Reconfigurable Mechanism for Mobile Robotic Platform

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***Abstract*—Future planetary exploration missions will require mobile robots which are able to carry out high-performance locomotion tasks. The robotic platform should be able to move between areas of interest quickly and safely. Improvement of robotics and or robotic movement is a continuing pursuit. Wheeled transportation can be characterized by greater efficiency or speed, while articulated leg transportation can be characterized by greater flexibility for movement over complex terrain. Wheels can rotate quickly, but can have difficulty on uneven terrain, while articulated legs can negotiate the uneven terrain, but can have difficulty with speed. Such wheeled transport can have limited mobility and behavior due to complex environment and lack of adaptability to unpredictable terrain. There exists now an interest for a new type of vehicle which inherits both advantages of legged and wheeled vehicles, namely the high adaptive capabilities of legs and the high velocity and payload of the wheels. In order to deal with the rough terrains of planetary surfaces, researchers put most of the efforts in designing new structure of rover body, but give less attention to new types of reconfigurable mechanism for wheels and trailing link (utilized in two wheeled robots).**

In this paper, "*Singrauli 1.0*", a novel reconfigurable mechanism for "*Elan Robot*", is proposed. This reconfigurable mechanism combines two elementary mechanisms. One is responsible for expanding the wheel and the other one for ensuring sufficient elongation of trailing link to maintain the stability of the robotic platform while encountering uneven terrains and negotiating stairs. This proposed reconfigurable mechanism "*Singrauli 1.0*", is a single degree of freedom mechanism. Reconfigurability enhances mobility capability in different terrains. "*Elan Robot*", utilizes perfect circular form as wheel with conventional width for travelling over even surfaces and also utilizes expandable wheel form for travelling over uneven surfaces. Proposed *Elan Robot* can move steadily and turn around agilely. Thanks to its novel reconfigurable mechanism which enhances the locomotion performance and enable robot to climb steps or hurdles whose height is almost four times higher than the radius of the robot's wheel. And, there is no resistance in between wheel tracks while expanding the wheel diameter.

Keywords— Mobile Robotic Platform; Reconfigurable Mechanism; Wheel Expanding Mechanism; Variable Wheel Diameter;

I. INTRODUCTION

Mobile robots are increasingly being used in high-risk, rough terrain situations, such as planetary exploration. Future planetary exploration missions will require mobile robots to perform difficult mobility tasks in rough terrain. Such tasks can result in loss of vehicle stability, leading to tip over, and loss of wheel traction, leading to entrapment. The Jet Propulsion Laboratory's Sample Return Rover (SRR) has been developed with the ability to actively modify its kinematic configuration to enhance rough terrain mobility. Previous researchers have suggested the use of kinematic reconfigurability to enhance rough-terrain mobility [1]. A Planetary Surface Vehicle (PSV) on an exploration mission with a reconfigurable locomotive system that can respond to changing terrain can be beneficial in ensuring that the necessary tractive ability is maintained [2]. Robots which have wheels for travelling over even surfaces and either lifts the same wheel to act as leg for encountering hurdles or to reconfigure its structure to improve stability have been discussed [1], [2], [3], [4]. In recent years, many types of planetary rovers were developed including tracked type, legged type, and wheeled type, etc. Other examples of hybrid robots can be found which have wheels and legs separately [5], [6].

Because wheeled rovers are well suited to provide smooth motion and offer a high payload capacity, they become the most popular and the mainstream in current rovers. The wheels are commonly used in most of the rovers that can move smoothly and turn around agilely. But its fatal disadvantage is that it cannot scale the step whose height is larger than the radius of the wheel, also it cannot cross the ditch whose width is larger than the diameter of the wheel. Hence, efforts have been done in varying the diameter of dimension of the locomotion mechanism for encountering hurdles of various heights, but they don't enjoy the advantages of conventional circular wheel [7], [8], [9], [18], [19]. Some robots have unconventional wheel width and also there is resistance in between wheel tracks while expanding the locomotion mechanism [8], [17], [18], [20].

Further efforts with no circular wheels but with only legs have been done [10], [11], [16]. Further improvement has been done with no wheels but with only blade wheels which can be folded manually for easier transportation of robot [12]. Robots with a transformation mechanism which directly changes the morphology of wheels (i.e. a full circle) have been discussed with various actuators which make the system complex, bulky and difficult to control [13], [14], [15].

There remains, however, a need for novel wheeled platform which inherits both advantages of legged and wheeled vehicles possessing the flexibility to provide superb riding conditions even as terrain conditions vary severely utilizing least actuators and are compact, light weight, easier to control and have no resistance in between wheel tracks while expanding wheel. With emphasize to design a robot with high performance locomotion tasks which can expand wheel, I have proposed *Elan Robot* which employs *Singrauli 1.0 mechanism* which is responsible for the reconfigurability and mobility.

II. Description of the System

This section will describe about approach for designing Novel Reconfigurable Mechanism step by step from what is desired and how it is proposed to achieve.

