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A Low Cost Mobility Solution for Physically Challenged People

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Abstract – **The most common approach used in most powered wheelchairs is having two motors for traction each driving a wheel on either side of the machine. Forward motion is achieved by keeping the speeds of the motors identical in one direction and the other direction for reverse motion. Turns are executed by making the speeds of the motors different. The radius of turn depends on the speed difference. By having one side motor run in one sense and the other at exactly the same speed in the opposite sense, it is possible to turn on the spot in a zero radius turn. With good fast response closed loop control of the motor speeds this technology works satisfactorily. This paper depicts three novel approaches for cost effectiveness and efficient working of the system, firstly having a powered wheelchair drive with a gear mechanism called "Double differential drive" used to generate the proper speeds of the wheels on either side based on two input rotations from a single powerful traction motor and a low power steering motor. The advantage of this design is that it makes the motor speed control much less critical and so; much cheaper. The straight line motion is achieved by keeping the steering motor switched off. And if the traction motor is switched off, the steering motor can be used to execute zero radius turns. Secondly, utilization of waste brake energy for battery charging which will lead to reduced cost of powered wheelchair in the long run. And finally, a new design of joystick has been proposed to keep the cost of the system as minimum as possible. Taking these approaches into consideration, a powered wheelchair has been designed and fabricated.**

Index Terms **– Brake energy, cost, differential steer, joystick.**

I. Introduction

There are different varieties of mobility solutions available in the market. Even there are chairs which can climb stairs, obey voice commands [16] or even respond to human thoughts. The costs range from a couple of thousand dollars to tens of thousands of dollars, which comes to be around one lakh to ten lakh Indian rupees or more. The bulk of the market is in a basic design which can provide mobility for a person on indoor level surfaces. It is assumed that the user can see where he is going and can press a few switches and operate a joystick control. Most machines have the capability to go up a short ramp, but not up steps.

All conventional powered wheelchairs have two motors; one each; driving one of the main wheels on either side of the vehicle. As in manual wheelchairs where the occupant of the chair uses his hands to rotate the main wheels on either side using handrails fixed to the wheels, all maneuvering is by varying the relative speed of rotation of the wheels on either side. This is technically called "Differential Steer". In motor wheelchairs the differential steer is achieved by properly controlling the speed ratio of the two motors [12]. The electronics has to interpret the two components of the joystick displacement and control the motor speeds accordingly. Apart from the main pair of driven wheels there has to be castor wheels for support. These align automatically to roll in which ever direction they are pushed.

This paper argues for a novel type of drive to achieve differential steer where the traction and the steering components of the drive are handled by separate motors with their proper synthesis to finally achieve the proper difference in speeds for the wheels being handled by a new gear mechanism.

Using this new gear mechanism to attain differential steer [20] along with the proposed design of joystick and the brake energy utilization, a powered wheelchair has been designed and fabricated keeping the cost as minimum as possible.

II. Differential Gear Mechanism

To start with let us briefly visit the kinematics of the standard bevel gear differential gear mechanism [21] which finds wide application in automobile transmissions. Fig 1 illustrates the mechanism. Gear G1 is fixed to shaft S1 and gear G2 is fixed to shaft S2.

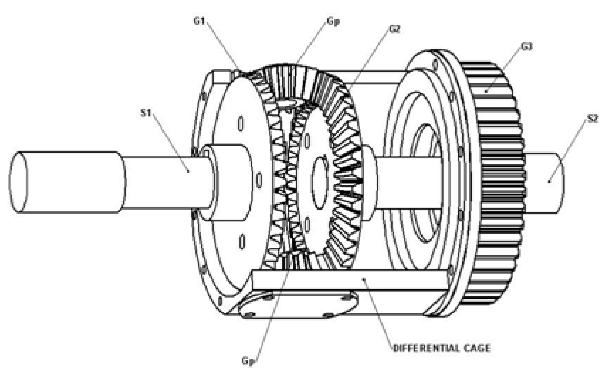

Fig. 1 Bevel gear differential gear mechanism

The "planet" gears Gp mesh with G1 & G2. The planet gear rotate on shaft Sp. Shaft Sp is fixed in a "cage " which in turn is fixed to gear G3. The gears G1, G2, and G3 are

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co-axial which means though they are not on a common shaft they are mounted in bearings fixed in a frame so as to rotate about a common geometric axis.

