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A Kind of New Wheelchair Based on Robot and Bionics Technology

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Abstract

Traditional wheelchair doesn't have the ability of climbing stairs and crossing obstacles. And it has poor ability of climbing slopes. Aiming at these problems, the author improved the traditional wheelchair with the help of robot and bionics technology. The improvement of the wheelchair simulates the movement of animals with four legs. Four mechanical legs are added to the wheelchair. When the wheelchair needs to climb stairs or cross an obstacle,the wheels retract and the four legs walk just like a four legged animal.When the wheelchair needs to climb a slope,the wheels work and the two back legs push it to increase its climbing ability to avoid sliding back. The seat keeps level while climbing stairs or a slope.The author analyzed its moving processes,designed the parameters of its mechanical legs and also analyzed its ability of climbing a slope.To some extend, the improvement of the wheelchair expands the living space of the aged and the disabled people and improves their living quality.

Keywords*: wheelchair, robot, crossing obstacles,climbing ability*

1. Introduction

With the improving of people's living standard ,the average life expectancy of human is going up gradually which will cause the arrival of the aging population.The population over 60 will double in the next 50 years.On the other side,with the progress of industrialization, there are more and more cars running on the road.Then the number of the disabled people caused by traffic accidents is increasing.Various natural disasters and diseases are also making this number increase .These people lose abilities of different degrees such as walking, vision, hands and language. The medical care and nursing for this special group will become a huge pressure of economic and social development.With the improvement of living standards, people also pay more attention to the living standard of the aged and disabled people.Intelligent wheelchair will have a huge space for use[1-7].

Intelligent wheelchair can be called manned mobile robot which is a typical product of many new technologies, such as pattern recognition technology, multi-sensor fusion technology and multi-modality human-computer interaction technology .Wheelchair robot is a service robot with people's action and thinking based on the ordinary wheelchair.For example,several mechanical arms can be added to the wheelchair to simulate our arms' actions, several mechanical legs can be added to make the wheelchair to walk like people.Some sensors can be added to it,then the wheelchair can see and hear like people.We can also add a controller to it to give it a brain.It will have a certain degree of intelligence to provide better service for the elderly and the disabled people.

With the development of the society,wheelchair will unavoidably need to climb stairs,cross obstacles and climb slopes.How to improve the ability of the wheelchairs in these areas obtains the attention of the society [8-15]. The robots with climbing ability have different styles which can be divided into four main types: leg type, planetary wheel type, track type and compound type.Each type has its own advantages and disadvantages.

(1) Leg Type

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This climbing structure adopts the principle of bionics and simulates the moving process of human and animals.It can walk on different terrain freely, chooses the best support points on the ground and has strong adaptability.It is more suitable for climbing stairs and climbing over obstacles.But its structure and control system are both complex .The commonly used robots of this type are four legged ,two legged,six legged and eight legged. The four legged robot simulates the action of four legged animals.It is more stable than two legged robot.Its structure is simpler than six legged robot and eight legged robot.It is a good choice for the wheelchair.

(2) Planet Wheel Type

Planetary wheeled mechanism has been widely used in robot to climb stairs. According to the number of planet wheels, the planetary wheeled mechanism can be divided into several types such as two planet wheeled style,three planetary wheeled style,four planet wheeled style and so on.This type of stair climbing device has compact structure, flexible movement and a wide application. But its center of gravity changes while climbing which reduces the climbing stability and causes transient instability. That will cause fear in the rider's heart.The number of the planetary wheels effects its performance directly. while climbing,the more planet wheels the robot has,the more stable the robot will be,the weaker the wave of the gravity center will be.In addition, the wheel group device is also become very large which can not be used in narrow stairs.

(3) Track Type

This type of stair climbing device has high efficiency, stable operation, smooth running and wide application.But it is bulky,has high energy consumption and low load capacity.It will damage the edge of stairs while climbing. It is more suitable for use in the field.It is very difficult to be used indoor and to be used for climbing stairs.

(4) Compound Type

This type of device has several structures such as leg-track, wheel-leg and wheel-leg-track. It has all the advantages of them, but at the same time,its structure design and system control will be more complex.

