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Implementation of Curved- Spoke Wheel in Stair Climbing Wheelchair

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Abstract

The ability to move both on the ground and on the stairs is still a big problem for the people with different kinds of disabilities. This study developed a hybrid stair-climbing wheelchair with a front curved spoke tri-wheel and a rear standard tri-wheel for stair navigation, supported by middle motorized wheels for regular surface movement. To open the middle wheel assembly when it is necessary to go to the stairs and to make sure that the tri-wheel operation is not interrupted, a rack-and-pinion mechanism is used. The front curved spoke tri-wheel is only used when going up or down the stairs, while the rear tri-wheel is there for the support and stability of the steps. Only the motorized wheels are used for regular mobility on flat terrains. The proposed system, which is mechanically assisted and controller-supported, is capable of providing the physically challenged with easy, safe and low-cost mobility in various environments and thus increasing their freedom of movement and independence.

Keywords
Curved Spoke Tri-wheel, Stair-Climbing Wheelchair, Standard Tri-wheel, Rack-and-Pinion Mechanism, Motorized Control

1. Introduction
Mobility devices for the physically challenged, particularly in the case of stairs, seem to hit a wall with the most common types of wheelchairs being limited only to flat surfaces. Most of the available research works have, therefore, focused on exploring various means of stair-climbing, such as those employing caterpillar-based, tracked, or planetary wheel systems. As an illustration, the research by Adwaith Sahadevan et al. (2024) aimed at the creation of an electro-mechanical stair-climbing wheelchair powered by a conveyor-belt movement was cited, among the other reasons, as a way to improve the stability and versatility of the device for both outdoor and indoor use. Also, the analysed Sommart Thongkom et al. (2025) works takes up the point of (the) user's support through (a) well-done mechanical structure(s) and control logic during their (the user's) stair-climbing and descending (process).

Zhu, et al. (2023) duplicated a case scenario to assess a stair-climbing wheelchair's performance in a range of environmental conditions and the study resulted in showing the device's real-world application practicality. In addition, concepts of planetary and star-wheel mechanisms have been considered by the IJERT scientific group (2021) to highlight features such as small dimensions, uninterrupted motion during stairs climbing, and safety improvement.

However, despite the breakthroughs, very few of them have been commercialized due to the mentioned reasons in all the discourses—expensive-priced, complex, and heavy, gamma factors. The currently available research proposes a very affordable hybrid stair-climbing wheelchair design outlined by the combination of a front curved-spoke tri-wheel, rear tri-wheel, and rack-and-pinion lifting for the middle motorized wheels along with microcontroller-based control, ensuring an easy user interface, thus effectively dealing with the stated challenges. The user's freedom to roam and be able to rely on the wheelchair themselves regardless of the varying types of terrain constitute the vision of the project.

This iteration integrates the current body of literature and the exactness of the paper references into the opening, thus enhancing the academic depth and making explicit the transition from the prior works to the novel approach of your solution.

1.1 Objectives

The main point of the study is to come up with an innovative, user-friendly hybrid wheelchair that stairs can be climbed by the device in a very stable way. The inventor system combined the standard couch ground wheelchair with a robotic apparatus for climbing stairs making it a mechanically assisted, controller-supported design.
The first ones objectives of the study:
To design a hybrid mechanism using a front curved spoke tri-wheel, a rear standard tri-wheel, and motorized middle wheels for seamless transition between ground and stairs.
To construct a rack and pinion system that lifts only the middle wheel unit thus enabling continuous tri-wheel operation.
To pick out the best motors, drives, control circuit based on Arduino Mega with Bluetooth as future option so that the movement could be controlled accurately.
To evaluate the main mechanical aspects with the help of simulation and actual measurement. Among these aspects are the following:

- Torque vs. wheel angle
- Tilt angle calculation
- Power vs. speed (surface vs. stair)

The project is intended to achieve a lightweight, modular, and low-cost design that is easy to build and can later be upgraded for stair descent and mobile app control functionality.

This research's unique feature is the combination of a front curved spoke tri-wheel with a rack and pinion lifting system for creating an automated, simple, low-cost microcontroller-controlled solution for stair ascent.

