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Design and Analysis of Omni-Wheel based Intelligent Wheelchair

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Abstract

Semi-paralyzed patients or patients with severely hampered motor skills find it difficult to operate wheelchairs and also move from the wheelchair to beds for resting. Motorized wheelchairs aid patients but restrict them to maneuver easily in tight spaces or go on uneven terrains. The main reason is when using 4 wheels it becomes difficult to maneuver the wheelchair in tight spaces be it a motorized wheelchair or manual wheelchair. By integrating the concept of Omni-Wheels and a stretcher converting capability we have designed a multipurpose wheelchair that has better maneuverability in close, tight spaces and also the feature to help patients switch the chair into a stretcher. We have fabricated a 1/4th scale prototype of the actual wheelchair design, assembled parts such as 3 motors,3 Omni-wheels, Arduino Uno, L298N motor controllers, breadboard, a 12v battery pack, and IR sensors for obstacle detection with the feature to recline fully and convert the wheelchair into a stretcher. The prototype does differ from the initial full-scaled design, in that it does not feature pneumatic actuators for the converting capability the wheelchair is designed in a cost-effective way which also ensures flexibility and mobility for the user with an extra feature.

Keywords: Robotic Wheelchair, Obstacle Detection, Omni Wheel, Stretcher

1. Introduction

In the medical world, the wheelchair is one of the most important pieces of hardware and is widely used in many places. Over the years there have been many pioneers who have made significant advancements in this field of wheelchairs like making them motorized, controlling via joystick, developing Hand rim-Activated Power-Assist Wheelchairs assisting old people, robotic wheelchairs with IoT features, etc. One design that is relatively not widely used is the wheelchair propelled by Omni-wheels. The Holonomic wheels have been used before in [9] to reduce the friction losses. The feature to convert the holonomic wheelchair into a stretcher to eliminate the need to move to and from a bed and wheelchair is also much needed for patients who are disabled or have severely hampered motor skills.

Another important asset to hospitals and healthcare centers is the Stretcher, this allows patients to be moved around freely in the hospital to operation theatres, other rooms, etc. Being able to integrate a wheelchair and a stretcher into a single machine will allow patients to sit and sleep at will without the need for aid in the same wheelchair is an idea suited for the pandemic [1] and also other patients. A problem that is faced by many motor-impaired patients that prefer outdoor activities is the constraints of a regular wheelchair that cannot drive over even small rocks. This is solved in the Rocker boogie wheelchair design where the wheelchair can climb rocks and also stairs. This will encourage patients to go out more often and not worry about encountering stairs or small rocks.

2. Literature Survey

The progress in the field of motorized wheelchair technology is at its peak. A lot of work has been done by the pioneers in the field of wheelchair technology and design. Wheelchair technology has evolved from manual wheelchairs to electric wheelchairs and then finally to robotic wheelchairs. The most effective control signal can be taken from the eyes, voice, tongue, hands, and brain. Some of such methods are discussed here.

Motion control of joystick interfaced electric wheelchair for improvement of safety and riding comfort. Apart from a joystick being used in video games and simulations, one can use it to control real-life objects as well such as a wheelchair. At times the movement from the joystick may not be as accurate due to the sensitivity of the sensors used, in [5] a DSP (Digital Signal Processor) is used to provide a smooth flow of power to the wheels with the integration of hall effect sensors when compared to regular encoders. Direct conversion of voltage signals to the references leads to the very sensitive motion of the wheelchair, and thus some signal processing is required to realize safe and comfortable operation. Locomotion on a wheelchair has its problems, one might make a small error and might collide with objects or humans, this will do more harm than good. The major accidents of a wheelchair were falling, stumbling, and hitting legs and hands to obstacles. In [6] A wheelchair is designed that can detect obstacles from 2 m to prevent collisions and wheelchair accidents. Wheelchairs have blind spots and sensors are used in these spots. In [9] Holonomic wheelchairs are known for easy maneuverability and being able to move in tight spaces. The proposed use is as an indoor mobility vehicle. Omni wheels provide a better turning radius compared to mecanum wheels but the mecanum wheels have a higher load-carrying capacity. Regardless of the surface type, all four wheels should receive equal ground reaction force (GRF), or else there are chances of wheel slippage. To provide the obstacle avoidance system Ananda S.K *et.al* have used Ultrasonic sensors and a voice synthesizer. We studied this paper extensively on how to integrate Omni-wheels with a wheelchair among others. Apart from having vast capabilities, a wheelchair must be light and functional. In [7] Modeling of a lightweight stretcher cum wheelchair-using CAD and making a prototype the main material used was steel and caster wheels were installed for the movement of the wheelchair cum stretcher. The above paper was one of our main references for the stretcher capability study.