Aiming at improving the ability of climbing stairs,crossing obstacles and climbing slopes of the wheelchairs, this paper improves the traditional wheelchair based on robot technology and bionic technology.A new moving mechanism is designed for the wheelchair which brings convenience for the aged and disabled people .

2. Overall Structure of the New Wheelchair

In order to make the wheelchair have the ability of climbing and crossing obstacles,Improved wheelchair are added the ability of simulating the climbing movements of four-legged animals. Four mechanical legs are added to the wheelchair.So the wheelchair has two walking mechanism.The legs are used to climb stairs , cross obstacles and walk on mountain path.It can also help the wheelchair climb a steep slope. The wheels are used to move on flat ground.Two mechanical legs are added to the front of the wheelchair and the other two legs are added to the rear which are called front mechanical legs and rear mechanical legs just like the four legs of an animal.Each mechanical leg has the same structure including a thigh and a shank. The thigh and the body of the wheelchair are connected by a rotating connection.So the thigh can rotate.The thigh and shank are also connected by a rotating connection.There is a moving connection in the thigh to adjust its length which can make the wheelchair stable while climbing.At the axle of each wheel there is a supporting leg with a moving connection in it. Its length can be adjusted when climbing a slope in order to maintain the level of the seat.When the wheels are not needed,they can also be lifted up through this moving connection.The structure diagram of the improved wheelchair is shown in Figure.1. When the wheelchair needs to climb up or down the stairs or climb over an obstacle, the wheels are retracted, and are replaced by four mechanical legs to walk.Riders are like to be loaded by an animal. The seat can be adjusted to be always level through the moving connection in the thigh which can make the rider to be always comfortable.When the wheelchair meets a steep slope,a wheeled wheelchair may slip down and can't climb to the top.Then the rear legs of the improved wheelchair can stretch out and provide thrust for the wheelchair alternatively to prevent it backward.In addition, one mechanical arm is added to one side of the back which can simulate the movements of people's arm just like a safety belt.The back and the seat are connected via a rotation connection, and the back can rotate to be any angle with the seat. After sitting in the wheelchair for a long time, the rider can lie down for a rest. Then the four mechanical legs support and prevent the wheelchair sliding.Reasonable planning of the movement trajectory and speeds of the four mechanical legs will make the rider comfortable and safe while climbing.

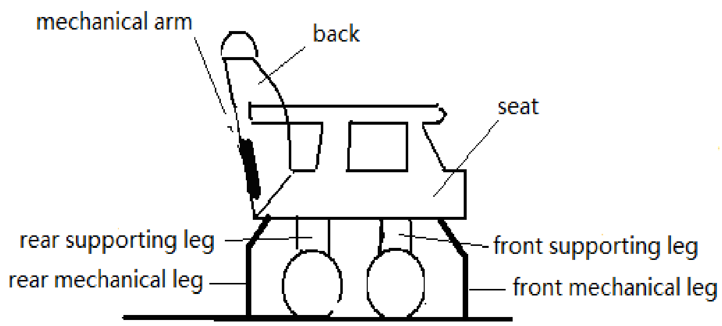

Figure 1. The Structure Diagram of the Improved Wheelchair

3. The Motion Planning of Wheelchair's Climbing Up and Down Stairs

When the wheelchair is climbing up stairs,its wheels are lifted up and its four legs walk.At first,the two fore legs go up stairs alternatively through the rotation connections between the body and the thighs and the rotation connections between the shanks and the highs.Then,the four shanks remain motionless,the four thighs rotate forward until the two fore thighs become upright. At the same time,lengthen the two rear thighs to make the seat level with the help of the sensors.At last,the two back legs go up stairs alternatively through the rotation connections between the body and the thighs and the rotation connections between the shanks and the thighs.At the same time,the rear thighs shorten to their original length.During the process, the shanks are kept vertical to make the wheelchair stable.Then one step of climbing is completed. This cycle repeats itself, and the wheelchair completes the whole climbing up process as shown in Figure.2~Figure.7.When the wheelchair is climbing down stairs,the action sequence of the four mechanical legs is the same .The fore legs go forward alternatively first.Then the body of the wheelchair goes forward with the help of the rotation connections in the four thighs.At last,the back legs go forward alternatively.The difference is that when the two fore mechanical legs stretch forward,its thighs should elongate.When the body moves forward,the two fore thighs should shorten to their original length.The whole process is shown in Fig.8~Fig.13. In the process of climbing up or down stairs, there are always three mechanical legs supporting the wheelchair to ensure the safety and stability of the wheelchair.With the help of the mechanical arm,the rider will feel comfortable and safe.