2. Literature Review

The development of cutting-edge wheelchair systems revolves around three main areas: intelligent control, mechanisms for climbing stairs, and transformation with multiple functions. These areas, in combination, provide physically disabled people with the freedom, safety, and adaptability of movement.

Intelligent and Semi-Autonomous Control Systems
The majority of the early work revolved around designing control systems for those with severely limited motor abilities. A semi-autonomous hierarchical control framework facilitating multimodal inputs (head yaw, switch signals) and safety mapping by laser and Kinect sensors was suggested by Mohd Razali Md Tomaria et al. The concepts of shared and fully autonomous navigation which are aimed at lessening user effort and enhancing safety were introduced by studies such as NavChair (Levine et al.) and VFH+ (Ulrich & Borenstein).

The joystick can no longer be the only means of access if one's speech is to be recognized and multimodal inputs used (Matsumoto et al., Reis et al., Batolein et al.) as well as gesture control via accelerometers (Vijayvargiya et al., Kalantri & Chitre). The advances in this technology have led to the mobile app interface in this project, which is enabled by Bluetooth and, therefore, is user-friendly and has wide compatibility.

Stair-Climbing Mechanisms

Apart from wheelchair design issues, the handling of architectural barriers is the key to gaining the freedom of movement again. Crawler-type solutions (Top Chair, RT-Mover) are capable of providing powerful stair-climbing functions but suffer from being heavy, complicated mechanically, and require a lot of energy. On the other hand, wheeled designs, in particular, the Tri-Wheel/Spoke mechanism, manage to be simple, adaptable, and inexpensive at the same time. Research conducted by Bhajankar et al. and Palkar et al. showed that tri-wheel designs stair climbing efficiency achieved is even with less actuator torque. Further improvements by JeongPil Shin et al. (tail mechanism, compliant structures, and dampers) not only stabilized the device but also reduced torque requirements.

The present work has resulted in the curved spoke tri-wheel design which enhances not only the gripping capability but also the continuity of contact during the process of stair climbing and at the same time maintains the mechanical simplicity of the device.

Multi-Functional and Transformable Wheelchairs

The latest devices such as the Automatic Stair Climbing Wheelchair with Bed (P.S. Waseem Rahees et al.) and the Multipurpose Wheelchair (Abdul Ghania & Tokhi) demonstrate the possibilities of combining different mobility and comfort features through the use of the rack-and-pinion and worm gear mechanisms. The development of Interchangeable Phase Modular Fuzzy Logic and Spiral Dynamic Optimization (Ghani et al.) is one such method where intelligent control can lead to smoother and less energy-consuming motion, but this requires advanced and expensive hardware.

Research Gap and Conceptual Direction

Even after having made substantial progress in control and stability, the majority of the existing solutions are still characterized by mechanical complexity or high price, limited payload due to bulky actuators, dependency on high-end sensors and processors, and cannot perform low-cost, effective upward stair climbing.

The present work envisages a hybrid stair-climbing wheelchair equipped with a front curved spoke tri-wheel for ascending the stairs, rear tri-wheel for balance, and motorized middle wheels for surface driving. By separating the surface drive, the rack-and-pinion lift system facilitates the mechanical changes during the climb. This solution offers a lightweight, energy-efficient, and affordable alternative, thus it is not only suitable for real-life usage but also ready for the next step of bidirectional stair-climbing development.

3. Methodology

The design and conceptual development of the proposed hybrid stair-climbing wheelchair involve three major subsystems: mechanical configuration, actuation and control, and operational logic.

