Simple Step Climbing Robot for Humans

IC201P: Design Practicum

Final Report

Group-12

Submitted by

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Also, we would like to thank the Indian Institute of Technology, Mandi (IIT Mandi) administration for providing us with the opportunity to work on the problem statement **"Simple Step Climbing Robot for humans".** The completion of this project would not have been possible without the participation and assistance of a lot of individuals and team members contributing to this project who guided us all along in this project.

Contents

1. Introduction

1.1 Abstract

Amid the intricate tapestry of our urban landscapes, the universal presence of stairs and steps, forms an inseparable part of architectural design. However, for individuals with limited mobility or in certain challenging situations, ascending or descending steps can pose a dreadful barrier to ***accessibility and independence***.

The statement clearly outlines the context and significance of the problem, emphasizing the need for a ***user-friendly, cost-effective, and efficient*** robot that can facilitate accessibility for people facing ***mobility limitations*** or challenges in navigating elevated surfaces. In response to this compelling challenge, our Design Practicum embarks on a transformative endeavor to conceive and create a ***"Simple Step-Climbing Robot for Humans."***

This innovative project seeks to redefine the boundaries of assistive technology, offering a dynamic solution to an age-old problem, thereby promoting independence to the agonized.

1.2 Need for the Step Climbing robot

The need for a simple step-climbing robot is rooted in a fundamental commitment to inclusivity and ensuring that everyone can ***navigate*** their surroundings with dignity and ease. Conventional methods of overcoming steps, such as ramps or lifts, often come with ***spatial, financial, or logistical constraints***, limiting their widespread adoption. Moreover, the prevalence of steps in everyday environments, from homes to public spaces, calls for a versatile and ***user-friendly solution*** that transcends the traditional accessibility barriers.

By addressing this need, our project aims to bridge the gap between architectural challenges and personal mobility. This project is very useful for the ***paraplegics, specially-abled and elderly people*** who face difficulty accessing the stairs and often require human assistance, or crutches. A Simple Step-Climbing Robot for Humans has the potential to revolutionize the way individuals interact with their surroundings, providing a ***reliable, cost-effective, and adaptable solution.*** Beyond its utilitarian purpose, the project serves as a testament to the transformative impact of technology in fostering independence and breaking down barriers.

As we delve into the intricacies of designing this innovative robotic solution, we recognize the profound implications it holds for individuals who face daily hurdles in navigating steps. This project is not just a technical exploration; it is a testament to our commitment to shaping a more inclusive world where everyone, regardless of mobility constraints, can confidently navigate their surroundings.

2. Specifications concerning Step-climbing

- **Step Climbing capability:**
  The step climber can efficiently climb a wide range of step heights and treads that practically makes the angle of inclination of the stairs between 0-35 degrees.
  It can climb steep inclines and declines smoothly and steadily. This specification is essential for ensuring the robot's adaptability to different architectural configurations be it the indoor or outdoor staircase configurations.
- **Load Carrying capacity:**
  The robot being about 30-35kg in weight, is expected to carry a payload of about 50-60 kg maintaining a pace of about 0.5 m/s maintaining its stability throughout incline or decline. The robot is designed in such a way that the impact of centre of gravity of increasing payload is taken into consideration.
- **Unalike environment adaptability:**
  This includes the surface variety, the robot’s ability to navigate different types of surfaces. Its navigation is not limited tiled steps, but also carpeted floors and concrete staircases.
  The robot can seamlessly travel both in indoor and outdoor staircases in homes, offices, public spaces, or during emergency situations where the robot adaptability becomes a defining feature.
- **Duty cycle:**

Since the robot works on high power consuming electrical components, basically high torque motors and linear actuators, its duty cycle is expected to be 25-30 min on a full stretch. There is a scope of improvement of the prototype in this context.

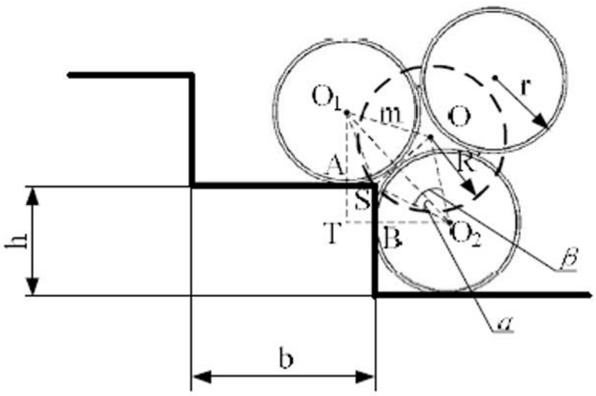
- **User-friendly:**
  The robot should come with simple and easily accessible manual controls. The robot should also be designed in such a way it is easily manoeuvrable.
- **Comfort :**
  The robot design should be ergonomic and easy to interact with and comfortable. The seats must be cushioned enough to avoid user fatigue. The robot's design should mitigate jerks occurring during inclination and declination.
- **Maintenance:**
  The robot's maintenance costs should be as much least as possible. The batteries should be rechargeable as well as replaceable.

3. Possible Solutions

Stair climbing has been carried out with robots using different types of locomotion. One can roughly distinguish them between wheeled, legged, and tracked robots.

