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MECHANICAL DESIGN OF A LEGGED-WHEEL HYBRID QUADRUPED ROBOT FOR MULTI-TERRAIN NAVIGATION

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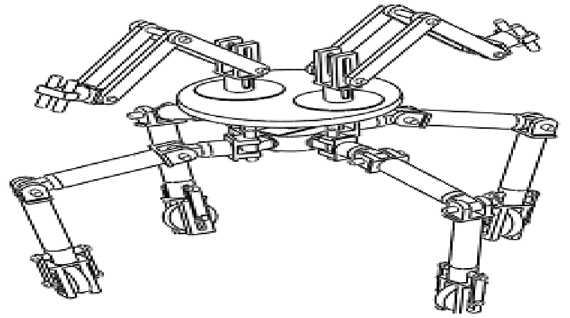
Abstract : The two most common modes of locomotion used by humans are legged mode and wheeled mode, the former an inherent gift while the latter being an ingenious invention on their part. While both have their advantages, they may fall short in some aspects for instance, legs may fail in terms of high speeds and wheels might prove not so handy in the more demanding and uneven terrains Thus, a leg-wheel hybrid platform promises to ensure both high speeds and good stability on a variety of terrains .

1. INTRODUCTION

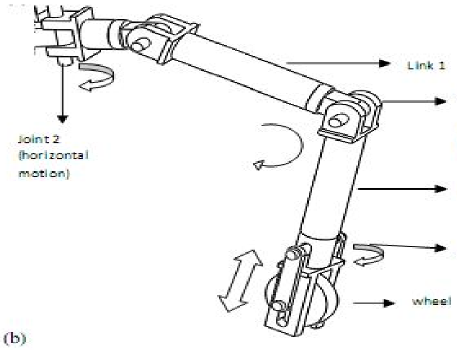
Based on the combination of the two modes(legged and wheeled) of operation many robots have been built in order to optimise the performance in terms of speeds and stability. One of such examples is Stair-climbing robot Zero Carrier [1] with eight legs having four active and four passive legs designed to provide mobility on plain surfaces. Similarly [2] "Wheeleg" employs 2 3-DOF front legs which are pneumatically actuated along with 2 independent rear wheels and Chariot III [8] has two big wheels and four 3-DOF legs for similar functioning. Quadruped design is also a very popular choice for the design of such robots because of the stability it provides to the robot given its inherent symmetry. Robot PAW [5] has four active wheels installed on the ends of its legs of the original quadruped Scott II and so do the robots Walk'n Roll [6] and Hylos [7] (with active 2-DOF suspension mechanisms). Also there are robots built with transition mechanism between wheeled and legged mode to facilitate the aforementioned optimization. For example, Roller Walker [8] with a passive wheel on the foot of the 3 (DOF) legs and Bipedal walker WS-2 with wheel driving mode when the wheeled foot module W-16 is mounted [9]. There are many more such examples using different techniques in making such robots. For example, Octal Wheel [10], which has a special wheel-arm mechanism comprising of an arm with two wheels on each side, and hence is capable of climbing over obstacles such as stairs. Whegs driven by four 3-spoke wheels without"rims" can easily move over flat and rough terrains both. After going through and analysing the existing types of such robots, we have tied to come up with a quadruped design (for the stability on uneven terrains) for the robot with inbuilt transition mechanism between wheeled and legged modes of locomotion (for higher speeds).

2. DESIGN CONCEPT

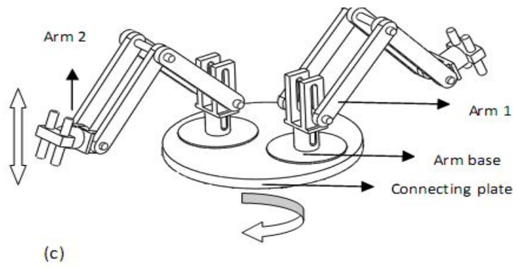
The basic design is based on a quadruped geometry. The reason behind selecting a quadruped design is its ability to remain stable in different conditions. The design proposed in this paper consists of various components. There are 4 legs provided in the design each symmetrically placed. Each individual leg further has 2 links which are connected via rotary joints. Joint 1 provides 1DOF (vertical motion) for the links to adjust according to the terrain. Joint 2 connects the leg to the centre disc and enables motion in horizontal direction. The bottom portion of the legged configuration is provided with a wheel transition mechanism, which will be required for the wheeled mode locomotion. There is also a provision for a vertical axis rotary joint (joint 3) which provides directional change to the motion of wheels. Each leg is connected to a basal disc which acts as its connector to the entire body of the robot. The bottom portion of the base disc consists of the four legs and the upper portion consists of the arm base plates and the robotic arms. The connecting rod, on which the arm base plate lies, can vary the height according to the requirements. The arms attached on to the upper base plate are provided 2 DOFs . For example, one of the arms can to be used for drilling purposes and the other for the picking and placing of the sample. The application of the arms can be varied using different gripper mechanisms.