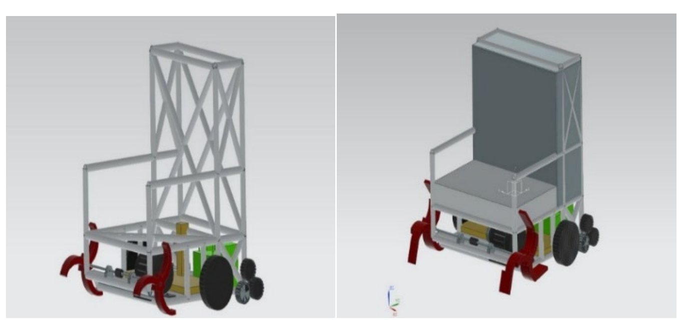

Figure1: Design of the wheel chair

3.1 Mechanical Configuration

The wheelchair structure integrates three sets of wheel assemblies: a front curved spoke tri-wheel, middle motorized differential surface wheels, and a rear standard tri-wheel. The front curved spoke tri-wheel is responsible for stair climbing and engagement on inclined surfaces, while the rear standard tri-wheel acts as a passive support assembly, providing balance and stability during ascent. The middle wheels, mounted on both sides, serve as the main propulsion system for flat surface mobility and turning. To ensure seamless transition between ground and stair navigation, a rack-and-pinion mechanism is incorporated. This mechanism lifts the middle motorized wheel assembly when stair-climbing mode is initiated, thereby preventing interference between surface and stair operation.

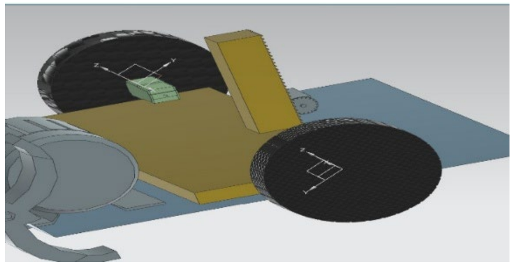

Figure 2: Rack and pinon engagement

The rack-and-pinion setup is mechanically synchronized to maintain equal lifting on both sides, ensuring stability and load balance.

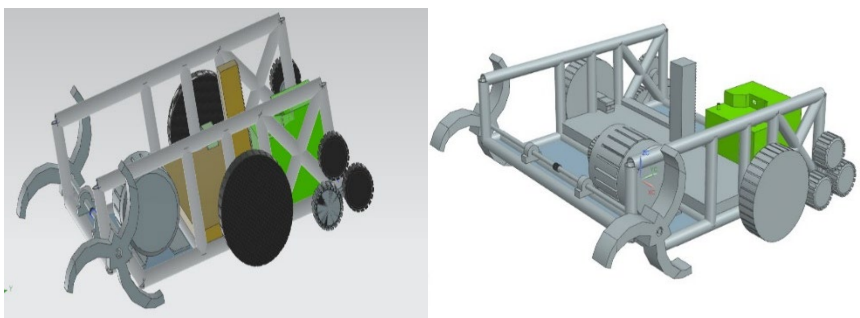

Figure 3: Front- Curved spoke Tri-wheel, Middle differential wheel, Tri wheel

3.2 Actuation and Control

The entire system is driven by DC motors selected based on torque and power calculations obtained from simulation data. A microcontroller-based control unit (Arduino Mega) coordinates the drive signals and operational logic. A motor driver circuit controls direction and speed, while Bluetooth connectivity (via an external Bluetooth module) is proposed for wireless user control through a mobile application interface. The mobile app design is conceptualized but not yet implemented at this stage.

3.3 Operational Logic

During surface operation, the middle differential drive wheels are active. The wheelchair moves forward when both wheels rotate in the same direction. Turning is achieved through a differential drive strategy, where one wheel rotates forward while the other rotates backward. This allows the wheelchair to finalize and adjust its direction precisely without additional steering mechanisms. Both the front curved spoke tri-wheel and rear tri-wheel remain idle during this mode.

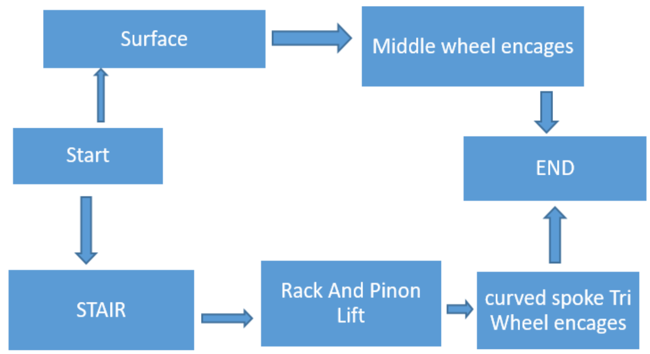

Figure 4: Block diagram of the wheel operation

3.4 Graphical Analysis

The concept evaluation includes graphical plots representing the relationship between major performance parameters:

- Torque vs Wheel Angle – to analyse load and motor torque variation during step engagement.
- Power vs Speed (Surface vs Stair Mode)
- Tilt angle calculation

These analyses help validate the theoretical feasibility and mechanical balance of the proposed hybrid stair-climbing wheelchair concept.