3.1 Planetary Wheel Climber

The planetary wheel mechanism is constituted by several small wheels that are equally distributed on a tie bar with shapes like "Y" or "+". The small wheels can revolve on its axis, and it can also make a revolution around the central shaft. Every small wheel revolves on its own axis, when the wheelchair moves on the ground; and every small wheel revolves round the central axis, when the wheelchair goes up or down stairs. This type of stair- climbing wheelchair can fulfil overloading and move smoothly but has low automation.

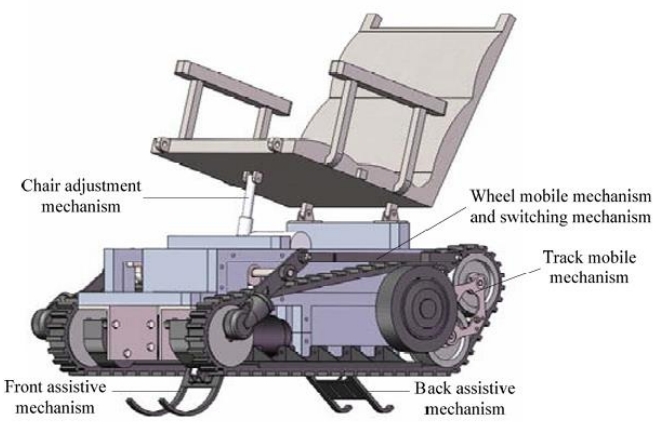


Planetary stair-climbing wheelchair
1. Light weight compared to tracked wheelchair, meanwhile effective protects the stairs;
2. Automation rate rises greatly compared to the leg stair- climbing wheelchair and stability increased.
3. Assist is reduced compare to the auxiliary stair-climbing wheelchair, compact structure and security improved.

3.2 Timing Belted Stair Climbing Robot

The whole process of stair climbing may be divided into six stages, including:
(a) touch the first step;
(b) climb up the first step;
(c) climb up the second step;
(d) leave the ground and ascend the stairs;
(e) touch the stairs and the top platform simultaneously;
(f) ascend the top platform.

Here, touching the step refers to the track around the approach angle climbing up the step while climbing up the step refers to the bottom track climbing up the step.



3.3 Quadruped Stair Climber

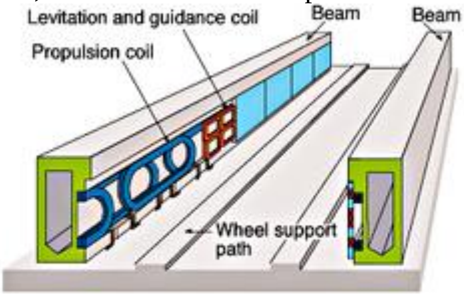
Quadruped walking robot can also walk on stairs. It is divided into two separated body segments- front and rear segment- to negotiate and maintain the height difference of front and rear landing points on the stairs.

3.4 Biped Stair Climber

The biped stair climber is a two-legged robot designed for graceful stair navigation and versatile terrain adaptation. With elegant movements reminiscent of a dancer, it effortlessly conquers stairs and uneven surfaces. Boasting smart balance, stability features, and user-friendly controls, this robot is a practical solution for urban environments, offering applications in delivery services, search and rescue missions, and beyond. The biped stair climber is not just a robot; it's a stylish and capable companion for ascending heights and exploring diverse landscapes.

3.5 Maglev Track Mechanism

Magnetic levitation, or maglev, is a mechanism that employs magnetic fields to suspend an object, overcoming the force of gravity. It relies on the principles of magnetic repulsion or attraction to achieve levitation without any physical contact with supporting surfaces. By using electromagnets or permanent magnets and carefully manipulating magnetic forces, maglev systems can suspend wheelchairs above a track, enabling frictionless movement. This technology is known for its smooth and efficient transportation applications, offering benefits like reduced wear, noise, and maintenance compared to traditional wheel-based systems.

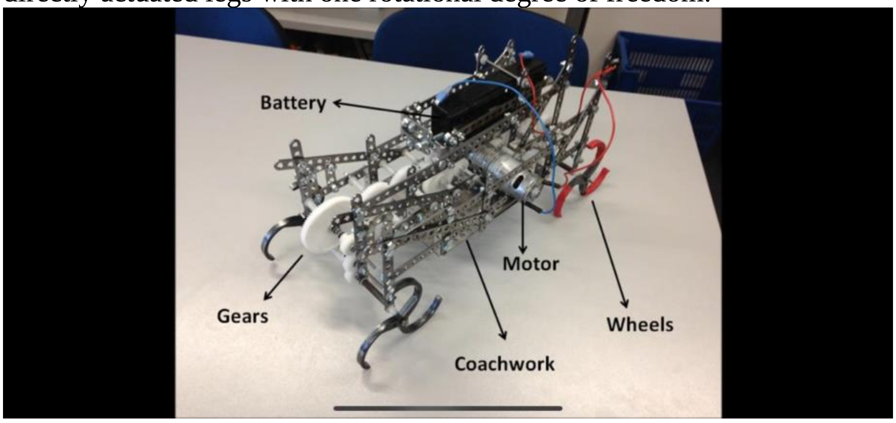


3.6 Six Wheeled Stair Climber

A six-wheeled stair climber is a specialized robotic device designed for efficient mobility on both flat surfaces and staircases. With three pairs of wheels strategically arranged, this unique configuration allows the robot to navigate stairs smoothly by adjusting the orientation of its wheels. The six-wheeled system provides stability and balance during stair ascent or descent, making it an ideal solution for tasks that involve moving loads or performing operations in multi-level environments. The combination of wheels and adaptive mechanisms enables the robot to seamlessly transition between different terrains, making it a versatile and practical tool for applications such as material handling, logistics, and facility maintenance.

