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Spring Supportive Mechanism to Assist Stair Climbing

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***Abstract*— Disease mobility is curse of human life, both physically and mentally. Particularly, old age faces difficulty in walking, climbing stairs, etc. As per UN world population prospects, the elder population in worldwide will reach up to 2.1 billion in 2050 (around 20%), which is more than double the population in 2017. It is observed that the majority of infrastructures in rural, urban and semi urban areas of developing nations are not equipped with elevators. Individuals have no alternative than utilizing stairs. The fundamental issue comes with an age where an incompetent body enforces to avoid climbing of any type. Literature supports different assisting tools for stair climbing. The use of external power source for driving such tools is a common practice. In this paper, the self driven mechanism is proposed to facilitate climbing. The system stores the energy while regular walking and the same can be utilized whenever required on the need basis. The natural walking style of the individual and its feel is preserved while designing the mechanism. The design further shows scope for similar applications. The detailing of design and the analytical formulations are presented to support the argument.**

Keywords*— *Spiral Spring, Kinematics, Stair Climbing

I. INTRODUCTION

It says, life is beautiful but for elderly population surviving is not at ease all the time. Among the many issues of old age, free unassisted walk is a key element which defines the quality of life. The loss of muscle strength and fitness forces people of old age to avoid stair climbing. Particularly in developing nations, the majority of infrastructures are not equipped with elevators. Individuals have no alternative than utilizing stairs.

Literature supports different assisting tools for stair climbing presented in table 1. Stair lifts [1] helps to climb using staircase lift. It works on battery power with rack and pinion as a driver. Stair climbing cane [2,3], is a specially design cane to have short steps while climbing stairs. The companion bird, is a support system on stair railing for strong grip while stepping-up. Body weight support system [4-6], presented by Honda is a walking assistance device even helpful for stair climbing. User friendly convertible staircase can be transformed into a ramp Automated wheel chairs for stair climbing [7-9] for handicaps. Also can be extended to assist elderly for up and down movement on the stairs. Overall the use of external power source for driving such tools is a common practice. Also, the cost and complexity of existing tools are motivations behind driving this research.

In this paper, we have proposed an innovative self driven mechanism to assist stair climbing. The system stores the energy while regular walking and the same can be utilized whenever required on the need basis. The natural walking style of the individual and its feel is preserved while designing the mechanism.

The paper is organized as follows: the design details of the proposed mechanism are presented after introduction. Next the analytical formulation for mobility and kinematic analysis of the system are presented. The paper also demonstrates the possible strain energy output for the system. Next the experimental model as an introductory attempt for the design and final conclusions are presented.

II. STAIR CLIMBING MECHANISM

This section develops the basic concept of the proposed mechanism for stair climbing in a step-by-step manner. The design is planned to mount on the thigh portion of leg and can be attached around the waist as shown in figure 1.

The objectives set while building the proposed mechanism are presented below in the form of advantages of the mechanism.

Advantages of proposed mechanism

1. It is a small, compact design
2. The design preserves the natural feel of walking
3. It is a simple design with less number of links which makes it light in weight and easy accessible
4. The design is easy to assemble and mount for use
5. The design is completely self driven. There is no need of external power source to operate

Table 1: Existing stair climbing tools

S.n.	Type	Source	Ref.
1	Stair lift	External - battery power	1
2	Stair cane	Manual- short steps	2,3
3	Companion bird	Manual- Slider	-
4	Weight Support	External- battery power	4,5,6
5	Convertible stair	External- battery power	-
6	Auto wheel chair	External- battery power	7,8,9

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The design is conceptualized in such a way that there is an input from the shoes while walking. The input is in the form of linear displacement which will rotate the ratchet in counter clockwise direction. The rotation of ratchet allows the twisting of spring and stores the energy. The reverse rotation of ratchet is locked with the use of supportive linkage. The stored energy can be further transferred to back disc. In this way, the stored energy in spring can be used while climbing through disc rotation and a push to the thigh.

The design mainly contains three parts: part 1, part 2 and part 3. The combined setup can be mounted directly on the thigh portion of leg and can be attached around waist as shown in fig 1(a). These parts are separately shown in disassembly view (figure 1 (b)). The detailing of design is shown in figure 2 with labels are shown in tabular form for each part.

Part 1: It mainly contains a mechanism to operate ratchet wheel as shown in figure 2(a). The synthesis contains six links with one tension spring.