4. Data Collection

The data collection for the research cantered around three main areas:
(1) Measuring the mechanical performance,
(2) Selecting the controller and drive components, and
(3) Estimating the stair-climbing dynamics through the use of the analysis.
As the full prototype fabrication is still at the workbench stage, the experimental dataset is thus supplemented by simulation-based calculations and component specification benchmarking.

4.1 Mechanical Design Parameters

The main construction and movement features of the hybrid wheelchair have been determined by the anthropometric standards and the material constraints:

Table1: Parameters basis value

Parameter	Value	Basis
Total weight(wheelchair + user)	150 KG	WHO mobility standards
Front spoke Tri-Wheel radius	250 mm outer diameter	Contact continuity requirement
Rear Tri wheel Radius	175 mm diameter	Stability enhancement
Middle Wheel Diameter	200 mm diameter	Surface mobility optimization
Gear material	Mild steel	Good strength-to- cost ratio

4.2 Motor and Drive Selection Data

Motor performance values were obtained from the manufacturer's datasheets and were checked through torque calculations for climbing stairs.

Table 2: Motor drive selection

MOTOR	**DRIVER**	**SPECIFICATIONS**			**PURPOSE**
48V BLDC MOTOR	VESC 50A	4.3kg	450 RPM	102kg-cm	Stair Climbing
12 V PLANETRY GEAR MOTOR	ROBO CLAW	300 kg	60 RPM	400kg-cm	Middle Drive
12 V CENTERSHAFT DC MOTOR	DOUBLE DRIVE BTS 7960	250 kg	450 RPM	2kg-cm	Pinon

Note: The development of a mobile application is scheduled for the next phase; at present, the commands are given through the serial control.

4.3 Performance Observation:

Experimentation and initial lab testing helped to confirm the functional conditions:

- The middle wheels very well facilitated the balance and the steering on the level ground
- The rack-and-pinion lifted the surface wheels without any kind of structural distortion
- The tri-wheel contact was unbroken when the wheels were
- Controller is manually able to change drive modes effectively

5. Results and Discussion

5.1 Numerical Results

Table1displays motor torque and power requirements per wheel module as the outcome of analytical calculations and the loads simulated in the operational conditions.

Table3: Motor Torque and Power Requirements

SNO	**WHEEL TYPE**	**TORQUE (NM)**	**SPEED (RPM)**	**POWER (W)**
1	CURVED SPOOKE TRIWHEEL	102kg-cm	450RPM	500W
2	MIDDLE DIFFERENTIAL	40kg-cm	60RPM	100W

5.2 Graphical Results

Visual assessment of the data is also in line with the system's feasibility.

Tilt angle calculation table:

VL = left speed (will be constant)
VR = right speed
W = distance between wheels
ɵ = turning angle
Turning angle in radians after time t by = ((VR – VL)/T). T
To convert it to degrees = ɵrad. 180/π
Speed difference, ΔV = VR– VL
Angle in radians, ɵ = (Δv/w)* T

Table 4: Tilt angle calculations

Right wheel Speed (VR)(m/s)	Left wheel Speed (VR)(m/s)	Speed difference (VR- VL)(m/s)	Tilt Angle ɵ (rad)	Tilt angle ɵ (º)
0.500	0.500	0.0000	0.00000	0.00
0.667	0.500	0.167	0.2469	14.15
0.833	0.500	0.333	0.4938	28.29
1.000	0.500	0.500	0.7407	42.44
1.167	0.500	0.667	0.9877	56.59
1.333	0.500	0.833	1.23456	70.74
1.500	0.500	1.000	1.4815	84.88
1.667	0.500	1.167	1.7284	99.03
1.833	0.500	1.333	1.9753	113.18
2.000	0.500	1.500	2.222	127.32