3.7 Hybrid Leg wheeled

The key idea is to use one rotating actuator for driving one or more simple legs around one axis. Sometimes referred to as compliant legs sprockets wheel, this approach makes often use of a very simple and therefore very robust locomotion principle. The prototype is driven by four directly actuated legs with one rotational degree of freedom.

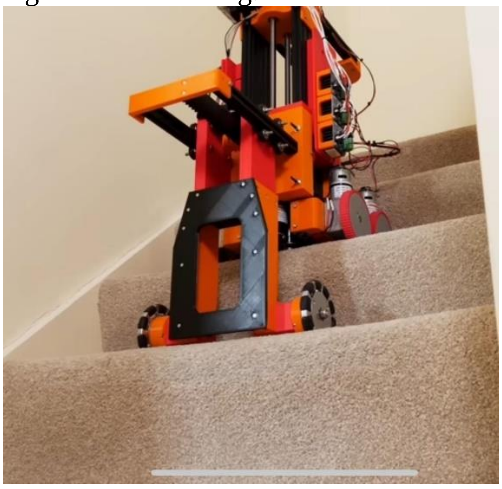


3.8 Gyroscopic Bi-wheeled

The wheels are made in such a way that their spokes are deformable. They are generally made of silicone rubber that allow their deformation at the point of contact with the stair. The centre of mass shifting is controlled by the linear actuators and tilt sensor. The stability of the robot is mainly controlled by the gyroscopic sensor.

3.9 Omni wheeled three legged splitter-slider

The robot can split itself into three vertical sliding sections to lift itself on each step. The middle section has omni wheels to hold it stable and move left or right. But, practically, this mechanism is very inefficient as it takes a long time for climbing.



3.10 Trolley based Stair Climber

It majorly consists of a trolley with specially fitted tri wheels. Its just similar to the Tri wheel mechanism but just the chasis design is changed a bit.

4. Statistical Evaluation of the possible solutions

Solution no.	Solution Description	Cost of the Idea ((30000/Amount)*10)	Availability of Parts	Ease of Manufacturing/ Assembly	Fulfilment of Purpose	Ergonomics / Aesthetics	Integration of Power Source	Integration of Electronics	Timebound Manufacturing Feasability	Maintainance/ Servicing Cost	Overall Feel/Confidence in the Solution	Overall Score	Extra Remarks
		Since the total cost is limited to 30k, you have to divide the cost of the idea by 30k and multiply by 10. So, if the cost of the idea is 30k, the idea will get 10 marks. If it is less than 30k, the idea will get more than 10.Else, if the cost overshoots 30k, the idea will get less than 10 marks.	If all the parts are available nearby Mandi, the idea gets 10 marks. If the parts will take some time for deliery (lets say they are coming from Delhi), the idea gets less than 10 marks.	If it is easy to manufacture the idea here at IIT Mandi, using the resources we have, the idea gets 10 marks. If the manufacturing is complex, the idea gets less than 10 marks; based on complexity.	If the idea is fulfilling all the purposes relevant to the problem, it gets 10 marks. If the idea is fulfilling partial purposes, it gets less than 10 marks. If the idea fulfils the purpose and also has extra features, it gets more than 10 marks.	For a customer, ff the solution is easy to use, it gets 10 marks. The same applies to aesthetics. The increase in complexity in use (by a customer) will lead to marks less than 10 for the idea	This is to determine how well the power source is integrated into the sensors or in the device. If it is very difficult to integrate the power source, the idea gets less than 10 marks based on difficulty. If it is easy to integrate the power source, the idea gets 10 marks.	This is to determine how well you can integrate the electronics into the device. If it is very difficult to integrate all the sensors and electronics, the idea gets less than 10 marks based on difficulty. If it is easy to integrate, the idea gets 10 marks.	Since you have to build the prototype within 3 months, the time-bound feasibility is really important. If an Idea can be manufactured within 3 months, it should get 10 marks. The marks will decrease with an increase in the manufacturing time.	Each prototype or solution requires maintenance or servicing after using a certain number of cycles. If the solution requires very less maintenance while serving for 10k cycles, it should get 10 marks. Otherwise, the marks should decrease with an increase in servicing requirements.	This is very subjective. Here you have to mark the idea on its overall feel i.e. how do you feel about the about. If you have a very good feeling about the idea it should get 10. The marks should decrease if you don't feel confident about the idea.	Total Out of 100	
1	**Planetary Wheel Climber:** Tristar shaped wheels that are apart by 120º,in which three wheels are arranged in an upright triangle with two on the ground and one above them. If either of the wheels in contact with the ground gets stuck, the whole system rotates over the obstruction	10	8	8	9	8	9	8	8	8	9	85	
2	**Conveyor belted Stair Climbing Robot :** similar to tanks, it will move with the help of conveyor belts,the belt tension mechanism is main part, moving on two endless chains called tracks.	10	8	9	9	10	10	9	8	9	10	**92**	*Turned out as the best feasible solution*
3	**Quadruped Stair climber :** A Four legged robot with each limbs having 2 DOF which can climb like dog on stairs while carrying a human load on its top.	9	7	7	7	8	7	6	8	7	8	74	
4	**Biped Stair Climber:** 2 legged bot with each having hydraulics, this bot will climb the each step, similar to humans.	7	7	7	8	7	8	8	7	7	8	74	
5	**Trolley based puller:** a cart pulling mechanism, with an external motor connected with a chain ,working like a lift on a slope	10	9	9	6	6	9	7	9	8	9	82	
6	**Maglev track mechanism:** similar to trolley based puller ,this would do more of work like maglev trains, that will be used to pull up through the stairs, being very fast , underneath, there's a magnetic layer that will levitate and move the cart, moving at some slope	3	5	5	9	8	7	7	4	6	7	**61**	*Least feasible to make in given amount of budget and time.*
7	**Six wheeled Stair climber:** each leg will have a separate motor and wheel, the frontier part of this in right plane is more like an inverse V with movable joint and each limb would be biwheeled(the back limbs with 1 wheel each)	9	7	7	7	8	8	8	8	8	8	78	
8	**Hybrid Leg-wheeled :** curved-spoke triwheel arranged in a triangular pattern;will be used so that when curved spokes rotates, the wheels to extend outwards.	8	8	7	7	8	9	8	8	8	9	80	
9	**Gyroscopic compressible biwheeled :** A 2 wheeled robot with compressible rubber spokes based tyres that will help climb the robot and the stability is controlled by gyroscopic sensor and centre of mass shifting done by actuators	9	7	8	9	9	9	9	8	8	9	85	
10	**Omni wheeled three legged splitter-slider:** robot which splits itself into three vertical sliding sections to lift itself up on each step. The middle section will have four wheels to hold it stable.	8	7	7	8	7	8	8	8	8	8	77	