[10]A Rocker bogie that can help wheelchairs climb obstacles is developed. The obstacles need not only be stairs, given that they are of reasonable height. This wheelchair's rocker-bogie mechanism is voluntarily moved using motors. Commercial finite element code and ANSYS is used to analyze wheelchairs. Static structural analysis is performed and certain parameters are analyzed like: Hydrostatic pressure, Total deformation, Normal stress, all found to be within acceptable limits and design is feasible. Design requirements and modeling: Longarm, Short arm, Main arm, Wheels (6). Meshing: Structured meshing is done using ANSYS. Boundary conditions: The joints are hinged, making it possible to form angles greater than 45 degrees. The system is designed to take a payload of up to 120kg. The more the area of the wheelchair using a rocker-bogie mechanism, the more the angle of operation that the system can form. Materials and other specifications: Stainless steel; density 7700 kg/m^3; tensile strength 2.5E + 08 N/m^2; Compressive yield strength 4.6E + 08 N/m^2.

3.Methodology

This research attempts to actualize a cost-effective and reliable design in which the wheelchair locomotion is via 3 Omni-wheels and the locomotion is controlled via mobile phone using Bluetooth. There is also an obstacle detection feature that allows the wheelchair to detect obstacles in the front, side, and back to prevent collisions and for the safety of the patients. The wheelchair also has a feature that allows the patient to fully recline and convert the wheelchair into a stretcher, thereby eliminating the need to move to and from a bed and wheelchair. Instead of fabricating a full-scale wheelchair, we decided to go with a scaled-down prototype with the exact same features that show how the real wheelchair and all the features will function. Our methodology is to first conduct a literature survey and find out what is it that the market of wheelchairs and health aid requires and how it is that the existing motorized wheelchair can be improved in a meaningful way. We first considered 2 designs, the stretcher-wheelchair with a rocker-bogie mechanism that would allow the wheelchair to climb stairs and one stretcher-wheelchair that would be propelled by 3 Omni-wheels that would allow the wheelchair to move in close quarters and tight spaces very easily. We decided to use only 3 Omni-wheels instead of 4 to reduce cost. Then, after designing both designs, conduction stress analysis, and motion analysis on both designs we decided on one model and that was the Omni-wheel stretcher design as it was proving to be more durable and sturdy, specifically for stair climbing. After finalizing a design, we conducted further stress analysis using weights 50kg through 120kgs and the design showed very minimal deformation. After which we decided on the features to add, which were remote control in a mobile phone via Bluetooth and obstacle detection. After that, the design was fabricated, assembled, and tested.