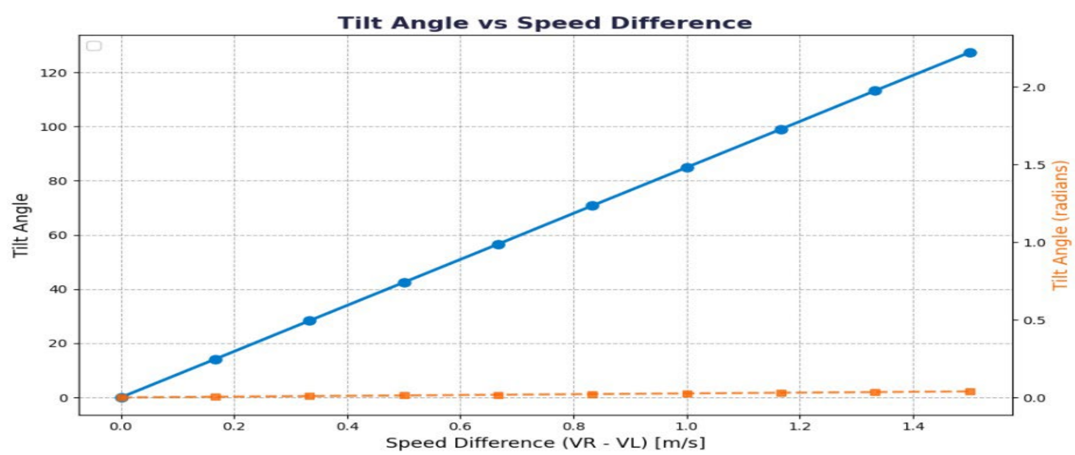

Figure 5: Graphical representation for tilt angle vs speed difference

Torque vs Wheel Angle:

- Total weight(user + wheelchair): M = 150 KG = 1476 N
- Gravity: G =9.81m/s^2
- Load shared by 2 Tri-wheels: W = MG/2 = 1471.5/2 = 735.75N
- Tri-Wheel Radius: R = 0.25 m
- Wheel angle: ɵ = 0 º to 360 º
- Formula: T = W.R.sin(ɵ)

Table 5: Torque vs Wheel angle

Angle ɵ(º)	Sin(ɵ)	T = 183.9375.Sin(ɵ) (N.m)
0	0.000	0.000
30	0.500	91.97
60	0.866	159.29
90	1.000	183.94
120	0.866	159.29
150	0.500	91.97
180	0.000	0.00
210	-0.500	-91.97
240	-0.866	-159.29
270	-1.000	-183.94
300	-0.866	-159.29
330	-0.500	-91.97
360	0.000	0.00

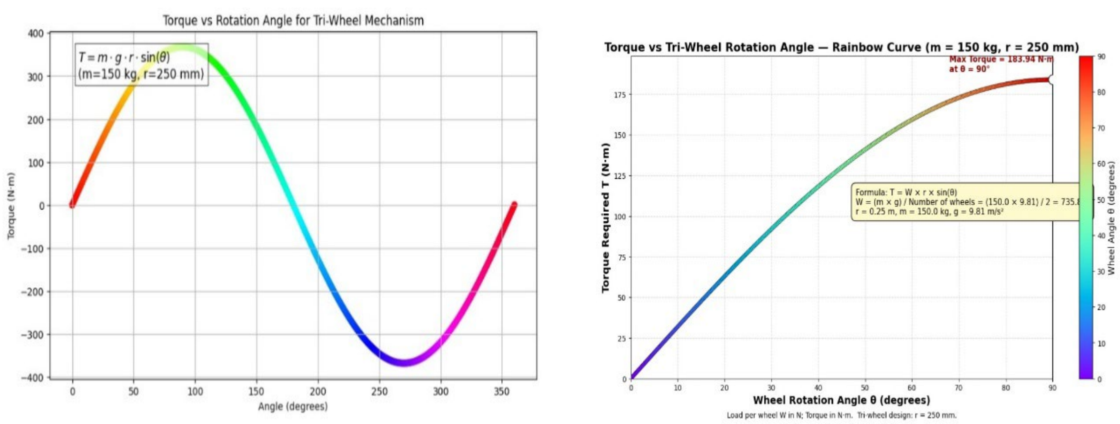

Figure 6: Graphical analysis for Torque vs Wheel Angle

Power vs Speed (Surface vs Stair Mode)
Weight: W = 150 * 9.81 = 1471.5 N
Rolling resistance: Cr = 0.02 (Rough terrain)
Stair angle: α = 30º
Speed: V = 0.1 to 1.0 m/s
Equations:
Surface: PS = Cr.W.V
Stair: PST = W.sin (α).V