5 The developed prototype

Based on the above design, the prototype and the system components of the developed ROBOT are shown in Figure 8 and Figure 9, respectively. The values of the main technical parameters for the prototype are summarized in Table 1.

Table 1. The main technical indexes of the ROBOT

Indexes	Parameters
Outline dimension	90cm×80cm×80cm
Weight	25 Kg
Maximum loading weight	75Kg
Maximum speed on the ground	1m/s
Maximum speed on the stairs	0.5m/s continuous
moving time on the ground	2h
Continuous moving time on the stairs	60min

Figure 8. The developed prototype

1.1 The control system and its operation

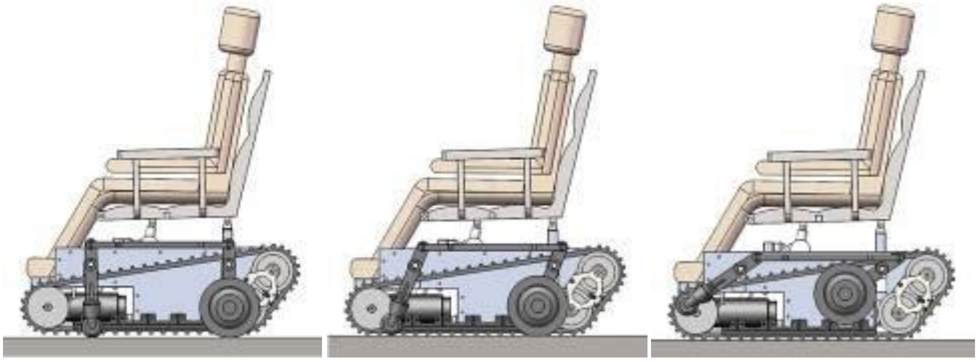
The ROBOT's controller uses an embedded microcontroller to manage hub and DC motors for movement and turning. It features four infrared sensors for obstacle and stair detection, two pressure sensors on assistive brackets for supportive force detection, and a tilt sensor to monitor the chair's angle. Control is via an onboard operation box and a remote controller, with the embedded system managing chair adjustment and assistive mechanisms.

Mobile modes and their application

The wheel-track hybrid ROBOT can choose mobile mode in different ground environments by a switching mechanism to fully take advantages of the wheel mode's high speed and efficiency and track mode's ability to climb the obstacle or stairs, thus achieving adaptive mobile in different environments. In this section, we analyze the different mobile modes of the ROBOT and their switching mechanism design.

1.2 The wheel mobile mode and its switching

The wheel mobile mode is mainly used for efficient motion on flat ground to expand the passenger's scope of activities quickly. We can press the switch button on the operation box or infrared remote controller to accomplish the switching from the wheel mobile mode to the track mobile mode, as shown in Figure 10(a)-(c). After finishing the obstacle crossing or the stairs climbing, we can perform the contrary operation to make the ROBOT switch from the track mobile mode to the wheel mobile mode.