The novel reconfigurable mechanism explores the integration of the concepts of reconfigurability and mobility in a mobile robotic platform. A primary goal of the said system design is minimal complexity. The robotic platform can move between areas of interest quickly and safely. The primary focus of the design will be to maintain a high degree of mobility over rough terrain utilizing different configuration with better power management, while simplifying the drive-train. It is important to simplify the drive mechanisms to increase reliability during operation and lengthen the life span of the rover. Emphasize on fewer component interfaces and moving parts to increase efficiency as well. Efforts will be to utilize lesser actuators (motors) for powering reconfigurable mechanisms and wheels, and to utilize only pivoted joints, as sliding pairs are not acceptable due to wear and tear and complexity in fabrication.

Mobile robot must be capable for travelling across structured and unstructured surfaces. It is a further object of this paper to provide such a robot which can be configured differently, manually or automatically, for operation on both flat and rough terrain. Still another object of the paper is to provide a vehicle having improved climbing and rolling capabilities and which can be used in an effective manner on terraced ground or stepped terrain.

A. Design Specifications

In order to meet the requirements, specifications for the mechanical systems of the Mobile Robotic Platform must be as follows:-

The robot must be small and compact. The robot must utilize circular form as wheel. The robot must utilize circular form as wheel with conventional width. The robot must utilize expandable wheel form for travelling over uneven surfaces. The robot must turn steadily, turn around agilely. The robot must climb the step or hurdles whose height is comparatively many times higher than the radius of the robot's wheel. Emphasis is to eliminate the use of sliding pairs as much as possible. Hence, emphasis is to utilize only pivoted joints for mechanisms. Proposed reconfigurable mechanism utilized for wheel expansion must be a single degree of freedom mechanism. Emphasis is to utilize least number of actuators. An actuator of wheel-rotation must be independent from wheel expansion. Wheel must be able to rotate at any state of wheel (closed wheel, any interim position of expanding wheel and expanded wheel) and in any direction. Only actuator of wheel must be responsible to rotate wheel in clockwise and anticlockwise directions. Only actuator of reconfigurable mechanism utilized for wheel expansion must be responsible to expand and contract wheel. There must be no resistance in between wheel tracks while expanding the wheel diameter. The value of wheel tracks must be constant while expanding the wheel diameter. The robot must utilize circular form as wheel with conventional wheel tracks. Weight of Wheel and all the components rotating with the wheel, in all states of wheel must be evenly distributed. Two wheel robot must utilize trailing link which is expandable. Two wheel robot must utilize trailing link which is expandable by the actuator of reconfigurable mechanism responsible for wheel expansion. Hence, expansion of trailing link utilized in two wheel robot must be a function of wheel expansion. Trailing link must be expanded in such a way that the distance between centre of the wheel and end point of trailing link must be more than twice the radius of wheel at all states for better stability of robot.

B. Concept of Wheel Expanding Method

Fig. 2, Fig. 3 and Fig. 4 here illustrates concept of different states of expanding method of a proposed wheel of mobile robotic platform. Fig. 1 is a schematic of proposed Expanding wheel. Fig. 2 is a conceptual illustration of closed wheel. Here O_1 is the centre of the Wheel. And, the each individual connecting links (show in cyan colour) are connected pivotally with the each individual arc of the wheels. In total there are four connecting links and circumference of wheel is divided into four arcs. Individual arc of the wheel is pivoted at one end with the outer plate (shown in blue). For expanding the wheel one end of the connecting link is pivoted to the arc of the wheel and other end is shifted away from the centre of the wheel. Shifting of other end away from the centre of the wheel should be done simultaneously for all the connecting links. For example, here Z_1 of the above arc link is shifted above as shown with arrow and Z'_1 of the below arc link is shifted below as shown with arrow. In the same way left and right side of the connecting links are shifted accordingly, for expanding the wheel.

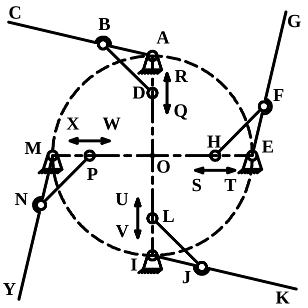

Fig. 1. Schematic of Proposed Expanding Wheel

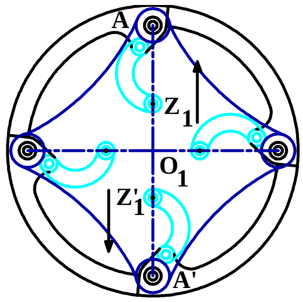

Fig. 2. Conceptual illustration of Closed Wheel

Fig. 3 is a conceptual illustration of expanded wheel. Here expanded wheel is shown with centre of the wheel as O_1. Here, Z_1 have further shifted to Z_3 and Z'_1 have further shifted to Z'_3. In the same way left and right side of the arc links are shifted accordingly.

