering Shear Failure

$$\frac{\sigma_s}{FOS} = \frac{\frac{2T}{d_{coupling}}}{w_c l_c}$$

Therefore with FOS = 2

l_c = 7mm

Gear Train Design also includes design of front and rear wheel shafts, intermediate shaft and front main shaft. Since the diameter of the main shaft is greater than the Wheel shafts and the load is lesser, the component can be assumed to be safe.

2.2 Seat tilting mechanism:

Most wheelchairs are oblique during the process of climbing up and down stairs, this arises problem in balancing weight of entire chair with the user, it will also feel uncomfortable for user, it can easily turnover, which poses a big safety risk. In order to overcome this problem, a seat backrest adjusting device is designed for our wheelchair, so before the wheelchair climbs up and down stairs, this device will adjust an angle for the seat and backrest to make sure the seat of the wheelchair keeps level with the ground all the time.

The backrest can be adjusted by either mechanical helical and worm gear mechanism, or by using hydraulic cylinder arrangement. We are going to use a hydraulic cylinder arrangement.

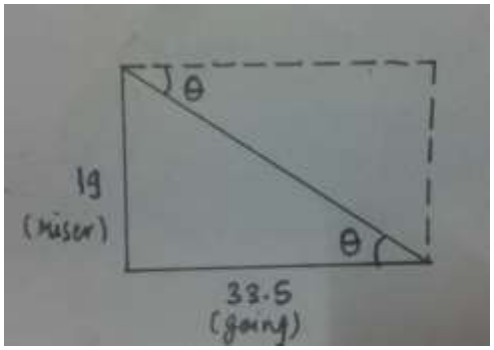

Fig No.9

From the fig3.2.1 we can see that-

tan(Ө)= 19/33.5

Ө= 33.7®

To minimize the stroke length, we trial the position of the cylinder at various length of the seat.

To find the stroke length-

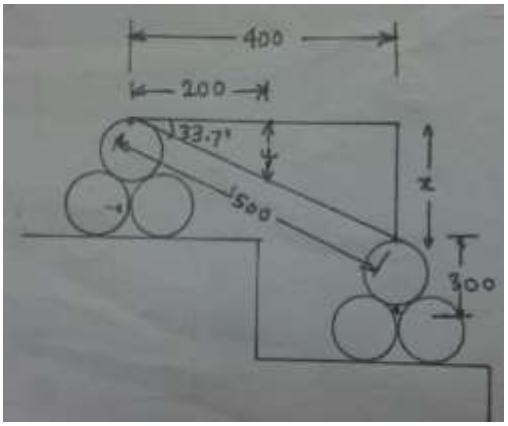

Fig No.10

If we fix the cylinder at the edge, i.e., position 1-

tan (33.7) = x/400

x=266.7mm

If we fix the cylinder at the center, i.e., position 2-

tan (33.7) = y/200

y= 133.38 mm

Therefore, we choose position 2.

Let us assume the maximum stroke of 150 mm.

Now the force calculations-

Assuming a weight of the person to be 100kgs i.e., 100*9.81= 981 N

Assume max load =1000N

The max allowable stress for our material is 276 N/cm²

Therefore, total load on hydraulic cylinder-

Taking FOS=3, the working stress=276/3= 92 N/cm²

For safe working, working stress= Total force/area of cylinder

92=1000/A

A=10.86cm²

10.86= π*d²/4

.: **d=3.72 cm**

But according to specifications of the manufacturer:

For 150 mm (6 inches) stroke-

- Bore diameter (d)= 2.5 inches = 63.5mm
- Cylinder blind end area=(π/4)*d² = 4.91 inch²
- Rod size= 1.4 inches= 36mm
- Outer diameter of cylinder= d+0.5 =3 inches
- Fluid pressure needed P= Force required/cylinder area

  P=1000/4.91 = 203.6 N/inch² (45.82 PSI)

Bearing for the pivot of backrest:

For the rod diameter of 30mm, according to standard bearing sizes for

- Inner diameter= 30 mm
- Outer diameter= 55mm
- Size= 6006
- Width= 13mm
- Weight= 0.242 kgv

2.3 Chassis:

The chassis or frame is the main load bearing structure of the wheelchair. In order to reduce the weight of the wheelchair, the material was selected as **Aluminium**. The frame is mainly made up of rectangular hollow sections of Aluminium with a thickness of 1.5mm. The frame is held together with the help M6 bolts and 5 mm Aluminium strips and L sections. The design earlier called for M4 bolts, but because of insufficient rigidity in the frame, M6 bolts were used. The frame was designed such that all the joints were at 90deg in order to effectively transfer loads from one member to another. The top member of the frame is used to mount the seat and cradle mechanism while the drivetrain assembly is mounted on the lower members. Intermediate members are used to mount the motor, gearbox and batteries.

The chassis is mainly under bending stress and hence a Finite Element Analysis was conducted in order to ensure safety of the system. The design of the frame as well as the result of the FE analysis is shown below.