Part 2: It mainly contains a flat spiral spring as shown in figure 2(b). It is used to store energy during regular walking. The same energy can be utilized for climbing.

Part 3: It mainly contains a disc with two rigid link as shown in figure 2(c). The stored energy in the spring will be able to transfer to thigh through part 3.

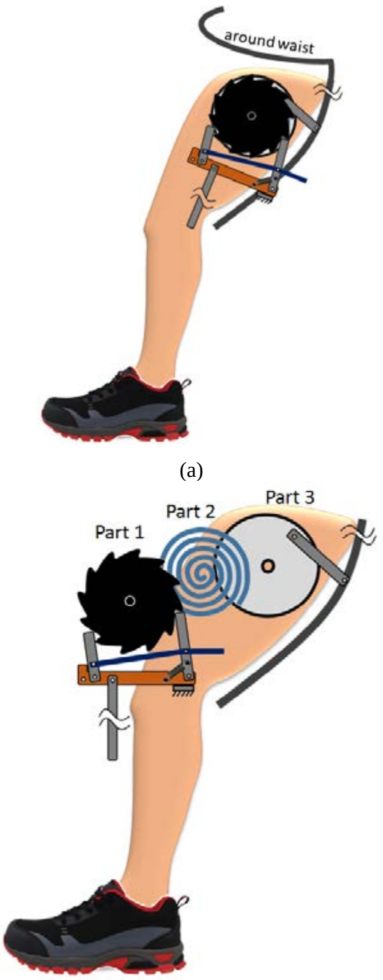

Fig 1: Self driven mechanism to assist stair climbing
(a) Design set-up (b) Disassembly view of design

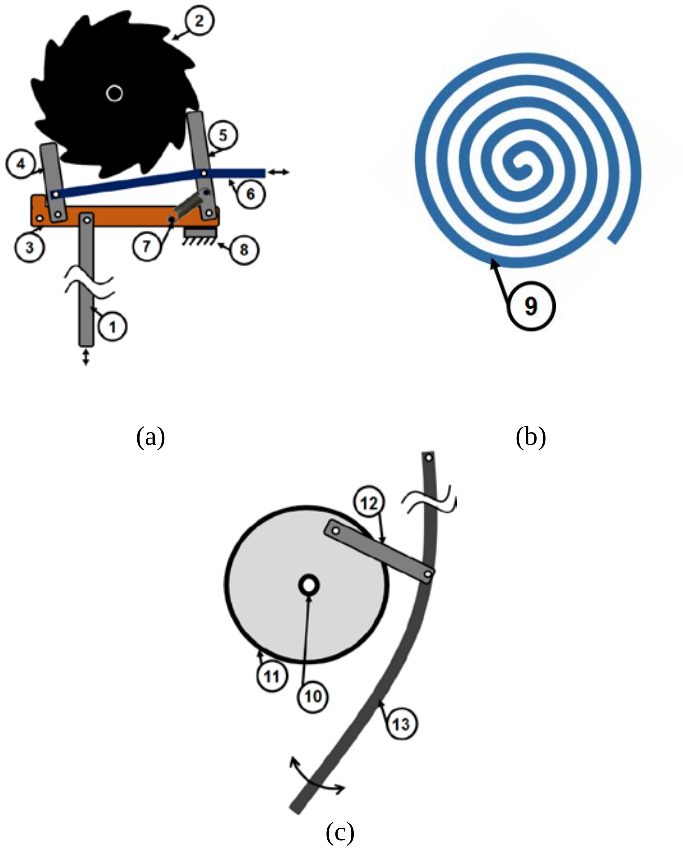

Fig 2: Detailed Design (a) Part 1 (b) Part 2 (c) Part 3

Table 2: Part 1: Ratchet Mechanism

Number	Description
1	Link 1 for input from shoes
2	Ratchet wheel
3	Link 2
4	Link to lock ratchet clockwise motion
5	Link 3 to drive ratchet
6	Link connects '4' and '5'
7	Tension spring
8	Fixed

Table 3: Part 2: Flat spiral spring

Number	Description
9	Flat spiral spring

Table 4: Part 3: Disc Mechanism

Number	Description
10	Center of disc
11	Disc
12	Link 12
13	Link 13

III. WORKING PRINCIPLE:

The working principle of the proposed mechanism (figure 3) is presented in step-by-step manner in this section.