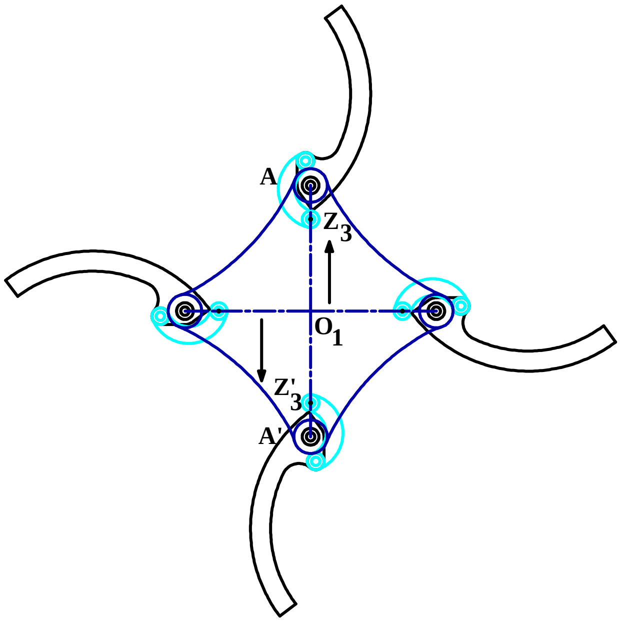

Fig. 3. Conceptual illustration of Expanded Wheel

C. Novel Reconfigurable Mechanism

Reconfigurable Mechanism is named ***"Singrauli 1.0 mechanism"***, after "Singrauli", the town of Madhya Pradesh, India where the crude idea of this mechanism is originated and 1.0 represents the first version of this mechanism.

Singrauli 1.0 mechanism is broadly constituents of following mechanisms:-

Exact straight line mechanism – This mechanism provides motion to the connecting link. This mechanism transforms the straight line motion into rotational motion of arc of wheel (segment of the circumference of the wheel) for expanding wheel diameter.

Mechanism for Slider link - This mechanism provides motion to the slider block, which transmits input motion to the above said exact straight line mechanism. This mechanism transforms the rotational motion of screw threaded shaft into translatory motion of nut.

Mechanism for Expanding Trailing Link - This mechanism provides motion to the trailing link. This mechanism transforms the horizontal linear motion of cuboidal nuts into vertical linear motion of the trailing link.

"Mechanism for Expanding Trailing Link", may or may not be included in "Singrauli 1.0 Mechanism", since only two wheeled robots utilize trailing link as a constraint mechanism to prevent rotation of the body or say frame.

D. Proposed Mechanism for Expanding Wheel

Different states of a single arc of proposed wheel is illustrated in Fig. 4. Here, Closed Wheel Position (shown in cyan colour) with centre of the wheel as O_1 is shown. To achieve interim position (shown in green colour) while expanding wheel Z_1 have to be further shifted to Z_2 . And, finally to achieve expanded wheel (shown in red colour) Z_2 have to be further shifted to Z_3 . In the same way all the connecting links are shifted accordingly. This figure clearly illustrates that exact straight line motion can deliver the desired motion.

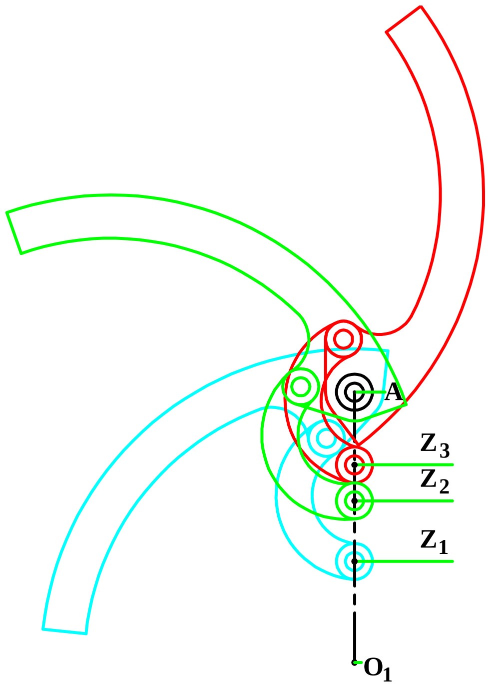

Fig. 4. Different states of a single arc of proposed wheel

E. Exact Straight Line Mechanism

A mechanism built in such a manner that a particular point in it is constrained to trace a straight line path within the possible limits of motion, is known as a straight line motion mechanism.

In the Fig. 5, exact straight line mechanism while wheel is closed is illustrated. The above mechanism can be referred as the Scott Russell Mechanism or a more descriptive name is the Scott Russell Exact Straight Line Mechanism. For this description to be true the acting length of the short link O_1X_1, needs to be half as long as the active length of the magenta one Y_1Z_1 and the pin that connects them must be concentric with the midpoint of the long or magenta link Y_1Z_1. One more requirement is that the connection pin of slider link WY_1 needs to be sliding in a line that would intersect the static pivot end O_1 of the short link O_1X_1. Here, $Y_1X_1=X_1Z_1= X_1O_1$.

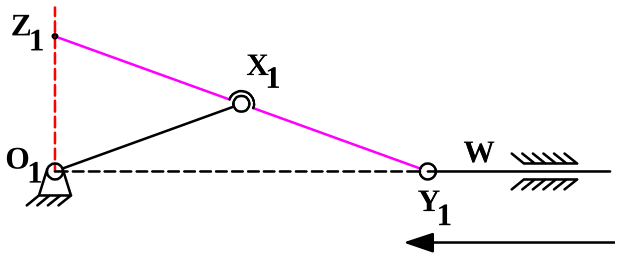

Fig. 5. Exact Straight Line Mechanism while wheel is closed

In the Fig. 6, Y_1 is shifted to Y_2 when slider link WY_1 is pushed in the direction of Y_2O_1. Hence, Z_1 is shifted to Z_2 in the direction of O_1Z_2. In this way the interim position while expanding wheel is achieved. In the same way, Y_2 is further shifted to Y_3 when slider link WY_2 is further pushed in the direction of Y_3O_1. Hence, Z_2 is shifted to Z_3 in the direction of O_1Z_3. In this way the expanded wheel is achieved.