Block Diagram

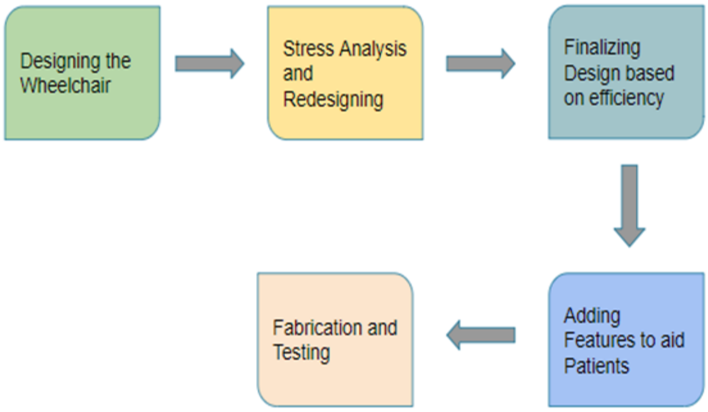

Fig. 1. Methodology and Flow Chart of wheelchair design and analysis

3.1 Designing

3.1.1 Design 1: Omni-Wheel Design

The Omni-Wheel design incorporates the ability to convert the wheelchair into a stretcher. The backrest and leg rest are connected to the seat via hinges that help it convert. There is a pneumatic actuator that pushes the leg rest upwards, the links connecting the leg rest and backrest help move even the backrest to a lower reclining position in tandem with the leg rest as shown in Fig. 2. (a). This movement helps convert the wheelchair into a stretcher. We also plan to add a hydraulic shock absorber of sorts to help make the jerky motion much smoother. The Omni wheels are 19.2cm in diameter.