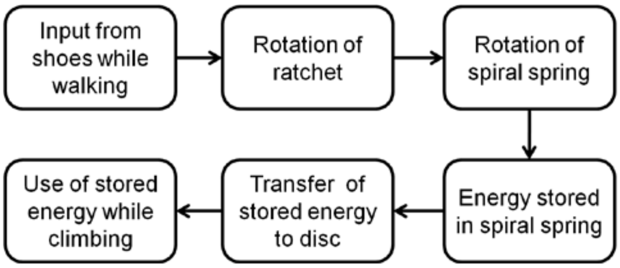

Fig 3: Working principle of proposed design

Step 1: Input from shoes while walking
The input in the form of linear displacement from the shoe while regular walking will be transfer to link 1. Further the displacement will be transferred to link 3. Link 3 is allowed to rotate only in one direction. The other direction is locked using fixed link 8. The rotation of link 3 is then transferred to link 5 for giving input to ratchet. Link 4 is used to avoid ratchet moment in clockwise direction.

Step 2: Rotation of ratchet
The input from link 5 allows ratchet to rotate in counter clockwise direction. With every input from shoe, there will be a respective rotation of ratchet through link 5.

Step 3: Rotation of spiral spring
As a part 2 of the design, there is flat spiral spring at the back of ratchet wheel. The center of spring is attached to the center of ratchet while the free end is kept fixed. With every rotation of ratchet, there is twisting of spring.

Step 4: Energy stored in spiral spring
In continuation to step 3, the energy will be stored in spring with every rotation of ratchet wheel. The energy will remain stored in the spring since ratchet is allowed to rotate only in one direction.

Step 5: Transfer of stored energy to disc
This is part 3 of the design. It will come in activation whenever there is a need from the user to climb stairs. With the help of link 6 presented in part 1 of system, the locks of ratchet will be taken out. The energy stored in the spring will be then allowed to transfer to back disc.

Step 6: Use of stored energy while climbing
The stored energy in the spring will rotate the disc. Link 13 is connected to link 12 and one end is pinned at the abdominal portion. With every rotation of disc, there will be oscillations of free end of link 13 which in turn pushes thigh while climbing. In this way, the input from the shoe will be used for stair climbing.
There is no requirement of any external power source for working of the proposed design.

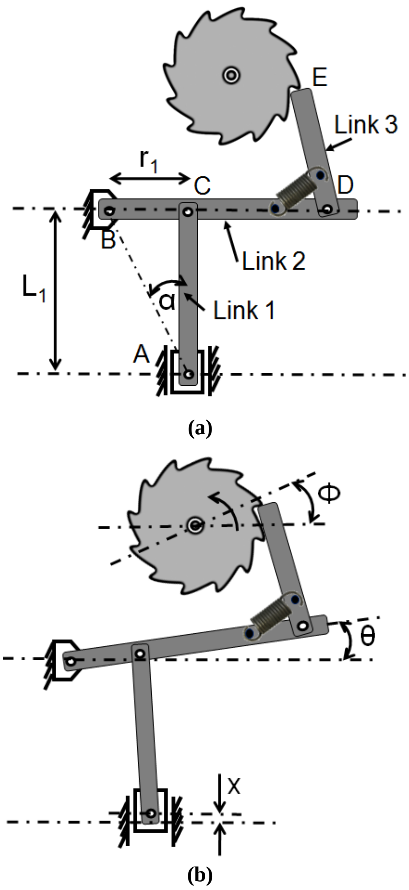

Fig 4: Synthesis of part 1 of mechanism (a) Initial position without displacement (b) Deflected position

IV. MOBILITY AND KINEMATIC ANALYSIS

This section presents the mobility and kinematic analysis of the proposed mechanism.

A. Mobility Analysis:

The mobility analysis is demonstrated using Kutzbach's criteria for calculating degrees of freedom for planar mechanism [10]. So, the mobility of a part 1 of the proposed mechanism is given by,

$$m = 3(n-1) - 2j_1 - j_2 \tag{1}$$

Figure 3 shows, number of links (n) are 6, number of pairs (j_1) are 6 and number of higher pair i.e. j_2 is 1.

$$\therefore m = 3(6-1) - 2*6 - 1 \tag{2}$$

$$\therefore m = 2 \tag{3}$$

The degrees of freedom are 2. It shows, the rotation of ratchet wheel is purely dependent on the displacement 'x' and the angle of rotation 'θ'.