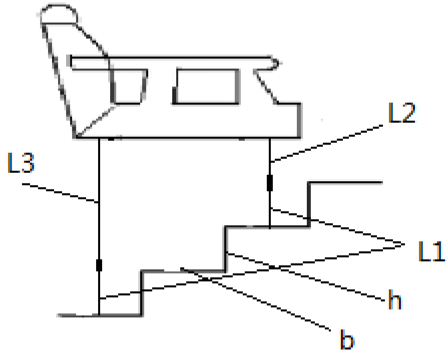

Figure 2. The First Step while Climbing Up the Stairs

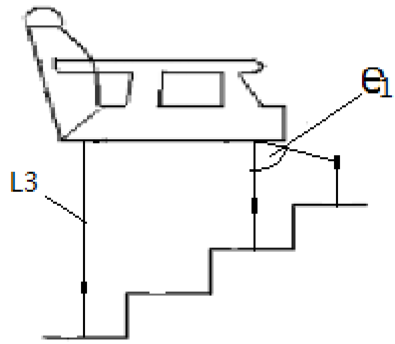

Figure 3. The Second Step while Climbing Up the Stairs

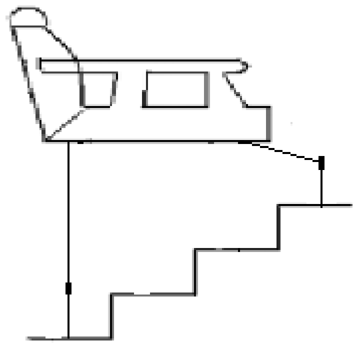

Figure 4. The Third Step while Climbing Up the Stairs

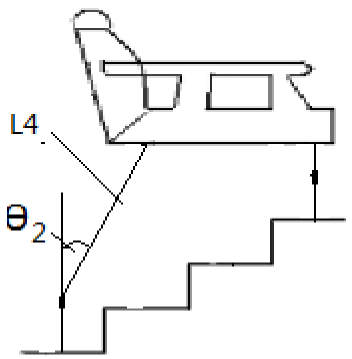

Figure 5. The Fourth Step while Climbing Up the Stairs

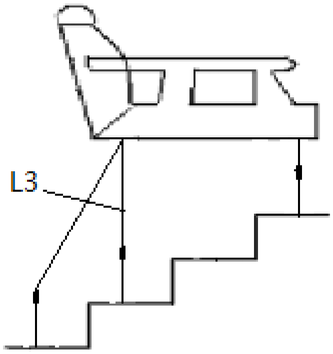

Figure 6. The Fifth Step while Climbing Up the Stairs

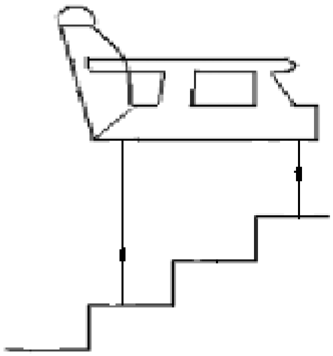

Figure 7. The Sixth Step while Climbing Up the Stairs

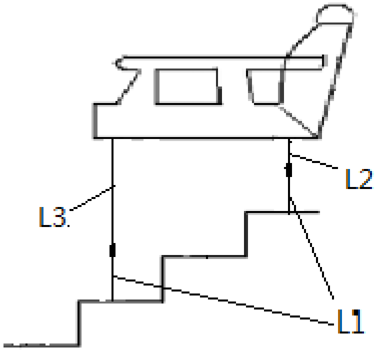

Figure 8. The First Step while Climbing Down the Stairs

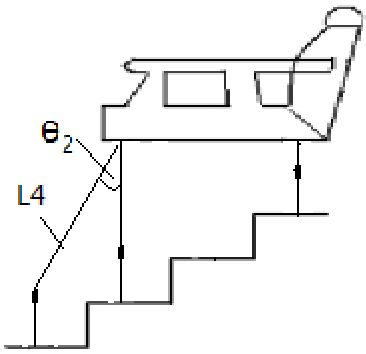

Figure 9. The Second Step while Climbing Down the Stairs

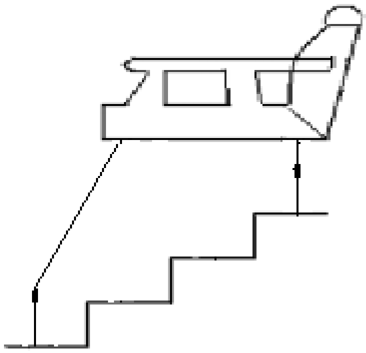

Figure 10. The Third Step while Climbing Down the Stairs

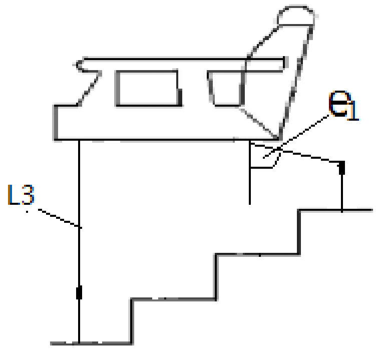

Figure 11. The Fourth Step while Climbing Down the Stairs

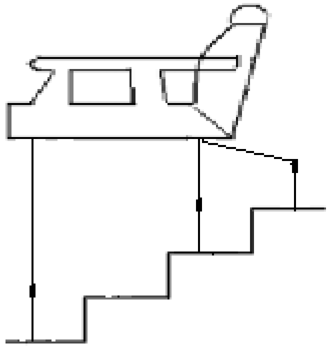

Figure 12. The Fifth Step while Climbing Down the Stairs

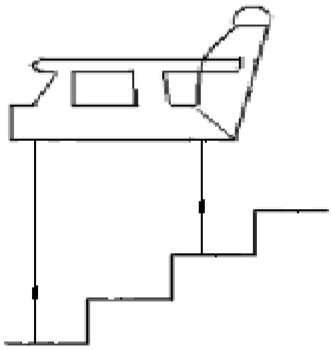

Figure 13. The Sixth Step while Climbing Down the Stairs

4. Parameter Design of the Mechanical Legs

Suppose the height of a step of the stairs is h and the width is b.The horizontal distance between the fore legs and back legs is designed to be 2b.And the wheelchair goes up or down one step one time.In order to low the gravity center to improve the stability of the wheelchair,the four shanks have