(a)



(b)



(c)

Fig 1 . Design concept. a) Quadruped design b) Leg configuration (c) Arm configuration

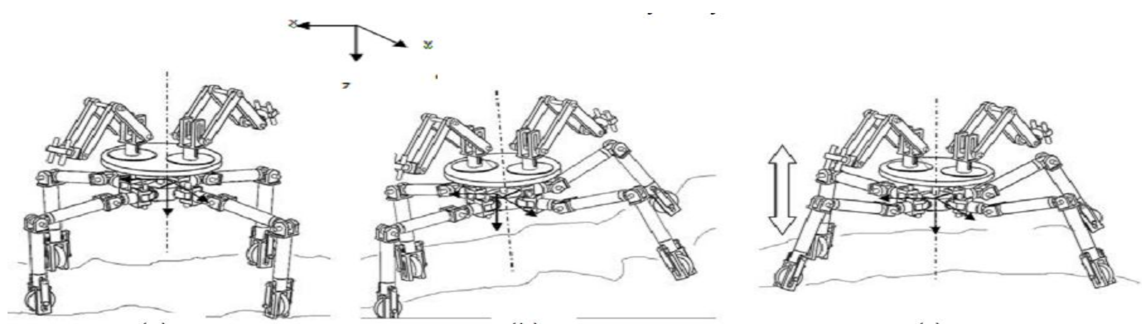
Table 1. Basic Specification

Size(home position)	Length (diagonally opp. legs) - 830mm Width (adjacent legs)-540mm Height-750mm
Weight	15-20 kgs
Key dimensions	Legs (full stretch) – 680mm Arms (full stretch)-500mm
Structure	4 legs , 4 convertible wheels , 2 arms

3. STABILITY CONDITIONS IN DIFFERENT TERRAINS:

The stability of any rover is dependent on the design criteria of the robot. The quadruped design is such that all the 4 legs tend to be symmetrically placed in almost all the types of terrains. Fig.2.(a) shows the position of the quadruped as on a stable or flat terrain. At this position the centre of mass of the structure is located at almost the geometric centre of the body, thus making it the most stable position. The exact positions of the centre of mass obtained from the DS Solidworks software are also shown along with the figure.

Fig. 2(b) shows the position of the robot on and uneven terrain . It can be seen that the position of centre of ass is slightly off set but this eccentricity does not affect the overall stability of the robot. The normal reaction in the two right most legs causes a moment about the centre but the normal forces from the symmetrically opposite forces are capable of balancing such moments. Fig .2. (c) shows the vertical height adjustment. During this motion, again, the centre of mass moves only in Z direction, thus preventing any sideways sways.



(a) (b) (c)

Center of mass:(meters)	Center of Mass : (meters)	Center of mass: (meters)
X = 0.00	X = -0.01	x = -0.01
Y = 0.00	Y = 0.01	Y = 0.00
Z = 0.04	Z = 0.08	Z = 0.12

Fig .2. Stability conditions (a) Stable terrain (b) Uneven rough terrain (c) Vertical height adjustment.

4. MOTION STUDY:

This quadruped robot has four limbs which move in a predefined sequence in order for the whole robot to move ahead. In addition to the legs the robot also has got the wheel transition which can help in wheeled motion too. The configuration used is as shown in the adjoining figure and the numbering is as mentioned.
The motion can be done in 2 ways:
1. Wheeled motion.
2. Legged motion.

WHEELED MOTION:

During the wheeled motion, the transition mechanism proposed later in this paper, lowers the wheels and enables the wheeled mode. When operating in this mode, the robot makes an adjustment in the level of the legs. The adjustment tries to bring the axis of the horizontal link of leg, in parallel with the ground. After this adjustments each of the wheels in the 4 legs align themselves in the same direction. The rotary joint attached just above the wheel enables this directional change. The figure below shows the directional alignment and the adjustment of the horizontal link.