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B. Kinematic Analysis:

The first part of the design is represented by figure 4. The displacement of point 'A' in terms of 'x' can be determined from the geometry of the mechanism, in terms of length 'L_1', 'r_1' and 'θ'. From the geometry, the rotation 'θ' and angle of rotation of link L_2 say 'β' are zero when x = 0. Here 'x' can be expressed as

$$x = r_1 \cos\alpha - r_1 \cos(\alpha+\theta) + L_1 \cos\alpha - L_1 \cos(\alpha-\beta) \quad (4)$$

Also from geometry,

$$r_1 \sin(\alpha+\theta) = L_1 \sin(\alpha-\beta) \quad (5)$$

and

$$[L_1 \cos(\alpha-\beta)]^2 = L_1^{\,2} - [L_1 \sin(\alpha-\beta)]^2 \quad (6)$$

Substituting for $L_1 \sin(\alpha-\beta)$ from equation 5 in equation 6, leaves 'θ' as the only variable on the right hand side of the expression,

$$[L_1 \cos(\alpha-\beta)]^2 = L_1^{\,2} - [r_1 \sin(\alpha+\theta)]^2 \quad (7)$$

Equation 7 can be then substitute to equation 4 to obtain the kinematic equation,

$$x = r_1 \cos\alpha - r_1 \cos(\alpha+\theta) + L_1 \cos\alpha - \sqrt{L_1^{\,2} - [r_1 \sin(\alpha+\theta)]^2} \quad (8)$$

The geometric parameters and material properties for initial set of calculations are shown in table 5.

Table 5: Geometric parameters and material properties

L1	Length of link 1 = 200 mm
r1	Distance BC = 50 mm
α	Angle BAC
r2	Radius of ratchet wheel =50 mm
L2	Distance BD = 150 mm
L3	Distance DE = 100 mm
L4	Distance between B and ratchet centre = 180 mm
E	Young's Modulus of spring= 200GPa
I	MI of spring (b=10 mm, t= 0.8mm)
l	Length of spring = 1000 mm

After initial set of calculations, the relation between the 'x' and 'θ' is shown in figure 5. It shows, the 10 mm of displacement as an input from shoe will rotate link 2 with an angle of 8 degrees.

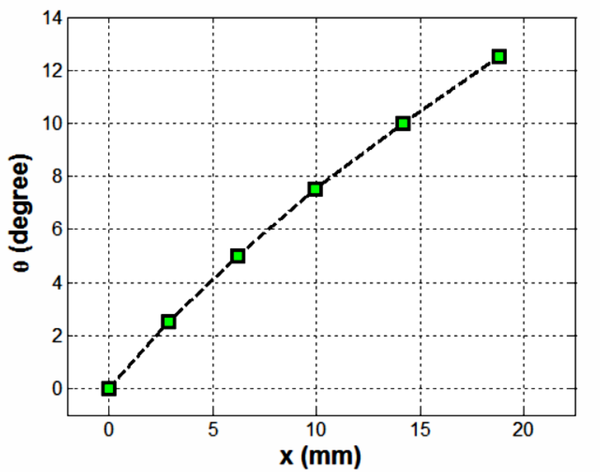

Fig 5: Relation between the 'x' and 'θ'

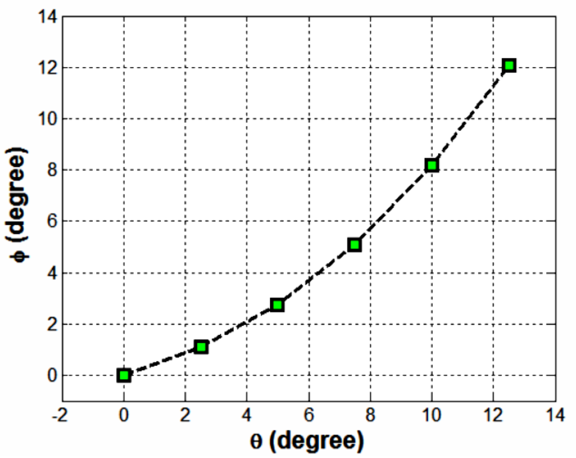

Fig 6: Relation between the 'θ' and 'ϕ'

Similarly, the rotation of ratchet 'ϕ' can be express by equation 9 using input angle 'θ'. The equation mainly contains 'r_2' as ratchet radius, L_2 as length of link 2, L_3 as length of link 3, L_4 as the distance between 'B' and the ratchet center. 'γ' is the angle of L_3 w.r.t. link 2.

$$\theta = 2\tan^{-1}\left[\frac{r_2 \sin\phi - L_3 \sin\gamma}{r_2 \cos\phi + L_2 - L_4 - L_3 \cos\gamma}\right] \quad (9)$$

After initial set of calculations, the relation between the 'θ' and 'ϕ' is shown in figure 6. The relation between the 'x' and 'ϕ' is also shown in figure 7. It shows, the 10 mm of displacement as an input from shoe will rotate ratchet with an angle of ~5 degrees.