the same length which is the same with the height of a step of the stairs.So the length of the four shanks is a constant which means $L_1 = \mathrm{h}$ .While climbing up the stairs,the wheelchair adjusts the length of the two back thighs and rotates the four thighs.The length of the two fore thighs remain constant.In order to climb up the steps,the four legs will go up one step alternatively.While climbing down the stairs,the wheelchair adjusts the length of the two fore thighs and rotates the four thighs. The length of the two back thighs remain constant.The four legs will go down one step alternatively.In order to prevent the legs from interfering with the stairs while climbing,the shanks should rotate backward or forward before the thighs finds their places.All the parameters of the legs are shown in Figure.2~Figure.13.

According to Figure.3,we can get an equations as follow:

$$L_2^{\ 2} = (L_2 - \mathrm{h})^2 + b^2 \quad (1)$$

$$\sin\theta_1 = \frac{b}{L_2} \quad (2)$$

$$L_3 = L_2 + 2\mathrm{h} \quad (3)$$

Then we can get:

$$L_2 = \frac{\mathrm{h}^2 + b^2}{2h} \quad (4)$$

$$\theta_1 = \arcsin\frac{b}{L_2} \quad (5)$$

According to Figure.5,We can get an equations as follow:

$$(3\mathrm{h} + L_2)^2 + b^2 = L_4^{\ 2} \quad (6)$$

$$\sin\theta_2 = \frac{b}{L_4} \quad (7)$$

Then we can get

$$L_4 = \sqrt{(3\mathrm{h} + L_2)^2 + b^2} \quad (8)$$

$$\theta_2 = \arcsin \frac{b}{L_4} \tag{9}$$

Through adjusting some parameters, the wheelchair can complete the climbing process one step by one step.