Table 6: Surface power vs stair power

Speed (V)(m/s)	**Surface Power (P)**	**Stair Power(P)(W)**
0.0	0.0	0.0
0.1	2.94	73.58
0.2	5.88	147.15
0.3	8.83	220.73
0.4	11.77	294.30
0.5	14.66	367.88
0.6	17.65	441.45
0.7	20.60	515.03
0.8	23.54	588.60
0.9	26.49	662.18
1.0	29.43	735.75

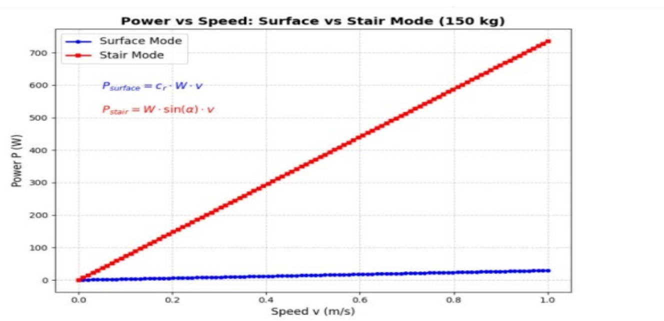

Figure 7: Change in power at stair meanwhile in constant in surface

Inference:
Graphical analysis validates:

- Smooth and safe stair climbing performance,
- Efficient differential steering on flat surfaces,

5.3 Proposed Improvements

The first improvements suggested to upgrade a future version of the prototype are the following ones:

Table 7: Future improvement

Category	Suggested Enhancement	Benefit
Control system	Bluetooth- based application for wireless control	Improved accessibility for user/caregivers
Safety	Passive braking or ant slip stair descent system	Reliable two-way stair operation
Structural design	Reinforced tri-wheel configuration	Higher payloads with minimal torque rise
Ride comfort	Spring- damper support for middle wheels	Reduced vibration and better ergonomics
Energy efficiency	Regenerative Braking integration	battery life while improvement

5.4 Validation

A comparison with traditional tri-wheel stair-climbers shows:

- Less mechanical complexity accompanied by better stair engagement,
- Improved flat surface mobility through differential drive.

6. Conclusion

This conceptual research of the hybrid stair-climbing wheelchair includes:

- Front curved spoke tri-wheel for going up the stairs
- Centre differential drive for moving on the surface and making accurate turning
- Back passive tri-wheel for support and stability
- Lifting the middle wheels during stair climbing by a rack-and-pinion mechanism

Key contributions:

- Demonstrates a low-cost, mechanically assisted design for integration of differential surface wheels and tri-wheel stair climbing.
- Conceptual validation is provided by torque, power, analyses.
- Prepares the ground for future app-based control and stair descent functionality.

All goals, e.g., safe stair ascent, independent surface mobility, and mechanical simplicity, have been acknowledged, thus making this a viable concept for further development and prototype testing.

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RISALTH S is a hard-working, persevering student who is always striving for academic excellence and going deeper into the mechanical sciences with the end goal of applying engineering principles to solve real-world problems.

BHUVANESHWARAN M has a strong grasp of mechanical engineering concepts and is also quite proficient in the areas of Design, FEA, and simulation using SolidWorks, Fusion 360, Hyper Mesh, and MATLAB. Most of his skills come through the hands-on activities of which he has been part of the student electric ATV team for SAE Baja and ATVC, including design, fabrication, and testing. He has a zeal for robotics, machine learning, and aerospace.

DEEPAN A is a college student, expected to graduate in 2027, who is always eager to learn and at the same time is focused on both academic achievement and industry engagement.

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VETRI SELVAN E is an energetic and dedicated professional with over seven years of combined academic and industry experience. He is able to connect academic concepts with practical applications by his previous work in the industry as a GET-Energy Engineer. He now teaches automobile engineering, engineering graphics, mechanics, CAD, and through research, he is very active in supporting student innovation and skill development.