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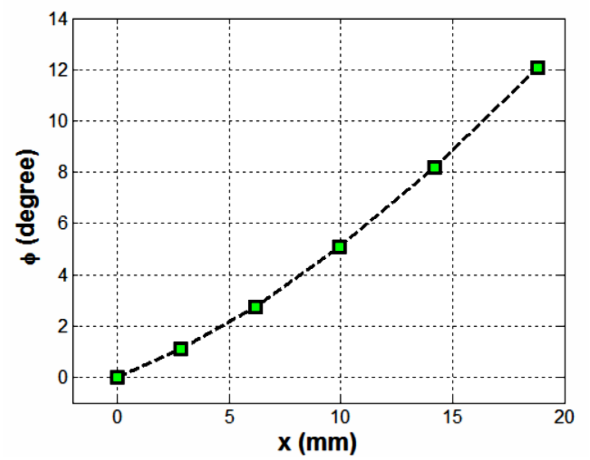

Fig 7: Relation between the 'x' and 'ϕ'

Further to understand energy storage in the spring, the outside free end of the spring is kept fixed as shown in figure 8 [11].

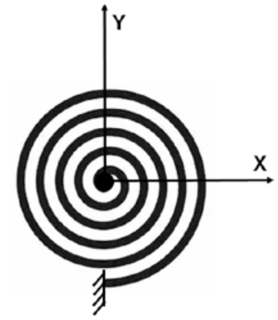

Fig 8: Flat spiral spring

When the ratchet wheel rotates, it applies torque at the centre of the spring. The torque produces the respective components of tangential force and radial force at the fixed end. For the infinitesimal unit length ds, the strain energy dU is expressed by,

$$dU = \frac{T^2 ds}{2EI} \tag{10}$$

where, E is the elastic modulus of the spring material, and I is the moment of inertia of cross section.
For length 'l' of the spring,

$$U = \int_0^l dU = \int_0^l \frac{T^2}{2EI} ds = \frac{T^2 l}{2EI} \tag{11}$$

'T' is related to torsional angle by,

$$\phi = \frac{\partial U}{\partial T} = \frac{Tl}{EI} \tag{12}$$

After initial set of calculations, the relation between the 'x' and 'U' is shown in figure 9. It shows, the 10 mm of displacement as an input from shoe will store ~3 J of energy.

All the calculations made earlier are on the basis of initial set of conditions. The output results can be different for different set of conditions.

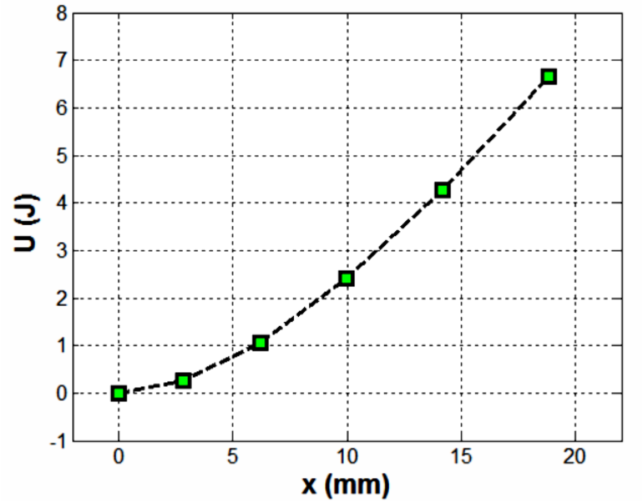

Fig 9: Relation between the 'x' and 'U'

When the lock of ratchet is disengage the stored energy in the spring can be utilized through part 3. The mobility analysis of part 3 is present in equation 13 which shows the mechanism is of 1-DOF where the input is in the form of rotation of disc. This rotation allows link 13 to oscillates. As the link 13 will be placed in support to thigh, the energy transfer from spring will come out as a push for stair climbing.

$$\therefore m = 3(4-1) - 2*4 - 0 = 1 \tag{13}$$

V. EXPERIMENTAL MODEL

This section presents the experimental model for the proposed mechanism. Here we have establishes the basic concept for understanding the working conditions and the limitations of design concept. The complete model is made up of acrylic material as shown in figure 10. It is not made to mount on actual leg. The fabrication is carried out as an example case to understand the constraints of mechanism. As per our observations, the linear displacement as an input stores the energy in the spring. Further it is transferred to link 13 for defined application of stair climbing.