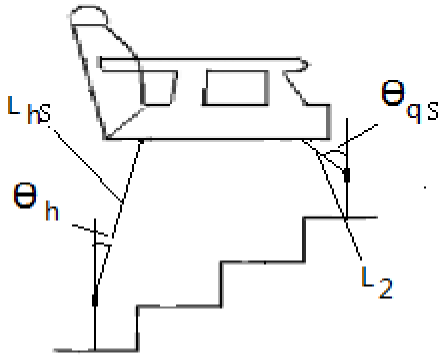

Figure 14. One Position in the Third Step while Climbing Up

During the third step while climbing up,the four thighs should rotate forward and at the same time,the two back thighs should elongate.The fore two legs have same paces and the back two legs have the same paces.Figure.14 shows one position during this step.To make the seat to be horizontal,the parameters must maintain a certain relationship which is as follow:

$$L_2 \sin\theta_{\mathrm{qs}} + L_{hs} \sin\theta_h = \mathrm{b} \tag{10}$$

Where θ_{qs} means the angle between the fore thighs and the vertical direction , θ_{h} means the angle between the back thighs and the vertical direction, L_{hs} means the length of the back thighs.And all the three parameters are variables.Differentiate equation(10),we can get

$$L_2 \omega_{\mathrm{qs}} \cos\theta_{\mathrm{qs}} + L_{hs} \omega_h \cos\theta_h = 0 \tag{11}$$

Where ω_{qs} means angular velocity of the two fore thighs and ω_h means angular velocity of the two back thighs. The angular velocity of the fore thighs and the back thighs must maintain the relation shown in equation(11) to make the seat of the wheelchair horizontal while climbing up. ω_{h} is a variable.The fore thighs are driven by motors and their angular velocity are fixed values which means ω_{qs} is a constant.Then, from equation(11) ,we can get

$$\omega_{\mathrm{h}} = \frac{L_2 \omega_{qs} \cos\theta_{qs}}{-L_{hs} \cos\theta_h} \tag{12}$$

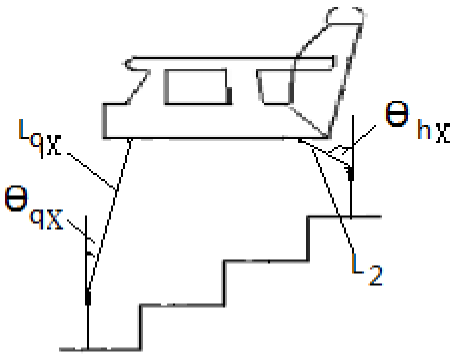

Figure 15. One Position in the Third Step while Climbing Down

During the third step while climbing down,the four thighs should rotate forward and the two fore thighs should shorten.The fore two legs have the same paces and the back two legs have the same paces.Figure 15 shows one position during this step.To make the seat to be horizontal,the parameters must maintain a certain relationship which is as follow:

$$L_{qx}\sin\theta_{qx}+L_2\sin\theta_{hx}=b \tag{13}$$

Where L_{qx} means the length of the fore thighs, θ_{qx} means the angle between the fore thighs and the vertical direction , θ_{hx} means the angle between the back thighs and the vertical direction.Differentiate equation(13)，we can get

$$L_{qx}\omega_{qx}\cos\theta_{qx}+L_2\omega_{hx}\cos\theta_{hx}=0 \tag{14}$$

Where ω_{qx} means angular velocity of the two fore thighs and ω_{hx} means angular velocity of the two back thighs. The angular velocity of the fore thighs and the back thighs must maintain the relation shown in equation(14) to make the seat of the wheelchair horizontal while climbing down. The fore thighs are also driven by motors and their angular velocity are fixed values.Then the angular velocity of the two back thighs can be get as follow:

$$\omega_{hx}=\frac{L_{qx}\omega_{qx}\cos\theta_{qx}}{-L_2\cos\theta_{hx}} \tag{15}$$

5. Ability Analysis of the Wheelchair's Climbing a Slope

When the wheelchair needs to climb a steep slope,it is hard for an ordinary wheelchair.It may slide back because it hasn't enough climbing ability.For this new wheelchair,it climbs with wheels. At the same time,the two back mechanical legs will provide thrust for the wheelchair to help it climb the slope as shown in Figure.16.The fore two mechanical legs don't work. The two back mechanical legs alternately provide thrust just like someone is pushing it from the backside.To simplify the movements and its control system,the shank of the working leg always keeps vertical.The moving connection in the working thigh elongates to provide forward thrust for the wheelchair.And the working thigh keeps parallel with the slope which can push the wheelchair to climb along the slope.In order to maintain a balance in the leg, a torque is applied to the working shank. The other leg will shorten its thigh to make it go a step forward and prepare for work.