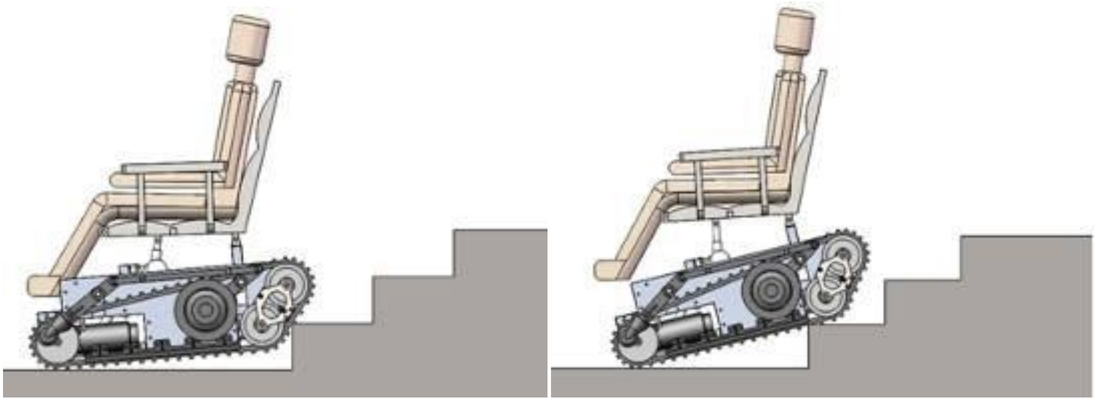
(a) β=90°, the wheel mobile mode(b) β=65°, the transition stage of mode switching (c) β=35°, the track mobile mode

Figure 10. The switching from wheel mobile mode to track mobile mode

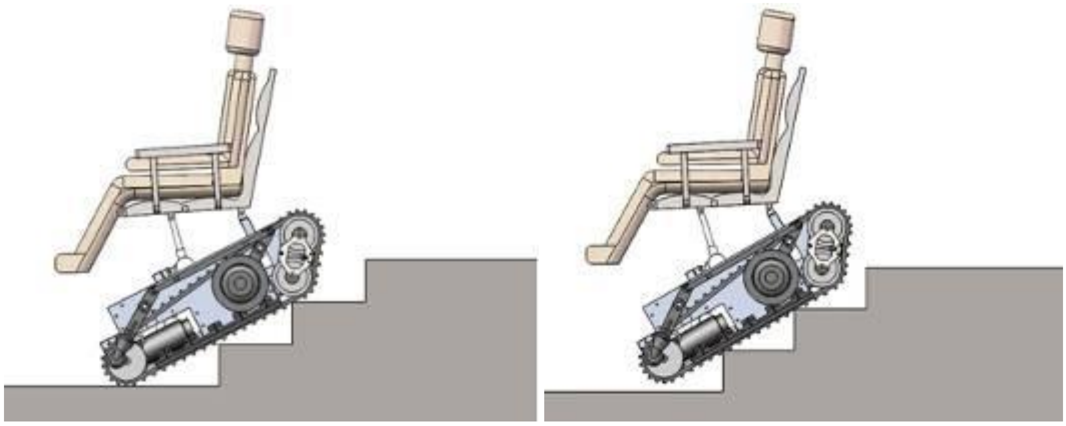
1.3 The track mobile mode

The track mobile mode is mainly used for climbing the obstacles or the stairs which is a challenging task to achieve using the wheel mobile mode. Due to that the obstacle crossing can be simply seen as a process of climbing up and down one step of the stairs, we only need to analyze the process of climbing up and down the stairs here.

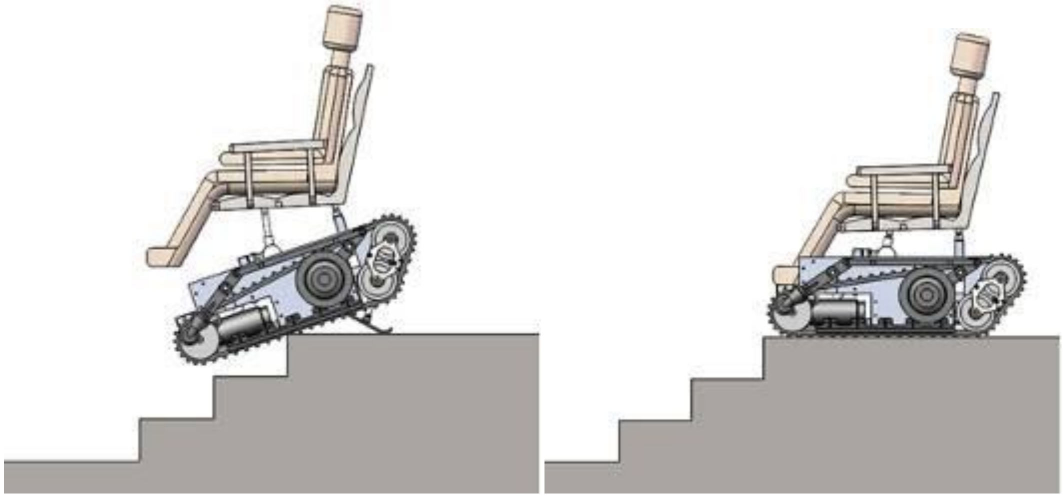
(1) The process of climbing up the stairs