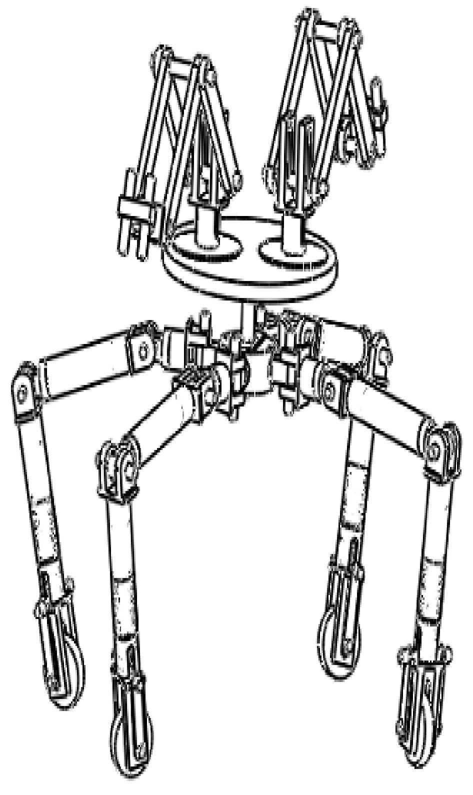


Fig.3.a Wheeled mode.

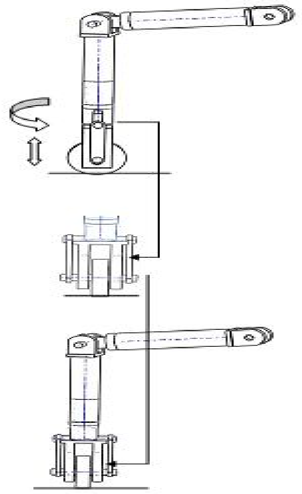


Fig.3.b Wheel alignment. Legged motion:

Motion ,as proposed, can be divided into six steps as shown in the following diagram. The sequence used in the locomotion is 1-2-3-4, as shown in figure 4.a. Further motion of each leg can be subdivided into two steps: each of the steps occurs simultaneously. One being horizontal motion and the other being vertical lift of the limb. In the step 1 limb 1 moves while the other 3 are resting. In the step 2, while the first is in air, the limb 2 starts moving while the other two are still at rest. By the step 3, first and second have reached their positions and by this time, limb 3 starts to move whereas fourth is still resting. As we can see by this time the body is progressively moving forward with the help of the motion of the limbs. In the step 4 we can see the third limb is undergoing the vertical lift while the fourth limb starts moving. Step 5 sees the start of motion of the fourth limb, the other 3 having reached their position. Finally in the sixth step, the robot has completed its desired motion with all the limbs at their new positions. The figure below shows these steps in the direction of motion as shown. The starting line, intermediate line and the finishing line have been tentatively shown as well.

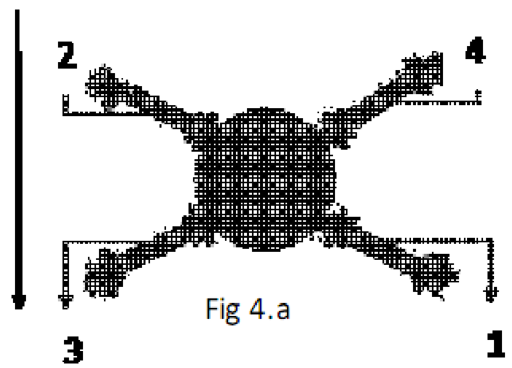


Fig 4.a

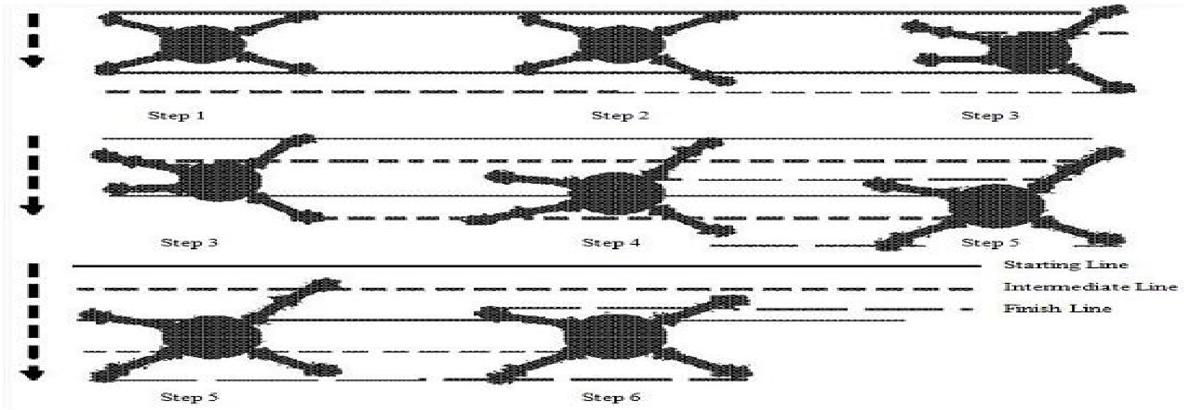


Fig 4.b: the figure shows movement of the robot within the given starting and finishing lines.