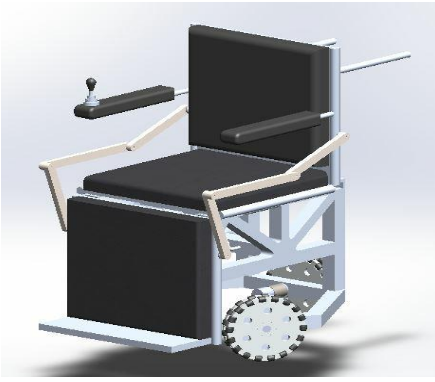

Fig. 2. (a) Chair mode orthogonal view

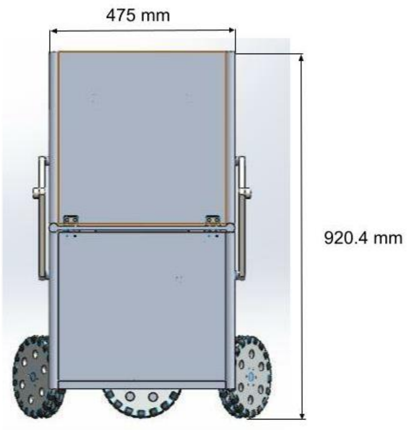

Fig. 2. (b) Front view

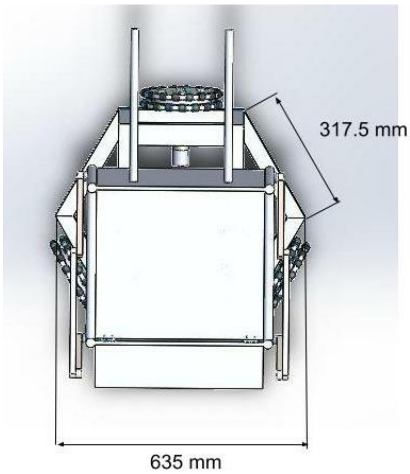

Fig. 2. (c) Top view

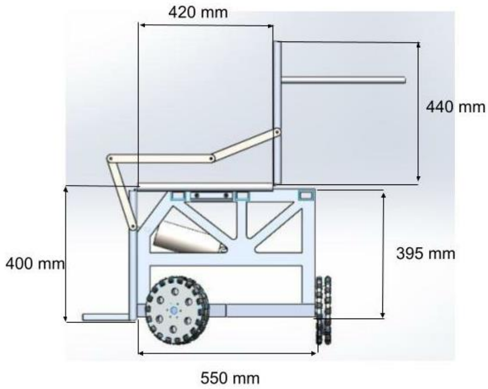

Fig. 2. (d) Side view

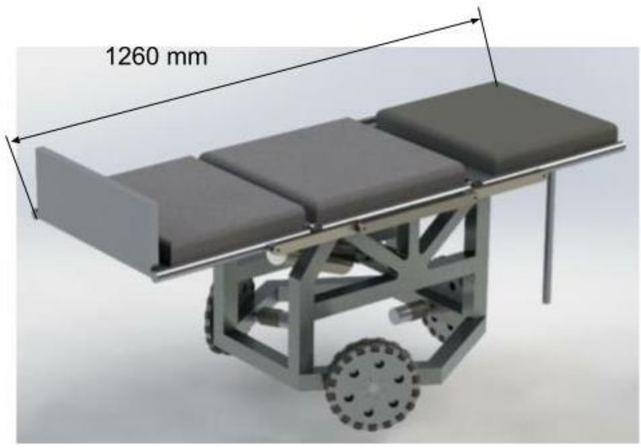

Fig. 2. (e) Stretcher mode orthogonal view

3.1.2 Design 2 Rocker-Bogie design

The rocker-bogie wheelchair was designed with the intention to make it easy to climb stairs. We have integrated a stretcher mechanism as well into the rocker-bogie design. The 4 small wheels in the front of the wheelchair are designed to pivot at a point to allow the wheels to go above stairs or objects. A unique approach has been taken by referring papers [10] and [18], this allows us to provide a lift for the patient as the conversion is taking place so that it's easier to access for healthcare workers. The lifting actuation is provided by 2 actuating cylinders as shown in Fig. 3. (a), (b) & (c).

However, we went with the Omni-wheel design as it was more efficient to fabricate and was proving to be more successful in motion analysis.

Fig.3 (a)

Fig.3.(b)

Fig.3 (c)

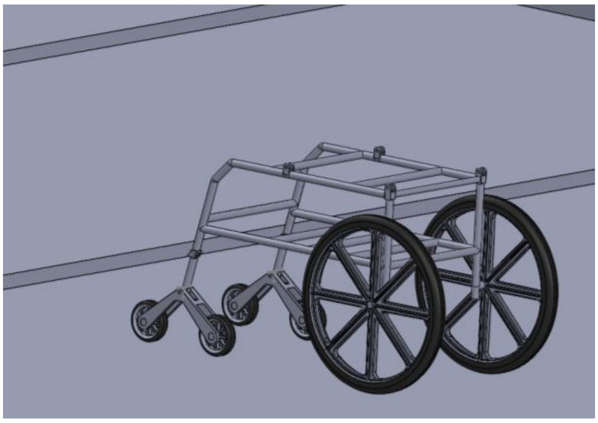

Fig.4.(a)

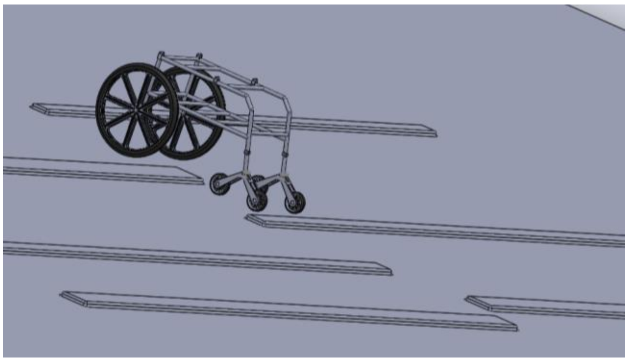

Fig. 4. (a) & (b) the motion analysis of the rocker-bogie design

3.2 Analysis and results

We conducted stress analysis and motion analysis for both the designs in Solid Works. In the stress analysis, we conducted stress analysis right from 50 kgs through 120 kgs, considering those weights to be the average range of weights of patients in India.