Now if we designate the rotation of gears G1, G2, and G3, as rG1, rG2 and rG3; the mechanism ensures that:-

$$rG3 = \tfrac{1}{2}(rG1 + rG2) \quad (1)$$

In an automobile transmission the engine drives G3 via a clutch and gearbox and shafts S1 and S2 drive the wheels on either side of the vehicle [20]. This means that the wheels can have different speeds for a particular value of rG3. This is required when going along a curved track, where the outer wheel has to run faster than the inner wheel. However, as the mechanism does not dictate any particular ratio of speeds for gears G1 and G2; it cannot be used to steer the vehicle.

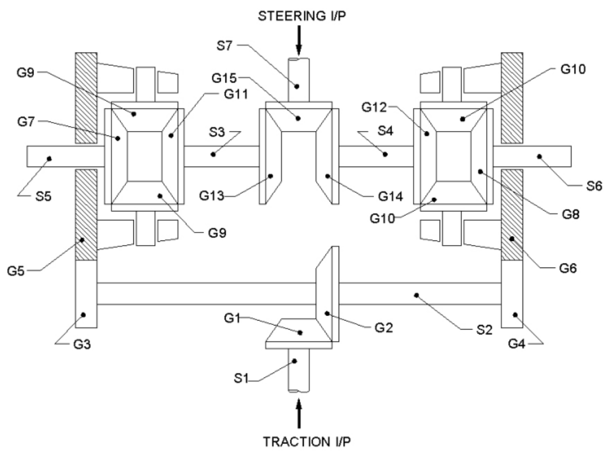

Fig.2 Gear Nomenclature

III. Double Differential Steering Drive

The double differential gear mechanism is illustrated by Fig 2. There are two differentials whose cages are driven in synchronism by a traction motor [20]. That is the cage drive gears G5 and G6 are driven at the same speed and in *the same sense* when the traction motor is activated. The steering motor causes the gears G13 and G14 to rotate through identical angles *in opposite directions*. Gears G13 and G14 are fixed to shafts S3 and S4 respectively. Shafts S3 and S4 in turn drive gears G11 and G12 respectively. Gear G7 is fixed to one of the output shafts S5 and gear G8 is fixed to the other output shaft S6. Bearing in mind the property of a differential mechanism given by (1) we can now write the following corresponding equations for the two differentials. The notation adopted to indicate rotation of the gears in (1) is retained here too.

$$rG5 = 1/2(rG7 + rG11) \quad (2)$$

And $$rG5 = rG6 = rT \quad (3)$$

But $$rG6 = 1/2\,(rG6 + rG12) \quad (4)$$

Where rT is proportional to the traction motor rotation.

And $$rG11 = -\,rG12 = rS \quad (5)$$

Where rS is proportional to the steering motor revolution.

From the above relations it follows that:-

$$rG7 = 2\,rT - rS \quad (6)$$

$$rG6 = 2\,rT + rS \quad (7)$$

The left hand side of (6) & (7) gives the output rotations of the mechanism while the right hand sides give the input rotations. In this case the input rotations determine the output rotations without ambiguity; unlike the automobile differential described by (1).

It may be noticed that keeping rS zero gives equal output rotations in the same sense while keeping rT zero gives equal and opposite output rotations.

The output rotations drive the wheels on either side of the vehicle. Suppose the distance between these wheels is ‘W’; which is called the track width in vehicle engineering. Then; according to the principle of differential steer the mean radius of turn ‘R’ is given by the following relationship:-

$$(2.rT + rS) / (R + \tfrac{1}{2} W) = (2.rT - rS) / (R - \tfrac{1}{2} W) \quad (8)$$

Which reduces to:-

$$R = W\,(rT / rS) \quad (9)$$

From (9), it follows that when rS is zero R is infinite: which means the wheelchair would go straight; and when rT is zero R is zero: which means the wheelchair would turn without going forward or backward. These points are further illustrated by Fig. 3 & 4. Of course other combinations of rS and rT would send the vehicle along curved paths of varying radii. Another way of describing the effect of the mechanism [21] is to say that the speed is entirely a function of the traction input ‘rT’ ; while the rate of turn is entirely a function of the steering input ‘rS’. The two effects may be mixed in any ratio to give any radius of turn.