VI. CONCLUSION

A self driven mechanism to assist elderly for stair climbing is presented in this paper. The proposed mechanism is simple and compact in design. Use of less number of rigid linkages makes the design light in weight. It can be easily mount on the thigh portion of leg. The design is conceptualized to protects the natural walking style of the human. The detailing of design with mobility and kinematic analysis are presented. The set of observations are presented for the input displacement from shoe and respective energy storage in the spring. Next the working model of the mechanism is presented as an example case.

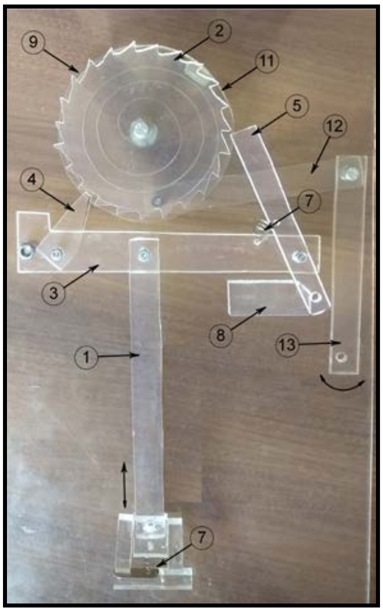

Fig 10: Experimental model of stair climbing mechanism

REFERENCES

[1] Johanne L Mattie, Jaimie F Borisoff, Danny Leland and William C Miller, 2015," Development of an integrated staircase lift for home access", Journal of Rehabilitation and Assistive Technologies Engineering, SAGE, Vol 1, pp 1-12.

[2] S. A. Bouhamed, J. F. Elleuch, I. K. Kallel, D. S. Masmoudi, 2012, "New electronic cane for visually impaired people for obstacle detection and recognition", IEEE International Conference on Vehicular Electronics and Safety (ICVES), Istanbul, pp. 416--420.

[3] J. M. Benjamin, N. A. Ali, and A. F. Schepis, 1973, "A Laser Cane for the Blind" Proceedings of the San Diego Biomedical Symposium, vol. 12, pp. 53-57.

[4] Yasushi Ikeuchi, Jun Ashihara, Yutaka Hiki, Hiroshi Kudoh and Tatsuya Noda, 2009," Walking Assist Device with Bodyweight Support System", The 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, October 11-15, St. Louis, USA.

[5] André Rodrigues, Jorge Sá Silva, Fernando Boavida, 2013, " iSenior—A Support System for Elderly Citizens", IEEE Transactions on Emerging Topics in Computing , Vol. 1, Issue: 2, pp. 207 – 217.

[6] Tran Van Thuc, Shin-ichiroh Yamamoto, 2016, " Development of a body weight support system using pneumatic muscle actuators: Controlling and validation", Advances in Mechanical Engineering, SAGE, Vol. 8(12) 1–13.

[7] Jesse Leaman, and Hung M. La, 2017," A Comprehensive Review of Smart Wheelchairs: Past, Present and Future," IEEE Transactions on Human-Machine Systems, Vol.7, Issue: 4, pp 486 - 499.

[8] D.K. Rathore, P. Srivastava, S. Pandey, and S. Jaiswal, 2014, "A novel multipurpose smart wheelchair", In IEEE Students Conference Electrical, Electronics and Computer Science, pages 1–4, Bhopal.

[9] M.J. Lawn, T. Ishimatsu, 2003, " Modeling of a stair-climbing wheelchair mechanism with high single-step capability", IEEE Transactions on Neural Systems and Rehabilitation Engineering , Vol.11, Issue: 3, pp. 323 - 332.

[10] V. B. Bhandari, 2007, "Design of Machine Elements", Tata McGraw-Hill Education, 2nd Edition - 861 pages.

[11] Wei Duan, Hengchang Feng, 2011," Stress and Modal Analysis of Flat Spiral Spring in Elastic Energy Storage Equipment", Applied Mechanics and Materials, Vols. 121-126 , pp 1754-175.