(a) touch the first step (b) climb up the first step



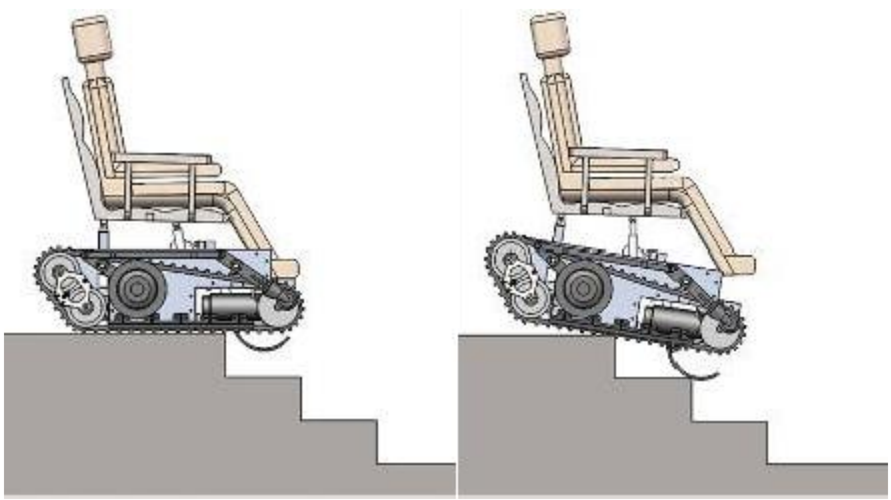
(c) climb up the second step (d) leave the ground and ascend the stairs



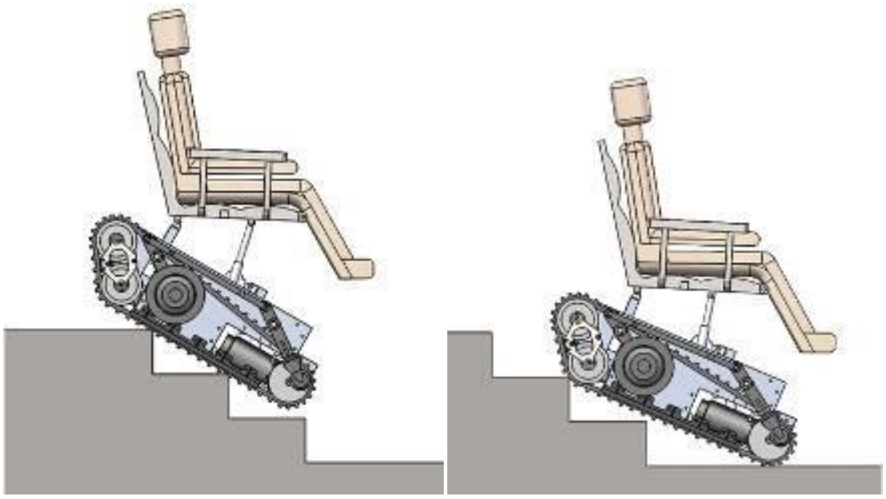
(e) touch the stairs and the top platform (f) ascend the top platform

Figure 11. The process analysis of the ROBOT's climbing up the stairs

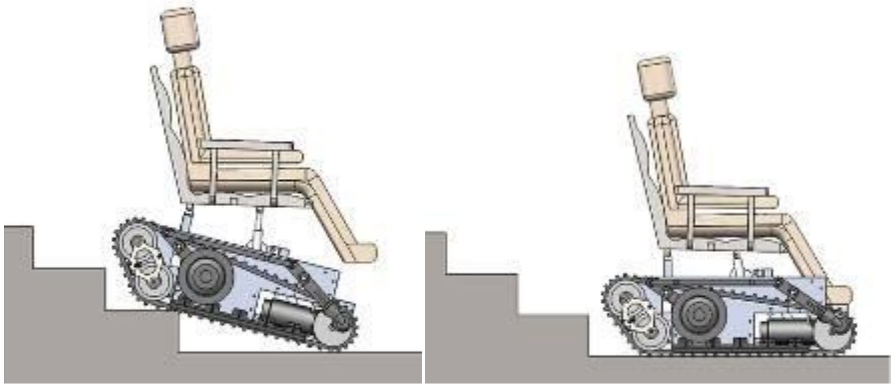
(2) The Process of climbing down the stairs



(a) launch the front assistive mechanism (b) the front assistive mechanism reaches the first step



(c) leave the platform and climb down the stairs (d) touch the second step and the ground simultaneously



(e) touch the first step and the ground simultaneously (f) arrive back to the ground

Figure 12. The process analysis of the ROBOT's climbing down the stairs

(3) The basic conditions for stairs-climbing

According to the stairs-climbing process shown in Figure 11, we can get two basic conditions of stairs-climbing for the ROBOT as below.

(a) The traction condition

The traction condition is to guarantee that the traction force from the driving motor can provide enough power by the requirements of the ROBOT in climbing the stairs. Let the driving torque and the resisting torque converted to the driving motor be M_k and M_f respectively, and the required traction during the climbing be F_k. Thus, the traction force

condition can be expressed by

$$(M_k - M_f) / R_t \geq \max(F_k)$$

(b) The friction condition

For no slipping,

Thus the friction condition can be expressed by

$$f_{max} \geq mgb / \sqrt{h^2 + b^2}$$

In addition, it is also necessary to ensure that no backward or forward tumbling happens during the ROBOT's climbing. The centre of the gravity position of the ROBOT and passenger is regulated at the appropriate region by the design of the assistive mechanism to prevent the tumbling happen. Moreover, we perform the speed synchronization control of the two driving wheels to avoid the tumbling of the ROBOT when it climbs up and down the stairs.

Mechanical Design and other aspects

These consist of literature survey along with some of our implemented insights.