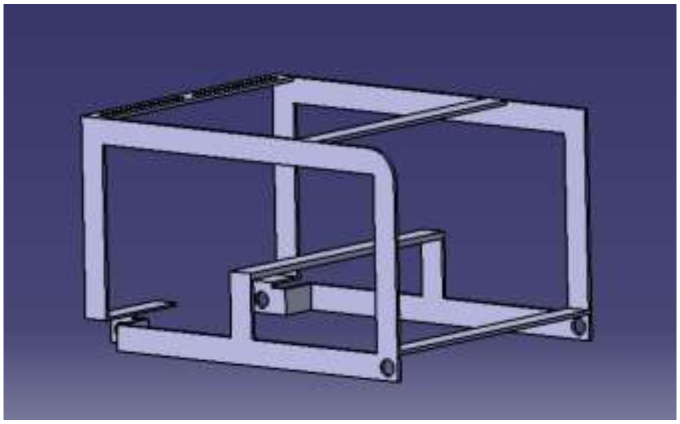

Fig No.11 Chassis Design

Analysis of Chassis in Ansys:

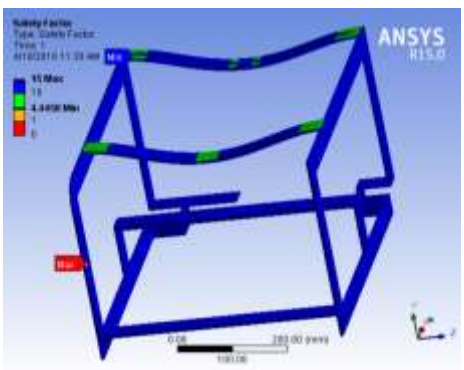

Fig No.12 Safety Factor

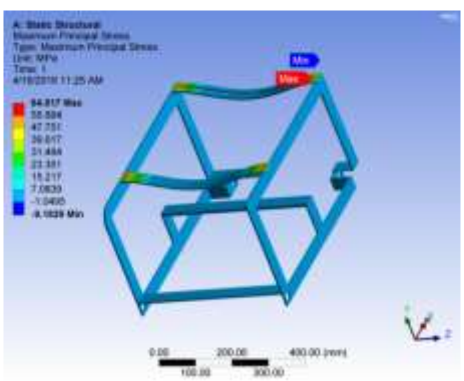

Fig No.13 Maximum Principal Stress

2.4 Motor, Gearbox and Batteries

2.4.1 Motor:

Considering a total weight of wheelchair and human being to be around 160 Kg and a factor of safety of 2, we needed a motor with high torque capacity but had a space constraint. Thus we decided to use a BLDC motor because of its high ratio of power to size. The advantage of using a BLDC motor is also that the speed can be controlled, making it easier to co-ordinate the two motors of the differential drive. Having constant torque also meant that the motor can be effectively utilized at any speed.

The specifications of the motor are:

BLDC Motor

Power: 1 HP

Speed: 2100 Rpm (No load)

Quantity: 2 Nos.

2.4.2 Gearbox:

Since the motor runs at very high speed, it is essential to reduce the speed of the motor to match the output speed of the wheel by using a gearbox. The gearbox also enables multiplication of motor torque. The self-locking characteristics of a worm gear drive were also of particular importance to us in terms of safety.

The specifications of the gearbox are:

Type: Worm gear

Reduction: 1:80

Rated Power: 1 HP

Quantity: 2 Nos.

2.4.3 Batteries:

The battery system consists two batteries in parallel to generate the 24volts required to run the BLDC Motor. From the ampere vs torque chart of the motor we chose the AH rating of the batter in order to ensure the battery lasts for one hour of usage with 30% of the time used for climbing.

Specifications:

Voltage: 12 V DC

Ampere Hour Rating: 7Ah

Actual Model of Wheelchair:

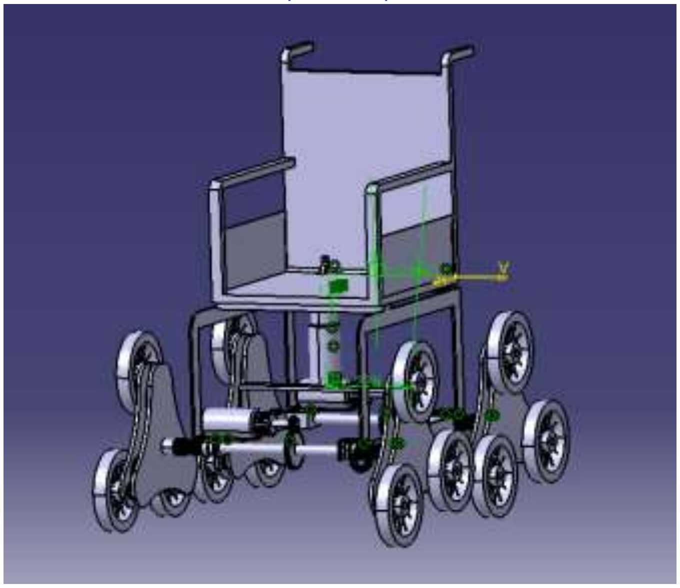

Fig No. 14 CATIA Model

3. LETRATURE REVIEW:

a) Rakshith R, Ritesh N Joshi, Suraj G D & Thrishool R designed the wheelchair which is compact and hence is able to climb almost all the stairs that we find at institutions, offices, industries and also at some homes. It has the ability to ascend a flight of stairs of 35-degree elevation carrying a weight of 55kgs.[1]