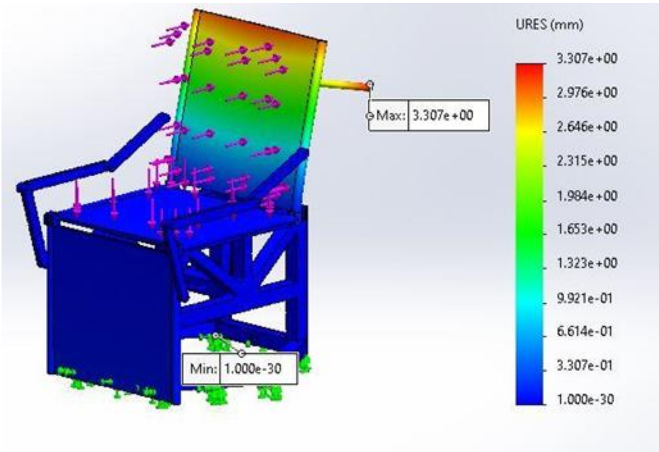

Fig. 5. Stress Analysis in Chair mode 120 kgs

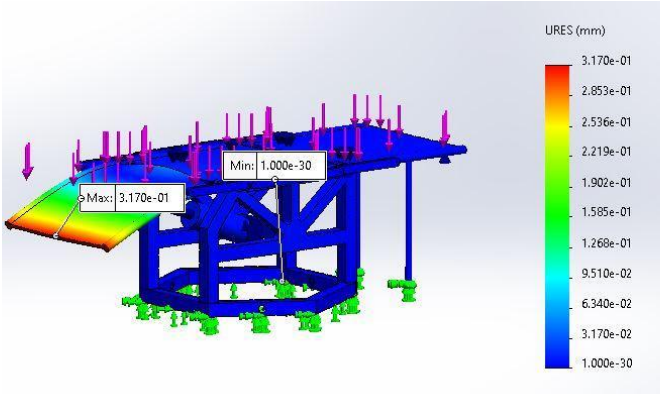

Fig. 6. Stress Analysis in Stretcher mode 120 kgs

Similarly conducted the stress and deformation analysis for both the designs (Omni-wheel and Rocker-Bogie) in both stretcher and chair modes from 50-120kgs. The following graphs as depicted in Fig.7 a & b, were plotted with regards to deformation at receptive weights. The material used for the chassis during stress, deformation, and motion analysis is Aluminum alloy Al6061. The following results are for the Omni-wheel design. The maximum deflection was found to be in the chair mode, 3.31mm. and stretcher mode was 0.317mm

Stretcher Mode	
Load(N)	Max(mm)
500	1.32E-01
600	1.59E-01
700	1.85E-01
800	2.11E-01
900	2.38E-01
1000	2.64E-01
1100	2.91E-01
1200	3.17E-01

(a)

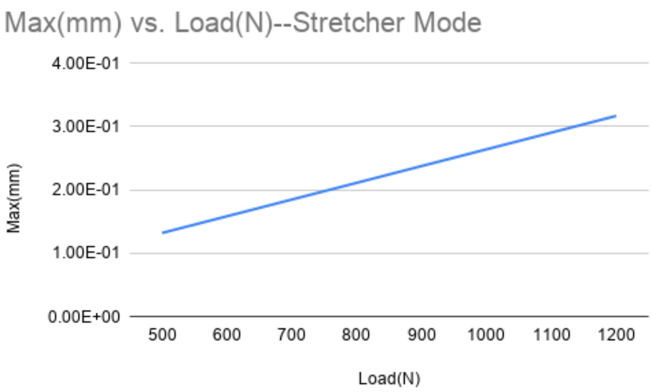

Fig. 7. (a) & (b) Results and graph plotted (Stretcher mode)

Chair Mode	
Load(N)	Max(mm)
500	1.32E+00
600	1.65E+00
700	1.90E+00
800	2.15E+00
900	2.48E+00
1000	2.73E+00
1100	2.98E+00
1200	3.31E+00

(a)

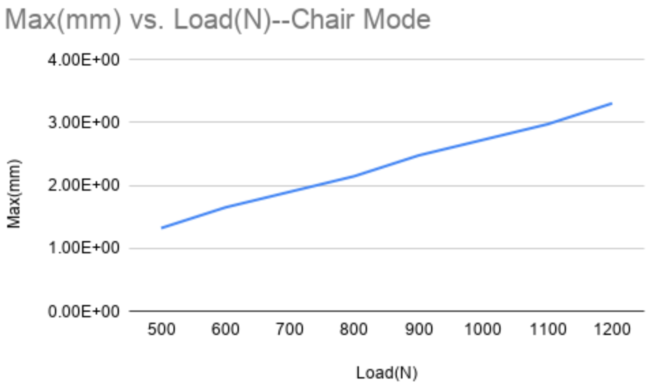

Fig. 8. (a) & (b) Results and graph plotted (Chair mode)

3.2 Parts Used

3.2.1 Arduino UNO Board - The motor controllers, Bluetooth module, and sensors are connected to the Uno via a breadboard.