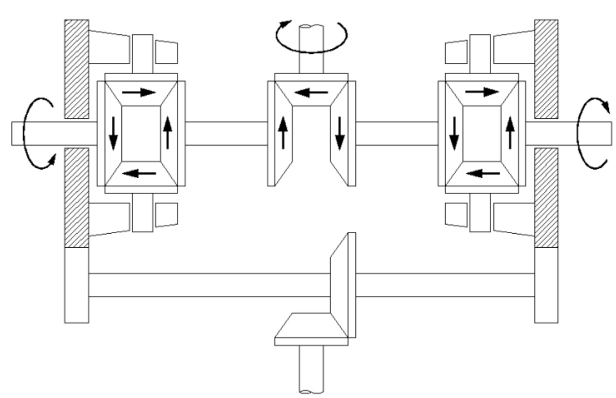

Fig. 3 Steering principle

The drive is immune to varying resistances which may be imposed on the outputs due to unequal rolling resistances of the wheels as far as differential steer is concerned. So motor speed controls are not so critical as in conventional motor wheelchair drives [15] where the two motors have to be controlled precisely to have the required relative speeds even when one of the wheels roll on to a carpet or encounter different rolling resistance to the other wheel for some reason.

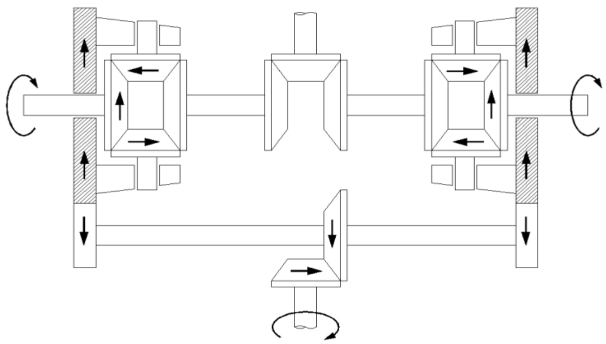

Fig. 4 Traction principle

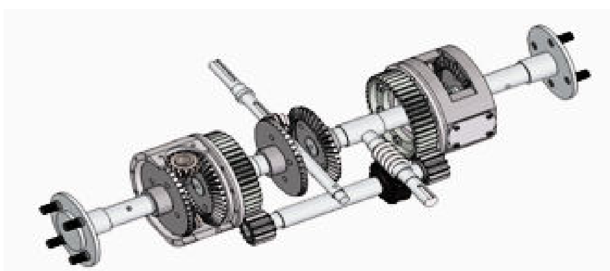

Fig. 5 Implementation of Double Differential Steering Drive Gear Mechanism

Fig. 5 shows the actual implementation of the Double Differential Steering Drive Gear Mechanism [21] in the concept proving prototype.

IV. Control of Traction & Steering Motors

The strategy for controlling the two motors is the same; though the power of the traction motor is over twice that of the steering motor. The motor control scheme is shown on Fig 6. The control input comes from the joystick; which carries the potential dividers JSP1 and JSP2 shown on the diagram. The joystick mechanism ensures that only one of the potential dividers is active at a time. When JSP1 is in operation JSP2 output is low voltage and vice versa. The control voltage from the potential divider controls the pulse width outputted by the PWM controller [23]. The PWM controller is also biased by the current going through the motor to limit the current to protect the motor. The output voltage [2] of the two separate dividers JSP1 & JSP2 has to drive the motor in opposite directions. When the comparator senses a small voltage from JSP2 the PWM controller is connected to it by relay 'R' and the motor connections are switched by the commutator relay to reverse the direction of the current through the motor. The delay circuit is employed to avoid abrupt reversals of the motor to give it time to stop before applying reverse current.