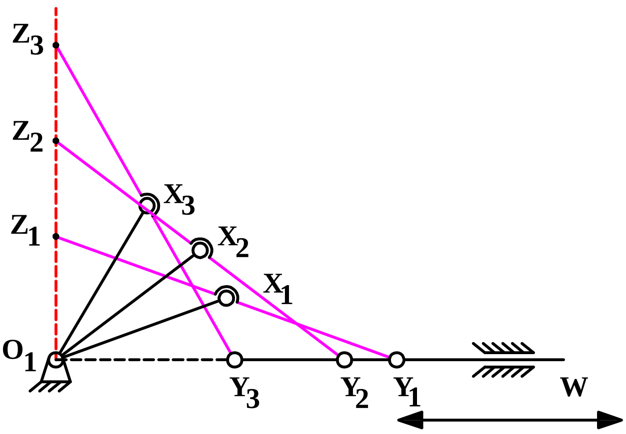

Fig. 6. Exact Straight Line Mechanism showing all states

In the Fig. 7, all the states of exact straight line mechanism is illustrated. It is clear from this figure that shifting of slider link WY_1 in left wheel expands the wheel diameter whereas shifting in right will contract the wheel diameter. In the Figure 8, right side of imaginary line PQ represents exact straight line mechanism which is utilized to transfer motion away from the centre of the wheel O_1 on individual connecting links pivoted with each arc of wheel. Slider link WY is either pulled or pushed in the direction of YO_1 for expanding or contracting wheel. Here, $Y_1Y'_1$ is the slider block which is pivoted over the slider link WY. And, static pivot end of the short link BX_1 is B and similarly for short link $B'X'_1$ is B'. All the static pivot ends of the short links are adapted to be pivoted with outer plate. Left side of imaginary line PQ represents two arcs of the wheel and is on different plane than exact straight line mechanism shown at right side of imaginary line PQ. Only two of the arc wheels are shown here for avoiding any misinterpretation. Arc of wheel shown above is pivoted with outer plate at point A whereas arc of wheel shown below is pivoted with outer plate at point A'.

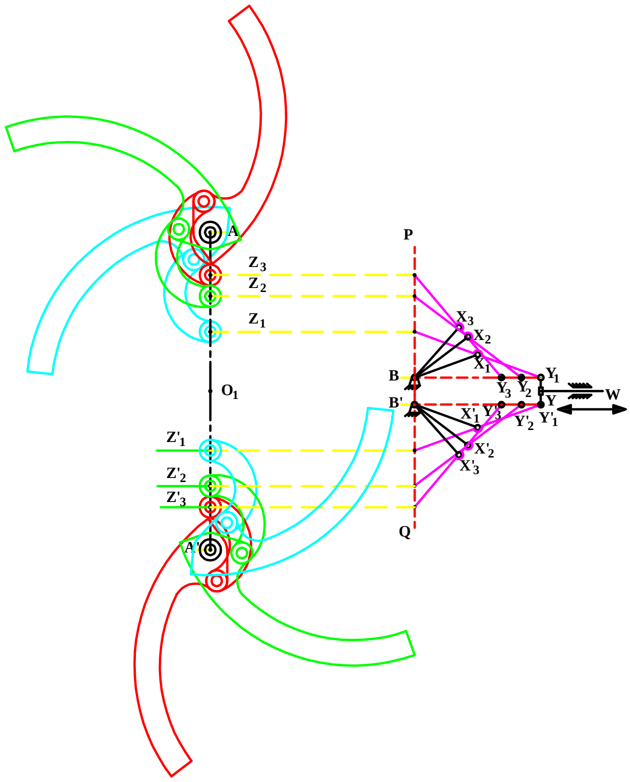

Fig. 7. Exact Straight Line Mechanism with only two arcs of wheel

F. *Mechanism for Slider Link*

In the Fig. 8, mechanism to provide linear motion for slider block is illustrated. Mechanism for slider link is composed of shaft with screw thread (which is rotated) and cuboidal nut (constrained to move only linear motion) with internal thread, which transforms rotational motion to linear motion. Shaft with screw thread is rotated which transmits linear motion to the cuboidal nut. Cuboidal nut is constrained to move only linearly as one of its side is rolled over a pivotally mounted roller, which is mounted with supports at both ends which are fixed with frame. Slider block is pivotally mounted over the slider link at one end where as cuboidal nut is connected over the other end of slider link. Slider block further delivers motion to the exact straight line mechanism.