Fig. 9. Arduino Uno board

3.2.2 L298N Motor Controllers - We used 2 L298N 2 channel motor controllers to power 3 DC motors.

The motor controllers have Enable pins, this allows us to program the controller to change the RPM of the motors.

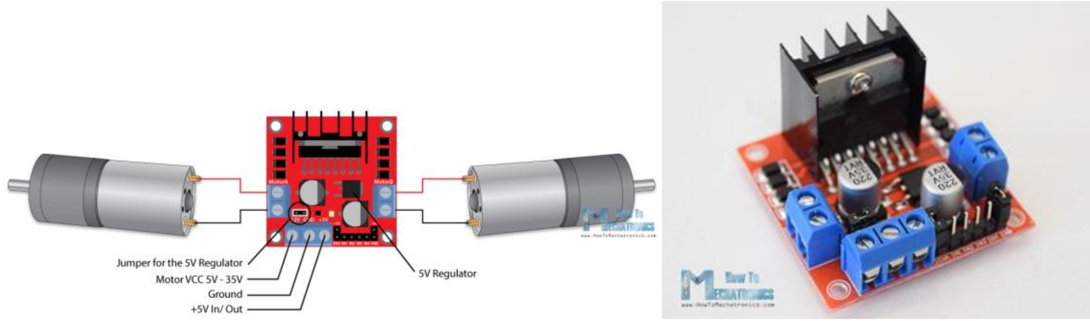

Fig. 10. (a) The motor controller controls 2 motors

Fig. 10. (b) L298N 2-channel motor controller

3.2.3 BO DC Motors (6V) - We used 3 Battery Operated DC Motors(BO DC Motors) to propel our 3 Omni-wheels.

Fig. 11. BO DC Motors

3.2.4 Omni Wheels (48mm) - These were the smallest Omni wheels we could find in the market and we scaled down our entire prototype design based on this Omni-wheels size.

Fig. 12. (a) 48mm dia Omni wheels

Fig. 12. (b) our Omni wheel is powered by BO DC Motor

3.2.5 Breadboard - A breadboard was used for better, convenience and more connections.

3.2.6 Bluetooth Module- an HC05 Bluetooth module was used which has a range of 10m.

Fig. 13. Bluetooth Module

3.2.7 IR Sensors - We used 3 IR sensors, 2 in the front and one on the back to detect objects and either change direction of movement or stop the wheelchair. These sensors can be calibrated to detect our desired distance and react according to the code.

Fig. 14. IR Sensor

3.2.8 Lithium-Ion Battery Pack (12V) We fabricated our own battery pack using the individual batteries and a BMS (Battery Management System).

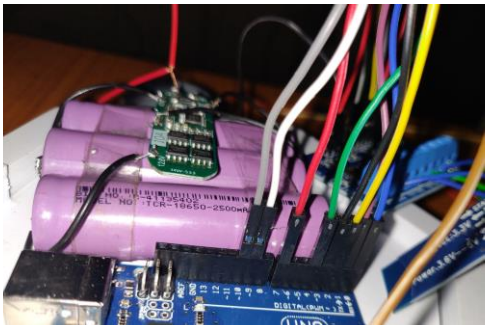

Fig. 15. 12V Battery pack

3.2.9 Bearings for links (9mm)

3.2.10 Wires and Jumper cables

3.2.11 FDM 3D printed chassis parts - All parts have 30% infill which has proven to have sufficient strength.

Fig. 16.(a) FDM 3D printed parts

3.3 Fabrication and Assembly

We decided to 3D print our chassis, frame, base plate, seat, back and front rest, links, and also the hinges.

First, we had to identify the Omni wheels in the market suitable for a small prototype. We procured wheels that were 1/4th the size of designed Omni-wheels, hence we scaled down the entire prototype to 1/4th scale.

The links, when scaled down proved to be too weak even at 100% infill, hence the design for links was changed for a more sturdy 3D print and also to accommodate the bearings available in the market for procurement. We used an Arduino Uno and connected 2 L298N 2 channel motor controllers to control our 3 BO DC motors. We also connected a Bluetooth module to the Uno. The motor controllers are powered using a 12V Battery Pack with BMS. We have made 2 codes for 2 modes; one is for remote control mode in the mobile phone via Bluetooth and the other mode is obstacle detection mode.