5. TRANSITION MECHANISM:

The transition between legged mode and wheel mode is done using a screw mechanism as shown in the figure (fig 5.a). The cylinder part just above the leg is grooved with inner threading of the same pitch and size as given to the outer threading on another inner cylindrical part which is fitted in turn, with two shafts(one above and one below).The upper shaft is connected to a motor whose direction of rotation decides the lift or fall of the wheel and whose rotation leads to the relative motion of the two cylinders along the threading given (up and down).This motion of inner cylinder lifts or drops the wheel attachment of the limb, connected via the bottom shaft. Further the threading helps in the locking mechanism required to hold the wheel in its desired position whether up or down (i.e. in legged or wheel mode) as the suitable amount of force needed by the attachment to hold its position can be easily withstood by this screw mechanism ,thus making it highly efficient as well as reliable. The mechanism can be easily understood with the help of the figure 5.b. the upper shaft when attached to a motor will rotate the inner cylinder in the direction of rotation of the motor, which will ultimately move the cylinder along the grooves of the threading given (up or down).Along with the cylinder, will move the bottom shaft attached, fixed to the shaft of the wheel attachment setup,thus moving the wheel up or down as required.

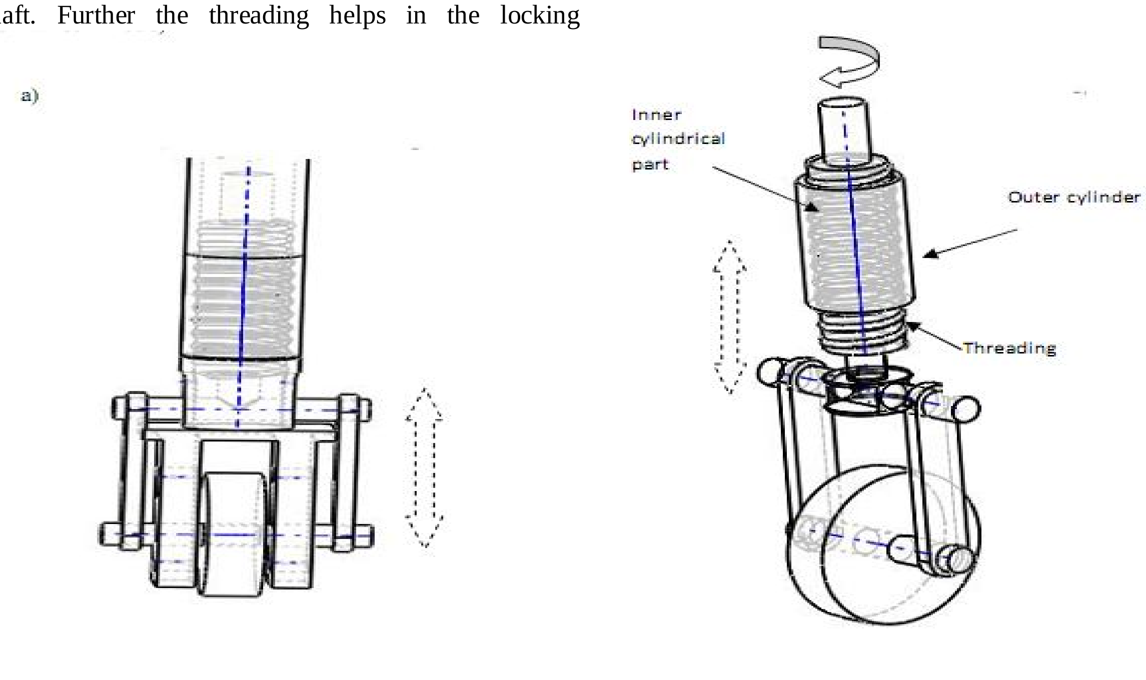


Fig 5. a) Embedded version of the screw mechanism used.
b) Screw mechanism functioning.

6. CONCLUSION AND FUTURE WORK:

We have reported on the design of a leg-wheel hybrid platform quadruped which includes a transformation mechanism capable of directly changing the morphology of four wheels of the platform into 2 degree-of-freedom legs. The locomotion behaviours of this robot can be switched between a four-wheel-drive vehicle (wheel mode) and a quadruped (leg mode). We have also discussed the stability criteria for the quadruped robot. We are currently in the process of mechanical stress analysis of the design. This would further require kinematic and load analysis. We further intend to test the design and mechanisms involved on a practical basis by experimental analysis of the system. This would further require the control system studies and mechatronics involved in working of such a design.

7. ACKNOWLEDGMENT:

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