To consider wheel's rotation, an actuator of wheel-rotation should be independent from wheel expansion, so for actuating wheel expansion here it is employed a shaft with screw thread further extended into a hollowed mounting block which pivotally supports wheel gears. At other end of wheel gear disc of conical cover is connected. Disc of conical cover is connected with one end of conical cover whereas inner plate is connected at the other end of conical cover. The wheel itself is rotated by actuation of wheel gears. A schematic of basic concept of this is shown in Fig. 9. Mounting Block is shown in Fig. 9. Mounting Block is fixed with the frame and is hollowed to pass the shaft and slider link. Embossed surface over mounting block is utilized to pivotally mount the wheel gear. Slider block is pivotally mounted over the slider link which is connected with the cuboidal nut.

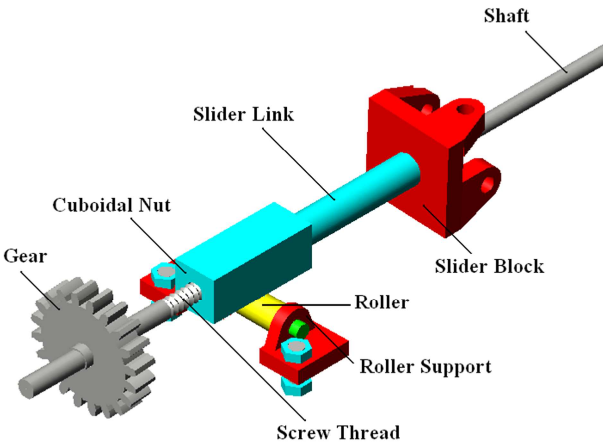

Fig. 8. Isometric view of Mechanism for Slider Link

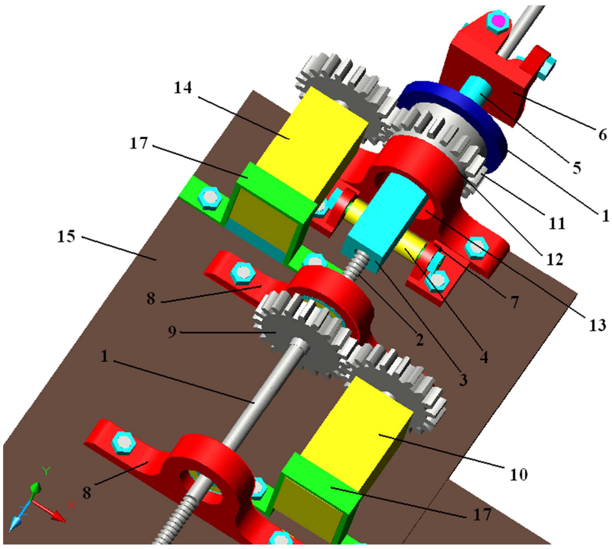

Fig. 9. Isometric view of Complete arrangement of Mechanism for Slider Link

1. Shaft
2. Screw thread
3. Cuboidal nut
4. Roller
5. Slider link
6. Slider block
7. Roller supports
8. Plummer Block (mounting for shaft)
9. Gear connected with screw threaded shaft
10. Screw thread shaft motor
11. Wheel gear
12. Mounting block for wheel gear
13. Hole of mounting block for passing slider link and shaft
14. Right wheel motor
15. Frame
16. Disc of conical cover connected with wheel gear
17. Clamps of Motor

Various positions achieved by the motion of slider link mechanism is shown in the Fig. 10, Fig. 11 and Fig. 12. Disc of conical cover connects conical cover at one end and wheel gear at the other end. Isometric view of ELAN robot without conical cover and cover plate, when wheel is closed, is illustrated in Fig. 10. Ribs over conical cover are embossed for providing further friction for encountering hurdles which touches the conical cover.

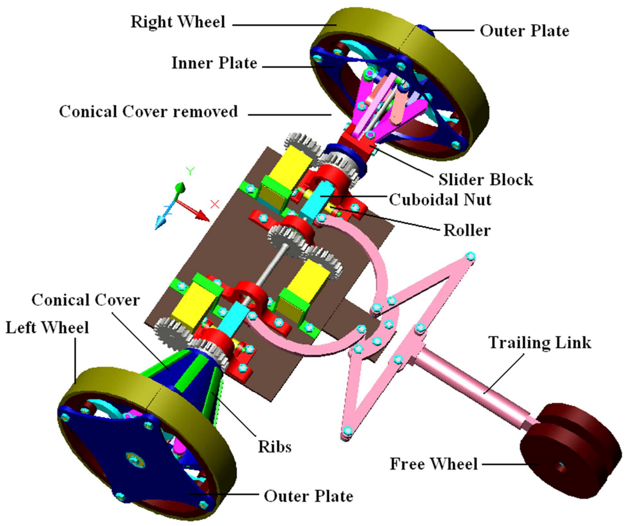

Fig. 10. Isometric view of ELAN Robot with right Conical Cover and Cover plate removed when wheel is closed

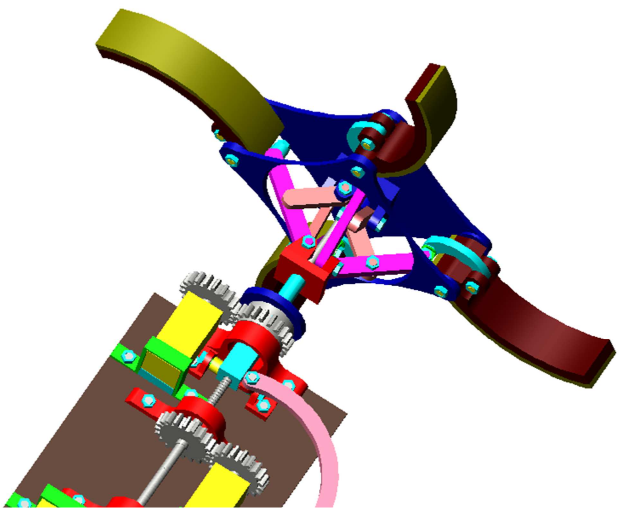

Fig. 11. Close view of slider link mechanism by removing conical cover while expanded wheel.