(1) Assistive support mechanism

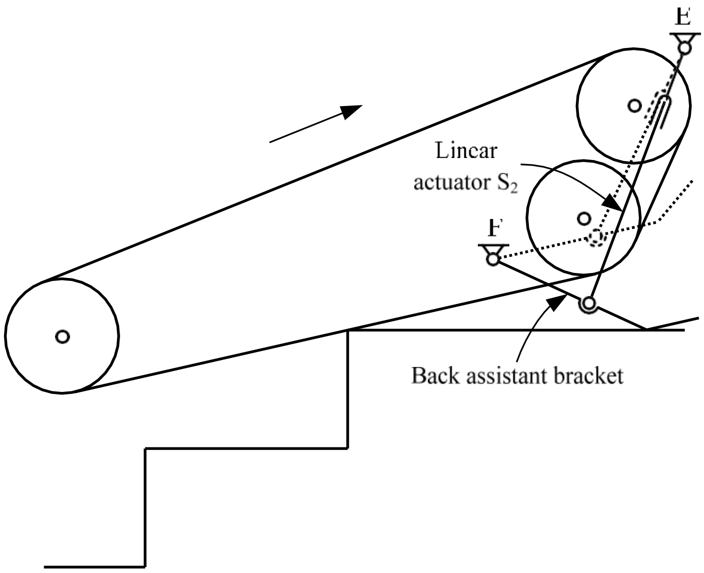


Figure 5. The back assistive mechanism during climbing up the stairs

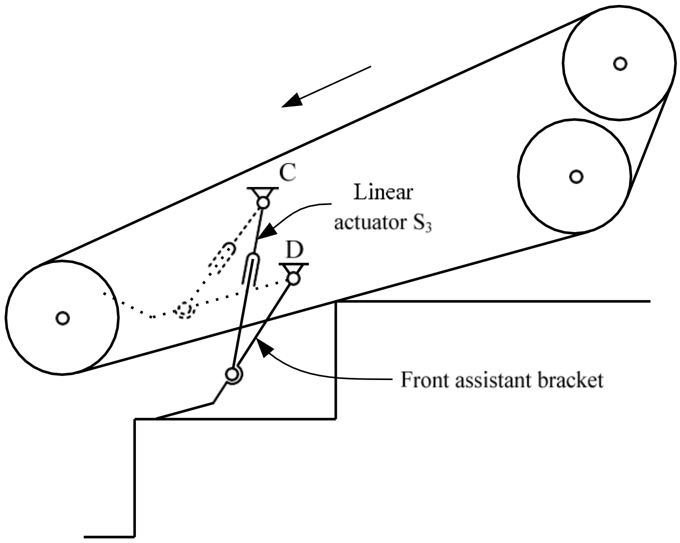
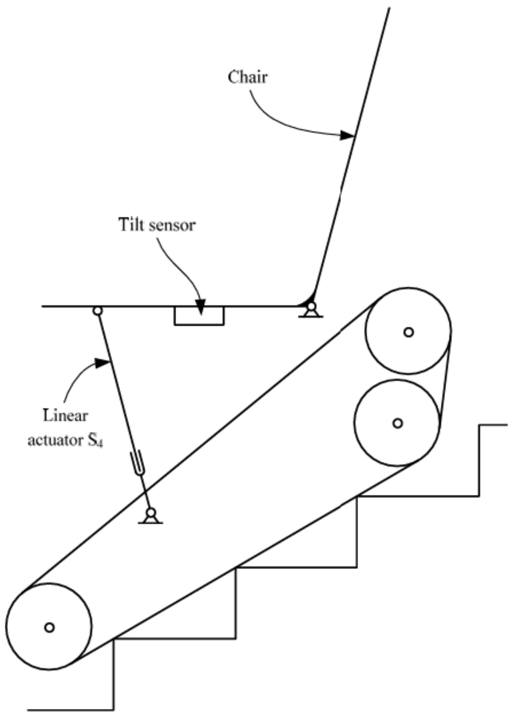


Figure 6. The front assistive mechanism during climbing down the stairs

To prevent tumbling during stair transitions, we designed front and back assistive mechanisms with linear actuators S2 and S3, respectively. When the robot climbs up to the platform, S2 elongates, lowering the back assistive bracket until it touches the platform. As the robot moves onto the platform, S2 shortens, and the track contacts the platform. For descending, S3 elongates, lowering the front assistive bracket to the first step. As the robot moves down, S3 shortens, and the track contacts the steps. Both brackets return to their initial positions after the transitions.

(2) Chair adjustment mechanism

Considering the comfort and safety of the passenger during climbing up and down the stairs, the chair must stay horizontal all the time and thus, a chair adjustment mechanism is designed to achieve the levelling task. The working principle of the levelling mechanism is shown below. This mechanism controls the linear actuator S4 to elongate or shorten and to keep the passenger seat staying horizontal during the stairs climbing through the measurement of the tilt sensor fixed on the chair's seating plane.