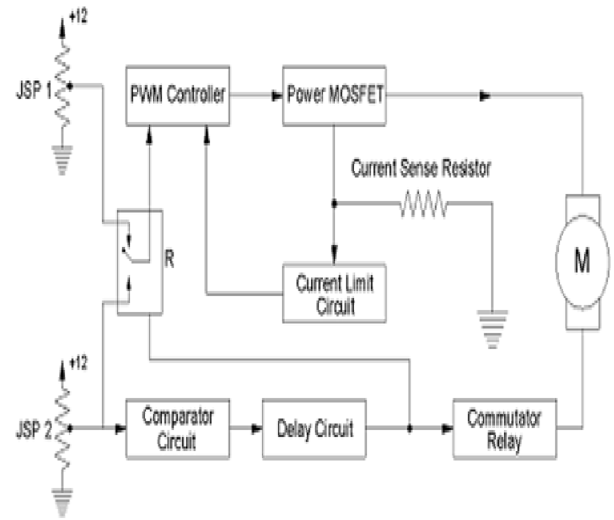

Fig. 6 Control circuit for wheelchair motors

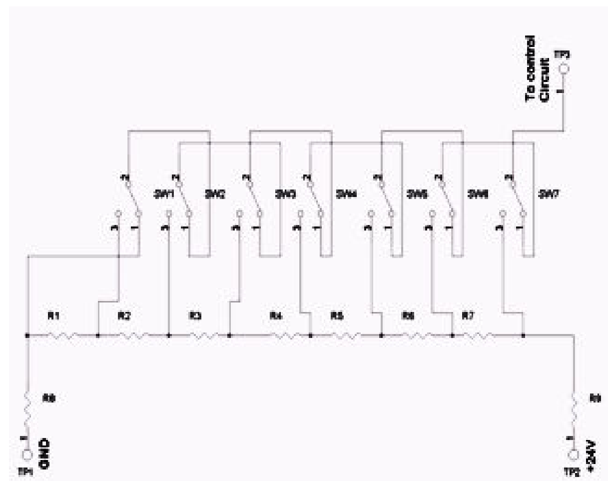

Fig. 7 Potential divider

V. The Joystick Mechanism

The joystick in essence is a single 2-D control which enables the operator to simultaneously address two separate control parameters [8]. In an aircraft (which was its first application) the joystick controls the pitch and roll motions of the aeroplane. In the motor wheelchair it is used to control the forward (or backwards) speed of the chair as well as right / left turns. The fore and aft motion of the stick gives speed control, while the transverse motion gives the direction control. So in the case of the double differential gear drive the fore and aft motion of the stick should create the signal voltage to control the traction motor and the transverse motion should generate the signal voltage for control of the steering motor.

Fig. 7 shows the potential divider circuit used to generate the signal voltages. A simple potentiometer was used initially but proved to be unreliable. Another problem encountered was that the initial portion of the pot rotation could not generate enough pulse width to get the wheelchair moving and so only part of the rotation was available to control the speed once the machine got going. So it was replaced by the seven step switching arrangement shown in Fig. 7. Here the joystick mechanism operates the switches in sequence from SW1 to SW7 to output increasing voltages. The value of resistance for R1 to R7 can now be chosen to give good response through out the range of motion of the joystick [9]. Further: the mechanism of the joystick ensures that at the transition point between two switches, both are pressed so that continuity is maintained.