G. *Proposed Mechanism Expanding Trailing Link*

A robot which has only two driving wheels requires a constraint mechanism not to rotate the body. Usually, the mechanism can be just a bar, and here it is termed as "trailing link". A function of the trailing link length corresponds to wheelbase of conventional automobile. Therefore, the longer the trailing link length is, the better stability the robot performs in case of its moving on a bumpy surface. However in practical case, there is a minimum length of the trailing link to surmount a certain height of step, in geometric analysis. Furthermore, the length better be minimum in consideration of energy-consumption and obstacles' interference with the trailing link [8]. Therefore, a mechanism of variable- trailing link is designed to respond to various heights of steps or say hurdles and to keep the stabilizer length short. Different states of this mechanism are illustrated in Figure 15 and isometric views of Elan Robot.

H. Mobile Robotic Platform

This section will visualize the Mobile robotic Platform by the use of CAD design program, shown below are various models and in various views from two wheeled robot to four wheeled robot in different forms such as without cover plate showing all the necessary elements of mechanism and with cover plate to eliminate further dust, dirt and foreign elements to disturb the smooth operation of mobile robotic platform. With the feeling of strong eagerness to redefine the limits what wheels can do reconfigurable mechanism is invented which add new dimensions for the capability of wheels for high performance locomotions. *Elan* means a feeling of strong eagerness (usually in favor of a person or cause). Hence, Innovative Mobile Robot is named "**ELAN**", after its capability and abbreviated for "**E**fficient **L**ocomotion **A**bility for **N**avigation". Rear hole (from where trailing link is protruded outside) of the cover plate constraints the trailing link to extend linearly.

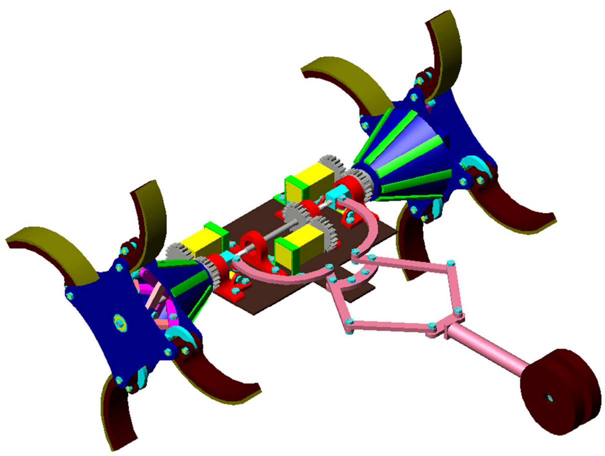

Fig. 12. ELAN Robot with frame while Expanded Wheel

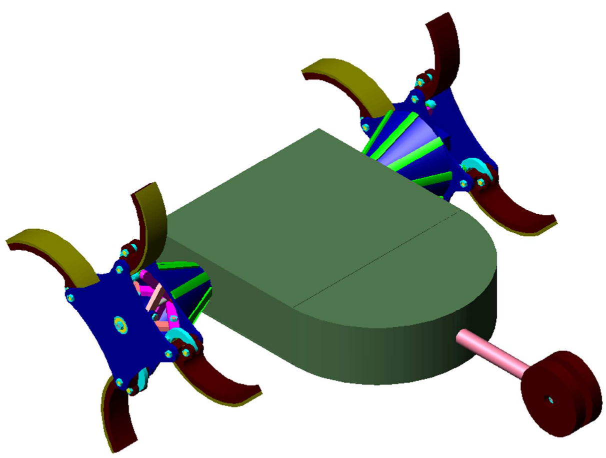

Fig. 13. Isometric View of ELAN Robot with Cover plate while Expanded Wheel

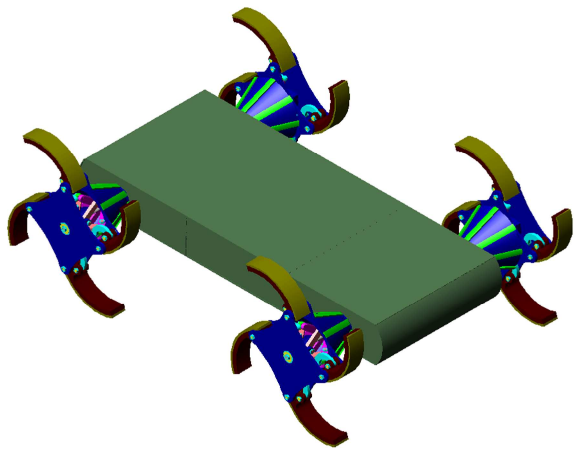

Fig. 14. Isometric View of ELAN Robot with four expandable wheels and cover plate while interim position of Expanding Wheel

III. CHARACTERISTICS AND RESULTS

Even though reconfigurable mechanism "Singrauli 1.0", is a spatial mechanism but they can be considered into different planes individually easily for ease in mathematical calculations.