b) Prashali Sharma , Shruti Kulkarni , Nilay Chowdhury , Pranamya Bandyopadhyaya & Tanay Chowdhury have described their prototype mode consisting of microcontroller, motor driver, smart phone, PC/Laptop, power supply and motors. The main aim of this project is construction of wheelchair having a direction control through voice commands, touches or hand gesture.[2]

c) Nidhin Peous, Nikhil Mohan & Nitin Jose concluded developing a triangular configuration of spur gears. Geometry consist of three way spur gear pair arranged in manner such that they are able to climb over staircase.[3]

d) Saddamhussain. N and Vasanthakumar. C concluded their design using Hydraulic Jack. For climbing upward Hydraulic jack will be in original position and seat with member sitting on seat will get lifted certain angle to nullify gravity. Use has to lift the lever for climbing up. For climbing downward, the hydraulic jack is lifted to a certain extent in order to nullify weight of user. While coming down user does not have to use any efforts. All he has to do is to break as and when required. Disc brakes are provided for braking.[5]

e) S.M.O. Tavares, N. Viriato, M. Vaz, and P.M.S.T. de Castro have explained modes of failure of hydraulic cylinder with maximum load 1000N. They have also analysed the cylinder in ANSYS and came to certain conclusion.[6]

f) Tadakamalla Shanmukh Anirudh and Jyoti Pragyan Satpathy have used track with rollers at both ends. Power to roller is transmitted from 2HP BLDC motor. Chair climbs the stairs as excavation moving on mountains. Standard commode facility is provided as it is mostly applicable for elder people in order to reduce efforts of transmitting them to toilet.[7]

g) Michael Hinderer, Petra Friedrich and Bernhard Wolf introduced a model consist of two legs. It also has ultrasound sensors in order to detect the stairs and obstacles. Both the legs are independent to move. This legs works same as human legs.[8]

h) Channabasavaraj B D, Ganesh N, Sachin N and Sumanth G Vaidya published paper consisting wheelchair. Assembly consist of 6 wheels, 2 belts, DC motor, etc. Rear two wheels are uplifted to a certain angle equal to angle of staircase and middle and front wheels are on flat surface. As it detects stairs, chain starts climbing backward adjusting weight of user.[9]

i) K. Narendra Kumar, A. Gopichand, M. Gopala Anjaneyulu, B. Gopi Krishna have developed a robot consisting wheels connected to the arms. Frame of the robot is adjustable. At the start of climbing single wheel is lifted up following by another, frame size is adjusted and then rear both wheels are lifted up. This way it climbs he stairs.[10]

j) R Rajasekar, K P Pranavkarthik, R Prashanth, S Senthil Kumar and A Sivakumar have constructed the chain having different wheel geometry. It cosist of 5 areas. Wheel is connected the end of the arm. Due to geometry, it climbs up.[11]

k) Richard Simpson, Edmund LoPresti, Steve Hayashi, Illah Nourbaksh and David Miller have used navigation assistance software in order to navigate current position of wheelchair. Software is developed in C^{++}. Language. Along with this, it uses drop off-detection sensor to detect the upcoming obstacles. Speed of the wheel chain depends upon the computational speed.[12]

4. FUTURE SCOPE:

1. Chassis/Frame weight can be reduced by using lighter material than existing one e.g. Carbon Fiber, Aluminium, Aluminium alloy etc.
2. Hand gestures system, Joystick system can be implemented for ease of turning. The interface we had in mind was a simple joystick that controls the direction and speed of the wheelchair. This would remove the amount of skill required to operate the chair enabling a larger number of people to effectively use the chair.
3. Hydraulic Piston cylinder arrangement can be used for adjusting seat in order to nullify users weight. By using pressurized oil we can lift whole weight of person to balance the forces.
4. To improve ergonomics and aesthetics of wheelchair. Ergonomics is the key part of comfort to user. All handlings, controls and Seating facility should be

developed considering ease in operation. While aesthetics give different impact visually, thereby it should be considered during designing.

5. CONCLUSION:

The reason we selected this project was because we felt a desire to use our engineering aptitude to help a section of society that was so far ignored. While we do not believe that our project is ready to be used immediately by consumers, we believe that we have gone a long way in advancing the amount of research in the field of a low cost stair climbing wheelchair.

The project, due to its innovative nature saw us using almost all the subjects we have learnt in the 4 years of Engineering. From Strength of Materials to Theory of Machines, Design of Machine Elements and even Manufacturing Processes. This project also showed us the difference between theory and practice and instilled in us the ability to look at a problem, find a solutions and most importantly execute the solution.

Nevertheless, since the project cannot be used directly to perform its required function, we must declare that our project is incomplete. That being said, we have made a note of what changes can be made in the wheelchair should anybody want to take the project further. Attached is also a list of goals we achieved during the course of the project.

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