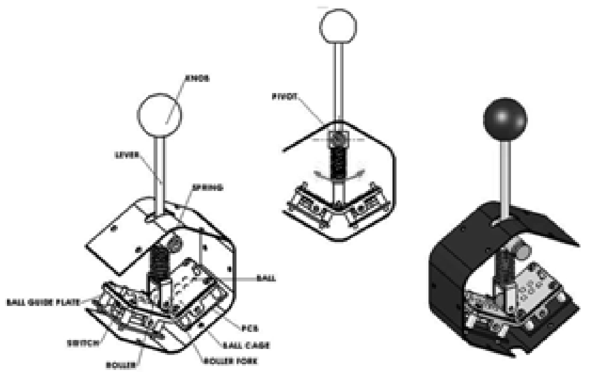

Fig. 8 Traction control

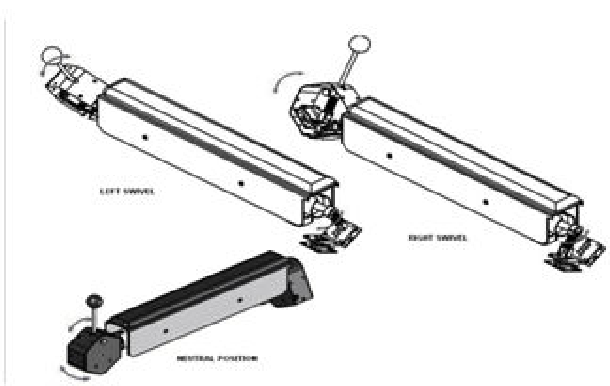

Fig. 9 Joystick assembly

Fig. 8 & 9 illustrate the mechanism of the joystick. Fig 8 shows the traction control. The joystick [8] carries a spring loaded roller which presses the switches soldered on PCBs via balls constrained in ball cages as shown. This ensures that the switch buttons do not suffer side thrust and also limits the button depression to a safe value --------- all in the interest of the life of the switches. As can be seen there are two banks of switches. One of these serves for forward travel of the vehicle and the other for reverse travel. As the roller rides up one row of switches the spring is compressed; the most relaxed spring position being at the apex of the two banks of switches; or in the neutral position where non of the switches are pressed. This means there is a good detent at the neutral position. The same mechanism is repeated at the rear of the armrest as shown in Fig 9 to give the left-right control. A shaft running through the armrest connects the roller arm of this mechanism to the fore & aft control mechanism frame shown in Fig. 8, so the whole frame may be rotated by the joystick to give left-right control.

VI. Usage of Brake Energy

This paper also depicts the innovative concept of utilization of waste brake energy. The idea here is to convert mechanical power into useful electrical energy during braking period and stores the same in the battery. Braking action of the vehicle starts at some distance before the vehicle stops, during this braking period our system actuates and the power during this period is extracted and stored in the battery.

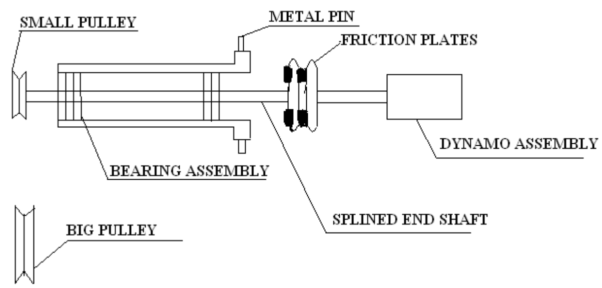

Fig. 10 Battery charging system

The system consists of two pulleys, two friction plates, clutch assembly, a diaphragm, a sleeve with shaft inside it, bearings etc. A pulley is fastened between the flanges of Rear universal joint, power from it is transferred to the smaller pulley fixed on the chassis. When the wheelchair is moving in normal speed, no power is generated but when the brake is being applied, air from master cylinder passes through the distributor and enters into the diaphragm which in turn pushes our designed assembly (designed on sleeve with splined shaft inside it) which in turn connects to the fixed plate of dynamo shaft. Due to friction between two plates, dynamo works and power is stored in the battery. When brake pedal is released friction plates comes into its original position and thus the process is repeated during every braking action.

VII. Modeling and Analysis of the System

After exploration of market and analyzing the existing mobility solutions, we have optimized our system so that it can provide the solution to physically challenged people at minimum cost. The wheelchair modeling (Fig. 14) has been done in Solid Works Software and the Load test analysis (Fig. 11, 12) was done in Cosmos Xpress.

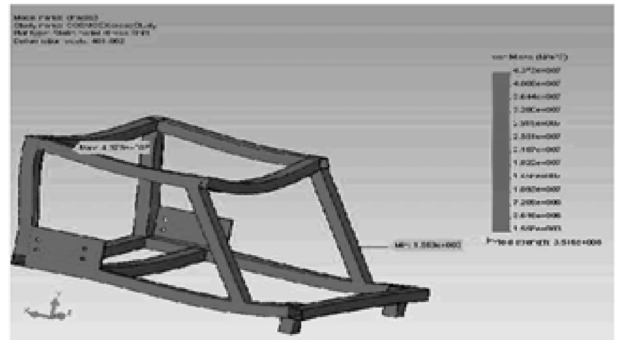

Fig. 11 Load test analysis for the frame designed

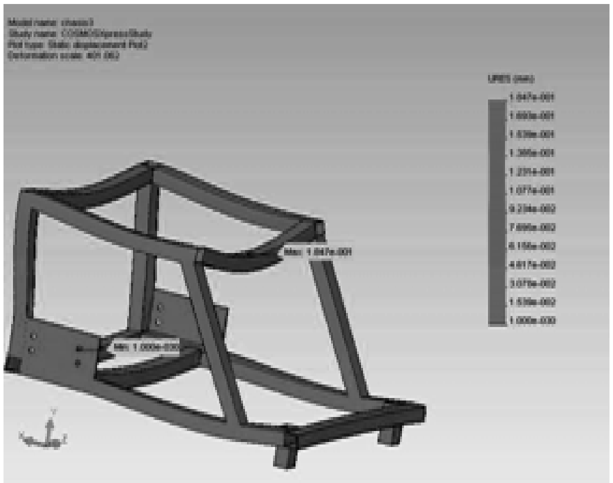

Fig. 12 Stress test Analyze for the designed frame

A basic motor wheelchair controller [12] circuit (Fig. 13) has been designed:

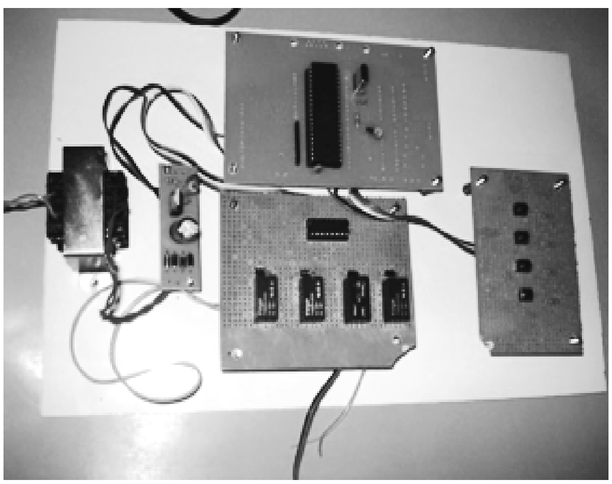

Fig. 13 Electronic fabrication

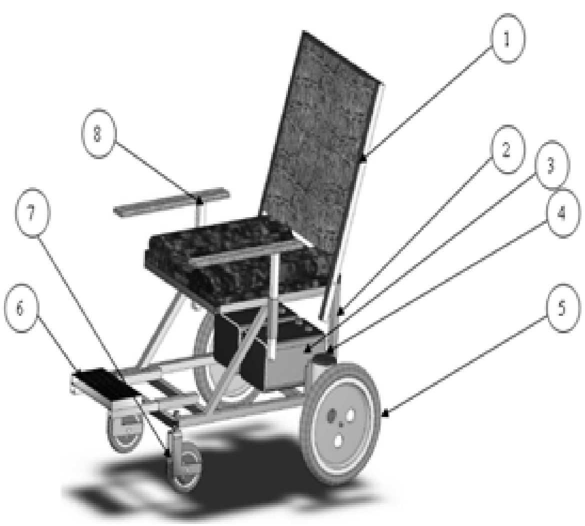

Fig. 14 Assembled System

Table I: Details of components of proposed wheelchair

Part No.	Part Name	Specifications
1	Chair	20"x 18 "standard cushioned chair
2	Chassis	AISI 1020, 1.2" square pipe
3	Battery	12Volts, 30 Ampere Hour, Lead acid batteries
4	PMDC Motor	100W, 24V Geared motor
5	Drive Wheel	10" Tubeless tire
6	Foot Rest	10"x 12" footrest
7	Front Castor wheels	6" Double Bearing
8	Arm rest	Standard part of the Chair

Table II: Details of components of existing wheelchair

Part No.	Part Name	Specifications
1	Motor	2 x 320 Watt 24 VDC Permanent Magnet
2	Wheelchair Control	Multi-Speed - Multi-Direction Joystick - "PG" Controller
3	Cruising Current	6 Amps - (Under normal conditions)
4	Battery	24V (2 x 12 V), 17Ah VRLA Batteries in Series
5	Maximum speed	9.0 Kmph Can be decreased to 6.0 Kmph if required.
6	Brakes	Electronic Circuit Braking.
7	Drive (Transmission type)	Geared Transmission with reduction to the 2 Rear Wheels
8	Maximum weight of Rider	85 Kg

The cost of existing wheelchairs [26] starts from USD 1550 or INR 61,500. And we have approximated the cost of our proposed chair to be approximately USD 500 or INR 20,000.

VIII. Conclusion

The innovations described above have been undertaken to reduce the cost of motor wheelchairs without sacrificing performance. Besides the double differential steering drive, the new joystick design and brake energy utilization attention was given to many other aspects like a seat designed for comfort in the warm climate of the country; a custom designed castor wheel; and an innovative armrest retraction for ease of getting on to and off the chair. A prototype (Fig. 14) for the same has been built and is currently under test.

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