Here as shown in Fig. 15 right side of O_1A is in another plane than left side of O_1A. Considering them individually in individual planes, we get two mechanisms working at two different planes which are shown individually in Fig. 16 and Fig. 17.

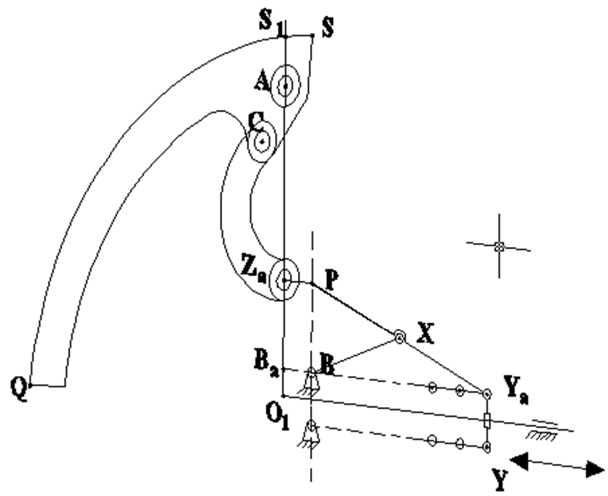

Fig. 15. Isometric View of wheel expanding mechanism

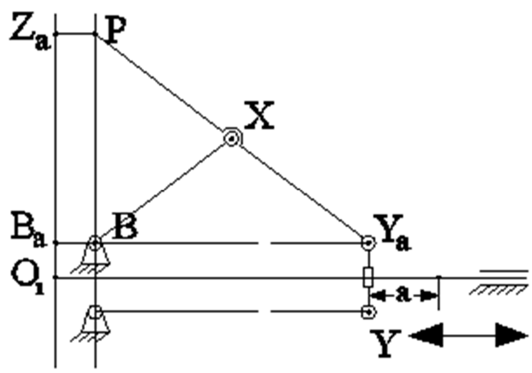

Fig. 16. Exact straight line mechanism

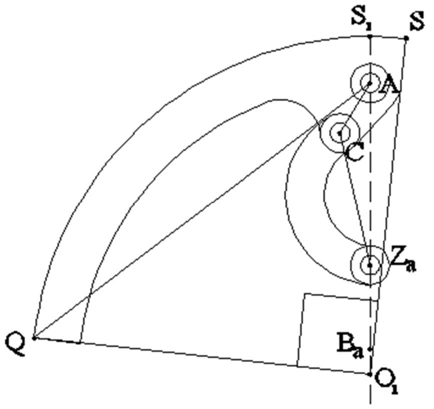

Fig. 17. Single arc of wheel with connecting link CZ_a

O_1 is the centre of the wheel. And, PY_a is equal to the displacement "a" made and BY_a, as shown in Fig. 16.

$$BY_a = PY_a - a \quad (1)$$

$$PB = [(PY_a)^2 - (BY_a)^2]^{(1/2)} \quad (2)$$

$$PB = Z_aB_a \quad (3)$$

PZ_a always lie on a straight line which is parallel to X-axis in ideal condition due to arrangement of mechanism. Maximum possible diameter of expanded wheel can be equal to $(O_1A + AQ)$, as shown in Fig. 17.

$$O_1A = AZ_a + Z_aB_a + B_aO_1 \quad (4)$$

$$B_aO_1 = ½ (Y_aY) \quad (5)$$

For finding the value of AQ at initial position i.e. at closed wheel either S_1S or angle SO_1S_1 is known. Assuming S_1S is known.

Angle $SO_1S_1 = \Theta$

$$\Theta = Cos^{-1}[\{(SO_1)^2 + (S_1O_1)^2 - (S_1S)^2\}/\{2(SO_1)(S_1O_1)\}] \quad (6)$$

Representing Angle AO_1Q as α and Angle CAZ_a as β,

$$\alpha = 90 - \Theta \quad (7)$$

$$AQ = [(O_1A)^2 + (O_1Q)^2 - 2(O_1A)(O_1Q) Cos\, \alpha]^{1/2} \quad (8)$$

$$\beta = Cos^{-1} [\{(AZ_a)^2 + (AC)^2 - (CZ_a)^2\}/\{2(AZ_a)(AC)\}] \quad (9)$$

Since, ponts C, A and Q are on the same component, so Angle CAQ will be always fixed and hence known. Taking Angle CAQ as fixed angle and representing here as β_1, and also representing Angle QAO_1 as Φ.

$$\Phi = \beta + \beta_1 \quad (10)$$

$$O_1Q = [(O_1A)^2 + (AQ)^2 - 2(O_1A)(AQ) Cos\, \Phi]^{1/2} \quad (11)$$

Hence with this equation we can calculate the radius of expanded wheel O_1Q with respect to the displacement "a" of cuboidal nut.