Fig. 17. (a) Prototype chair mode **Fig. 17. (b)** Prototype stretcher mode

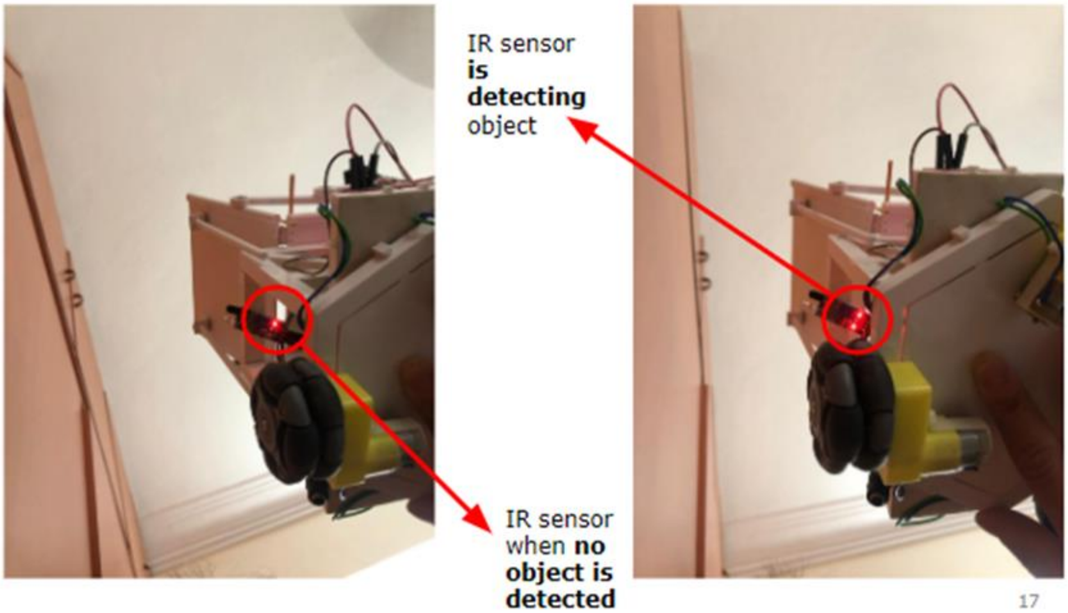

Fig. 18. IR Sensors

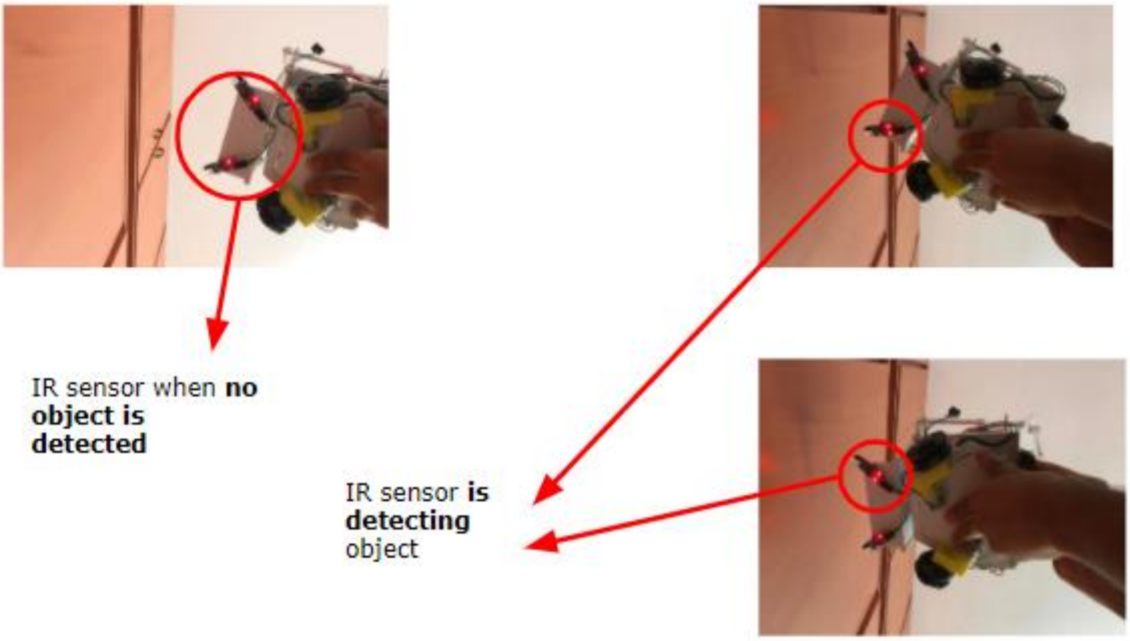

Fig. 19. IRSensors

3.4 Cost Estimation

Part	Size/Spec	Rate	Quantity	Total	Remarks
ELECTRICAL					
Battery	2 Lead Acid Batteries	5000	2	10000	24 V, 14.4 Ah
Motors	24V, 77W	4000	3	12000	Buhler 24V
IR Sensors	SHARP Distance Measuring	1650	3	4950	100 to 550 cm -GP2Y0A710K0F
Motor Drivers	40V 20 A	2832	3	8496	Rhino Motion Controls
Micro Controller	STM32F103	800	1	800	
Bluetooth Module	HC-05	850	1	850	
Switches		50	3	150	
Sensor Modules	ACS712-20A	169	3	507	
Master Controller	Intel NUC	25000	1	25000	
Air compressor	12V DC, 300 psi	450	1	450	
BMS	24V PCB BMS	350	1	350	
			TOTAL	63553	
MECHANICAL					
Al 6061 Sheets				3000	
Omni Wheels	8 inches (20.32 cm)	7339	3	22017	EasyMech 203mm Double Aluminium Omni Wheel (BUSH TYPE ROLLER)
Pneumatic cylinders	bore 32mm, stroke 300mm,p range 1-10bar	2400		2400	Janatics A12- 032 -0300 -O Air Cylinder (Bore Size 32mm Stroke 300mm)
Al Box channels	40mmX20mm (8mm thicc) 60cm each	320	8	2560	
Al pipes	20mm X 470mm(L)	200	2	400	
Hinges	35mm X 20mm X 5mm	100	6	600	
Bearings	36mm(OD) X 12mm(ID)	500	8	4000	
Links			6	500	
seating/cushioning			3	1000	
Hydraulic Shock absorber	8 inch (20.32 cm) stroke length		1	2000	60si2MnA spring steel
pneumatic pipe	3m		1	2000	Polyurethane
			Total	40477	
			GRAND TOTAL	104030	

4. Results & Discussion

The prototype of the stretcher-Wheelchair works satisfactorily. The stress and deformation analysis show very minimal deformation in the design in both modes; stretcher and chair mode. Further speed and CG analysis are to be done in Matlab Simulink. Cost estimation for full-scale usable wheelchair ready for civilian testing is yet to be done.

The wheelchair is also tested in the said obstacle course as shown in Fig.17.

Fig. 17. Obstacle Avoidance analysis on Wheelchair

Further design changes can be made to the wheelchair which was once realized after making the prototype, an actuator/ extension mechanism can be provided for the chassis so the height of the stretcher can be adjusted. An IV mount can be installed onto the wheelchair. A more efficient method to convert the wheelchair to a stretcher can also be implemented. More accurate obstacle detection sensors like **LiDAR** sensors can be used for obstacle detection over IR sensors.

5. Conclusion

This project is a step forward in the improvement of design and efficiency of a motorized wheelchair that is also cost-effective, convenient to use via mobile phone, and also has the much-needed feature of converting into a stretcher to eliminate the need to move to and from a bed and wheelchair for patients with severely hampered motor skills. The design is different from most products in the market in that it has Omni wheels that move tight spaces like homes and hospitals much easier. The design also features obstacle detection which gives the wheelchair the much-needed safety aspect which will prove necessary since it is a motorized wheelchair. The wheelchair with the required sensors and electronics will cost approximately 1 lakh which is significantly cheaper compared to wheelchairs with robotic capabilities like obstacle detection and stretcher conversion.

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