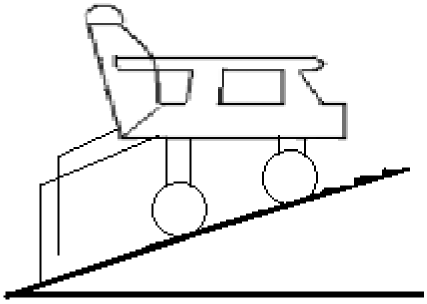

Figure 16. The Posture of the Wheelchair while Climbing Slopes

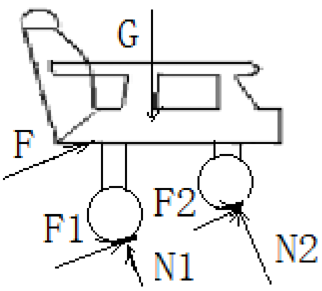

Figure 17. The Force Diagram of the Wheelchair

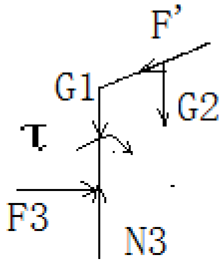

Figure 18. The Force Diagram of the Back Leg

Take the wheelchair without back legs as the object of study to analyze its forces which is shown in Figure.17. The wheelchair is subjected to friction forces F1 and F2, support forces N1 and N2 ,gravity G ,counter-force F from the working back leg.The equation is as follow:

$$G\cos\alpha = N1 + N2 \tag{16}$$

$$G\sin\alpha = F1 + F2 + F \tag{17}$$

$$F1 + F2 = \mathrm{f}(N1 + N2) \tag{18}$$

Where f means the friction coefficient and α means the angle between the Inclined plane and the ground.From the above equations, we can get

$$F = G\sin\alpha - fG\cos\alpha \tag{19}$$

Then from equation(19),we can get the force that the working thigh should provide for the wheelchair.Take the back leg as the object of study to analyze its forces which is shown in Figure.18. The wheelchair is subjected to friction force F3, support force N3 ,gravity G1 and G2 ,counter-force F' from the wheelchair and torque τ from the motor.Then the rotation equation is as follow:

$$\tau = F' l_1 \cos\alpha - G2 \frac{l_2}{2} \cos\alpha \tag{20}$$

Where $F' = F$, l_1 means the length of the shank and l_2 means the length of the thigh.From equation(20),we can get the torque that the motor should provide for the working shank while the wheelchair is climbing a steep slope.

6. The Motion Planning of Wheelchair's Crossing an Obstacle

When the wheelchair is crossing an obstacle,the wheels can't work.It takes back its wheels and stretches out its four legs.Suppose the wheelchair meets an ditch and it must cross it.At first,the two fore legs cross the obstacle alternatively.At the same time,the fore thighs should elongate with the help of sensors on the legs to make the foot touch the ground on the opposite side of the obstacle.Then,with the rotation of the thighs,the body of the wheelchair go forward .At the same time,the thighs of the back legs should elongate and the fore thighs should shorten to their original length..At last,the two back legs cross the obstacle alternatively.Their thighs shorten to their original length.During the process, the shanks are kept vertical to make the wheelchair stable.The wheelchair completes the same steps again.Then the obstacle will be behind which is shown in Figure.19~Figure.23.No matter the obstacle is above or under the ground,the wheelchair can cross it with the same steps if it is not too large.