Schematic diagram of mechanism for expanding trailing link is shown in Fig. 18. Here Angle KJL, Angle JLM and Angle MLF is represented as ε, γ and Θ_1 respectively. Angle KJL is equal to Angle JLX and, Angle MLF, Angle XLN and Angle LNV are equal.

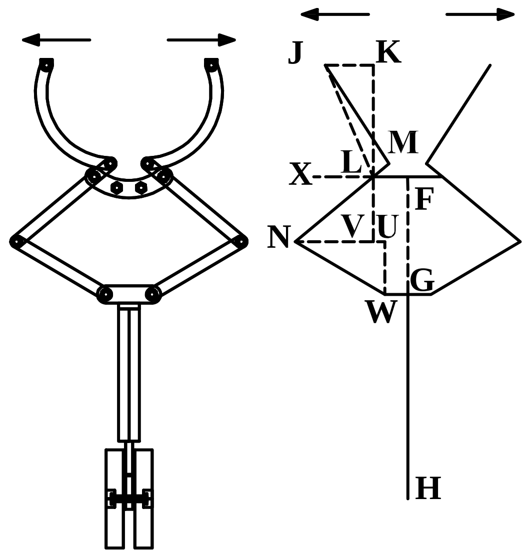

Fig. 18. Mechanism for expanding trailing link

$$\varepsilon = tan^{-1} (KL/JK) \quad (12)$$

$$JL = [(KL)^2 + (JK)^2]^{1/2} \quad (13)$$

$$\gamma = Cos^{-1}[\{(JL)^2 + (LM)^2 - (MJ)^2\}/ \{2(JL)(LM)\}] \quad (14)$$

$$\Theta_1 = 180° - (\varepsilon + \gamma) \quad (15)$$

$$LV = LN\, Sin\, \Theta_1 \quad (16)$$

$$NV = LN\, Cos\, \Theta_1 \quad (17)$$

Since VU will be known,

$$NU = NV + VU \quad (18)$$

$$UW = [(NW)^2 - (NU)^2]^{1/2} \quad (19)$$

Actual expansion of trailing link is represented as FG.

$$FG = UW + LV \quad (20)$$

Total length of trailing link from axis of wheel = (KL+FG+GH). (21)

With the Equation (21) we can calculate the value of total length of trailing link from axis of wheel at any instant with respect to the displacement of cuboidal nut.

All of the design specifications outlined in Section II.A were met. Table I clearly depicts that the robot can climb the step or hurdles whose height is comparatively many times higher than the radius of the robot's wheel. As the diameter of Closed Wheel is just 17.4 cm and it can have maximum diameter of expanded wheel as 36.6003 cm, it clearly indicates that robot with this design can surmount step or hurdle within 36.003 cm, which is approximately 4.2 times the radius of closed wheel. Moreover this capability of rover can be increased by many different variations, such as overlapping the arcs with extended length and placing them in different planes and also by using least number of arcs (as the arc of circumference of a wheel with same diameter utilizing only three arcs will give higher value of diameter of expanded wheel).

TABLE I. TRAILING LINK ELONGATION FROM AXIS OF WHEEL

S.No	State of Wheel	"C" Distance from Axis of Powered Wheel to Centre of free wheel of Trailing Link in c.m.	"D" Maximum Diameter of Powered Wheel in c.m.	C/D
1.	**Closed Wheel**	32.3531	17.4	1.859374
2.	**Interim Position while Expanding Wheel**	38.9375	31.5569	1.233882
3.	**Expanded Wheel**	42.8935	36.6003	1.171944

Table III clearly depicts that the trailing link is expanded in such a way that the distance between axis of the powered wheel and centre of free wheel of trailing link is higher than diameter (twice the radius) of powered wheel at all states for better stability of robot.

IV. CONCLUSION AND FUTURE WORKS

A novel reconfigurable mechanism *Singrauli 1.0* that employs only three motors in two wheel mode has been presented. This method is simple to implement and employs least components. The actuator of wheel-rotation is independent from wheel expansion hence, *Elan Robot* is able to rotate at any state of wheel (closed wheel, any interim position of expanding wheel and expanded wheel) and in any direction. *Elan Robot* which employs *Singrauli 1.0* reconfigurable mechanism is easier to control, there is no resistance in between wheel tracks while expanding the wheel diameter, utilize circular form as wheel with conventional width whereas it is also capable to climb the step or hurdles whose height is comparatively many times higher than the radius of the robot's wheel and utilizes trailing link which is expandable. When two different motors are employed to power the left and right side of the reconfigurable mechanism in a two or four wheeled robot, the centre of gravity of the robot can be shifted to the small diameter side of the wheel for stability and can improve the steering capability of the robot. As far as I know, this is the first time wheeled mobile robot with an expanding wheel possessing above said features and capabilities altogether in a single system is proposed.

Although I have successfully proposed reconfigurable mechanism for mobile robotic platform, I will consider designing, manufacturing and selection of materials for pivoted joints more deeply for smoother operation. On the other hand, to improve the robot's operation, sensors to detect surroundings and surveillance cameras have to be implemented over a working model. In future work, experiments will be done to characterize the global behavior of the wheel.

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