Work principle of the chair adjustment mechanism

Calculations for motor

Here, F= Frictional force

m= Total mass of robot + Payload

h=rise

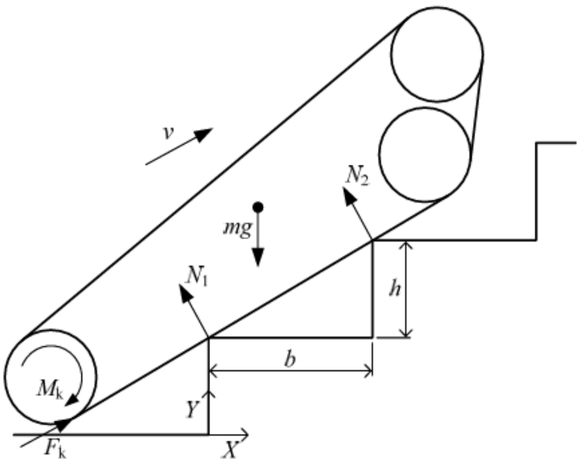
b=tread

M_k= Motor torque

R= radius of wheel

P= power required from motor

v= linear climbing speed of robot



$$F_k - mg\sin(\arctan(h/b)) = 0$$

$$-mg\cos(\arctan(h/b)) + N_1 + N_2 = 0$$

$$-mgd_2 + N_2\sqrt{h^2+b^2} = 0$$

We now can solve for F, as we know h and b.

So, **F_k = mg sin(arctan(h/b));**
M_k = R*F_k;
P= F_k*v

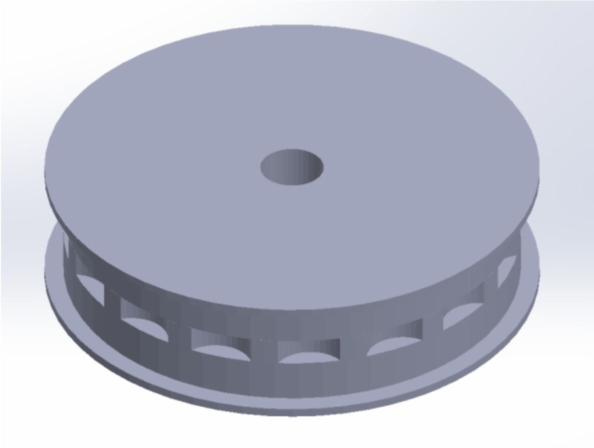
Taking m=100kg, R=5cm, v=0.5m/s, h=6 in, b=12 in, g= 9.81m/s^2, we get,
F_k =438.71 N
M_k= 21.93 Nm
P= 219.35 W
This torque and power have been calculated for two motors. So, for a single motor,
M_k= 10.965 Nm
P= 109.67 W
But still there is a catch here! We have not accounted for the power lost in real time scenario. Power gets dissipated as noise and heat. Therefore, we take a buffer of about 3 times.

So, finally we opted for a motor with torque about **30Nm** and Power of **300W**.

Double Sided Timing Belt Design and Pulley

We have researched and developed a special Double sided teeth timing belt with variable pitched teeth on both the sides. The total length of the belt per side is 108 inches along with 1 inch width.

Also, we designed 6 pulleys, got them 3D printed with 50% density using PLA, of 4 inches diameter whose grooves are designed in such a way that the teeth of the belt fit exactly into them for smooth rotation.
Moreover, the outside pitch of the belt is such that its pitch directly fits itself onto the edge of the staircase.



Specialized Pulley

Fully-developed Prototype

Double sided teeth silicon rubber timing belt with specialized hardness so that it does not break apart upon load

Stability Testing

Coupler attaches motor shaft to pulley

Support Wheel Mechanism

5. Discussion

The wheel-track hybrid ROBOT allows users to switch to wheel mode for high speed and low energy consumption on flat ground, and to track mode for climbing stairs or large slopes. However, the prototype is heavy, increasing energy consumption and reducing mobility. The assistive support mechanisms are too low and risk scraping on uneven ground, necessitating redesign. Future plans include optimizing the structure and using lighter materials.

The track mobile mechanism adapts well to stair geometries, allowing the ROBOT to climb most common stairs with a slope less than 35º and compliant step sizes. Occasionally, wider steps in public buildings may cause slight pitching, but the ROBOT can still climb stairs at reduced speed. A caregiver is recommended to assist during stair climbing for safety.

Experimental results show that the ROBOT is prone to forward tumbling when the driving wheel leaves the ground and the fulcrum shifts to the corner of the first step. To prevent this, the center of gravity is carefully regulated, the chair remains level, and speed synchronization of the driving wheels is maintained to avoid lateral deflection.

6. Conclusion

To elder or disabled patients who use ROBOTs to move around, they have to face the challenging task to climb up the obstacle or stairs by ROBOT. Aiming at this problem, a new type of the wheel-track hybrid ROBOT was designed and tested in this paper. The wheel-track hybrid ROBOT combines the wheel mobile mode and the track mobile mode with an effective and safe switching between these two modes. The acquired achievements for the ROBOT design can be summarized as follows:

(1) The mechanical structure of the wheel-track hybrid ROBOT is designed, the hardware design of its control system is given and the prototype of the EPS has been demonstrated.

(2) The wheel-based and track-based mobile modes as well as their switching design of the ROBOT are analyzed and discussed.

(3) The mechanics calculation model of the switching mechanism between the wheel- and track-based mobile modes and stair climbing are discussed and presented.

(4) The effectiveness of the ROBOT motion, including the wheel- and track-based motion on flat ground and stairs climbing was verified and demonstrated through experiments.