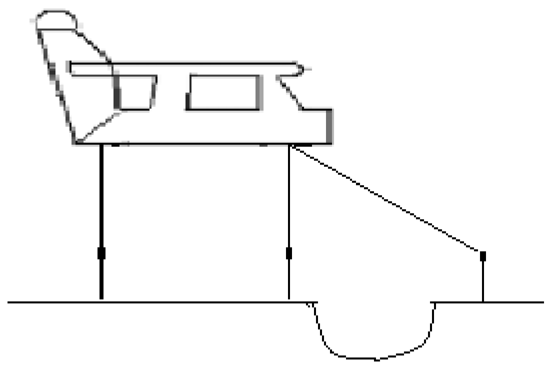

Figure 19. The First Step while Crossing an Obstacle

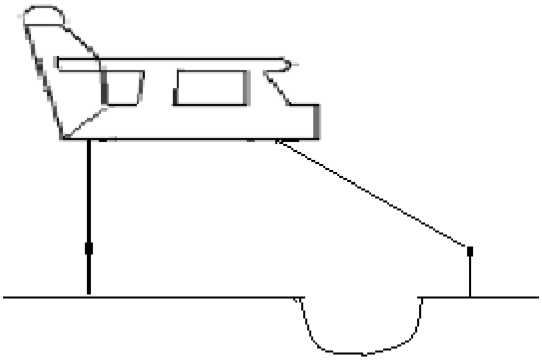

Figure 20. The Second Step while Crossing an Obstacle

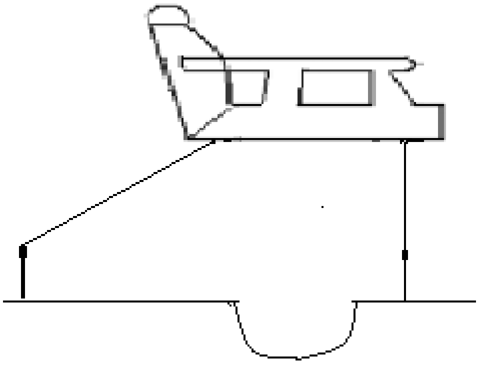

Figure 21. The Third Step while Crossing an Obstacle

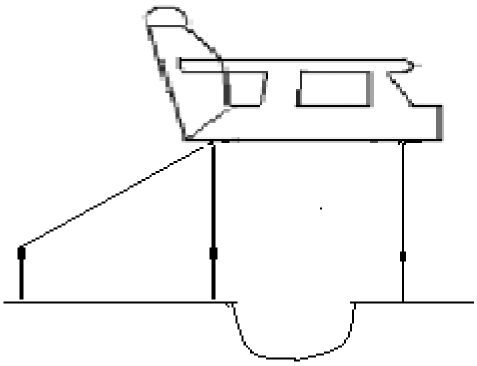

Figure 22. The Fourth Step while Crossing an Obstacle

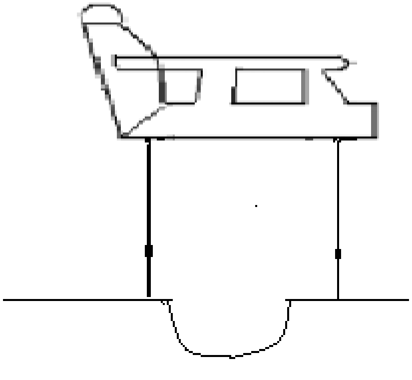

Figure 23. The Fifth Step while Crossing an Obstacle

7. Conclusion

The ordinary wheeled wheelchair can not go up and down stairs and has poor ability to climb slopes.It can't cross obstacles.When it walk on mountain path or any other uneven road,the rider will feel dis-comfortable and fear.Aiming at these problems,the traditional wheelchair is improved based on the robot technology and bionic technology.Four mechanical legs are added to the traditional wheelchair to simulate the action of four-legged animals.When the wheelchair needs to go up or down stairs or crossing an obstacle or walk on uneven road,the wheels retract and the four legs walk.When the wheelchair needs to climb a slope,the wheels work, the two back legs push it to increase its climbing ability and avoid sliding back. During climbing stairs or slopes,the seat can be adjusted to be always level to make the rider comfortable.A mechanical arm is also added to one side of the seat which acts as a safety belt.So comfort and safety of this wheelchair are improved which is very important to the rider. This new wheelchair expands the living space and quality of the aged and disabled people.

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