Mechanical Design of A Quadruped Robot for Horizontal Ground to Vertical Wall Movement

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Abstract In this paper the emphasis is given towards the mechanical structure of a quadruped robot able to walk on ground, climb on vertical walls, and perform the ground-wall-movement automatically. The overview of the robot is shown, the configuration, number of DOFs, and the actuation system of the leg is analyzed. Biologically inspired gaits of the robot are discussed. The movement of the leg from the ground to the wall is analyzed. The integrated leg movement-trunk regulation sequences are simulated. And the trajectories of specific points on the trunk are traced, showing the limits for safe movement inside meandrous chimneys or zigzag tubing.

Keywords
Quadruped, Wall-Climbing Robot, Transition gait, Leg design.

I. INTRODUCTION

The modern civilization and the associated continuous technical developments have brought new human necessities and new ideas of practical solutions for these necessities. In the high rise buildings, nuclear plants, chemical industry, naval industry, oil industry and different other fields, there are many important, but hazardous works, which should be accomplished. And one of the practical ideas to accomplish these tasks was to build legged machines. These machines must be able to walk on the ground, to crawl on the walls and the ceilings, and to perform the ground-to-wall transition movement automatically.

As for the legged vehicles, since the technology about locomotion on ground or wall is relatively well-developed, the crux to realize the above comprehensive locomotion should be regarded as the ground-to-wall transition [1][2][3][4]. In this paper, the authors pay their attention to the mechanism of the leg as one of the main obstacles, which stand across the way to solve this crux.

The leg configuration, number of degrees of freedom, and the actuation system of a quadruped robot have been analyzed. Biologically inspired gaits, of this robot for walking on the ground, and climbing on the wall are discussed. And the steps to move the leg from the ground to the wall, and the integrated leg movement-trunk regulation sequences of the robot, while performing transition movement, are simulated, showing the limits for safe movement inside meandrous channels.

II. GENERAL VIEW ON THE ROBOT

It is a quadruped, electrically actuated, walking and wall-climbing robot. The trunk consists of one part only, and the legs are mounted, symmetrically, on the corners of the trunk, Fig. 1. Each leg has three links and three actuated joints connecting these links. Hip horizontal joint is used to swing the three links of the leg in a plane parallel to the ground while walking, hip vertical joint, to attach-detach the foot on and from the terrain for swing and support stages, respectively. And knee joint, to extend the lower link forwards, or upwards. Three DC-motors, concentrated, together, on the first link, which is mounted on the frame of the trunk, actuate the three joints. The first joint is actuated via a direct spur gear system, and so the second joint. While the knee joint is actuated via spur gears and synchronized pulley-belt system. The first gear is fixed to the shaft of the motor and drives the second one, which is attached to the first pulley and rotate freely around the shaft of the second joint. The second pulley is fixed to the shaft of the knee joint and driven by the belt, which connect the two shafts.

Two reasons are behind this mechanism. The first one is to minimise the weight of the leg, hence, to reduce inertia and the torque which is applied on the first and second joints [5]. And the second is to achieve parallel actuation, which will offer more power for climbing [6], and help in controlling the different behaviours of the leg in walking, climbing, or transition movement.

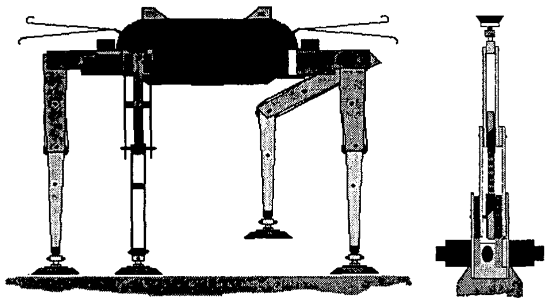


Fig.1. The robot, and the leg

III. WALKING GAITS

Two different walking gaits can be achieved using the above mechanism. The first one is inspired by the locomotion of the reptiles [7], which have the upper parts of their legs configured laterally and each leg swings, about vertical axis, in a plane parallel to the terrain. While the second one is inspired by the mammalians [8], which have their legs configured vertically, and both the hip joints and the knee joints, in their legs, rotate, about horizontal axes, in a vertical plane extended longitudinally with the body of the animal.

- In the first gait of our robot, the hip vertical joint is to be actuated for lifting the leg up, then the hip horizontal joint will be actuated for swinging the leg to the new position. Finally, the hip vertical joint returns the foot to the ground in the new foothold, for the support phase. In the support phase, the hip horizontal joints of the four legs co-operate, together, to shift the trunk in the direction of movement, as explained graphically in Fig. 2.

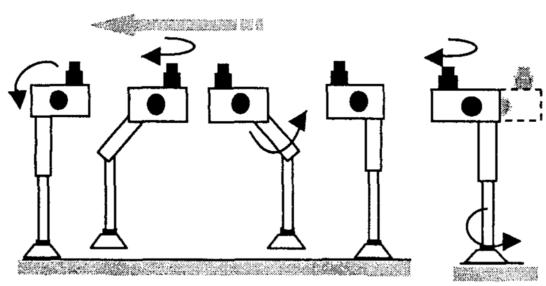


Fig 2 Left-Swing-Lift walking gait of the robot
–a- Leg movement. –b- Trunk movement

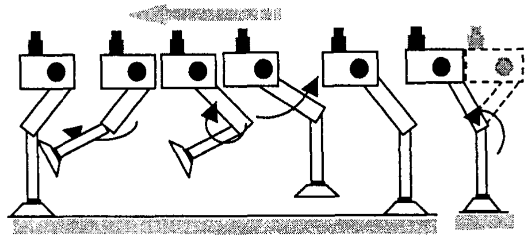


Fig 3 Left-Extend-Lift walking gait of the robot
–a- Leg movement. –b- Trunk movement

- In the second gait, the hip vertical joint is actuated to lift the leg up. After that the knee joint is actuated to lift the lower part to allow the movement toward the new position. Then the hip vertical joint moves the leg forwards. And finally, the knee joint is actuated again to return the foot to the new foothold. In the support phase, the four knee joint co-operate, together to move the trunk forwards. This is shown in Fig. 3.

It is clear from Fig. 2 and Fig. 3, that the lower part of the leg is always, oriented towards the terrain, unless the knee joint is actuated. This is what makes the control easier and the power consumption less.

IV. WALL CLIMBING GAITS

Due to the gravity, there are two problems related to the wall climbing. The first one is the slippage tendency, which is the direct effect of the gravity force. And the overturn tendency, which results from the moment that is generated from the gravity force and the distance between the centre of gravity of the robot and the surface of the wall. [9]. Suction pads are used to generate the frictional force, which prevents the slippage. And the distance between the centre of gravity and the wall was considered in the design to be minimised, as much as possible [10] [11]. Both the walking gaits of our robot are useless for climbing, because the total length of the second and the third links makes the distance between the centre of gravity and the wall impossible to be overcome by the small DC-motors. To reduce this distance, the design was prepared to take the configuration of the spider. The spider's configuration seems to be the optimum for the climbing [3], where it is suspended by its legs, and its belly is about to touch the wall surface, what causes a minimum moment. In our design, the rotational angle of the hip vertical joint covers about (135)B, which allows the robot to take the spider shape, where the second link moves up and the distance of moment becomes little more than the difference between the length of the second and the third links. Fig. 4 shows the wall climbing configuration of our robot.

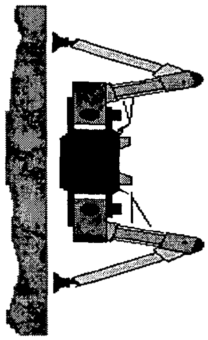
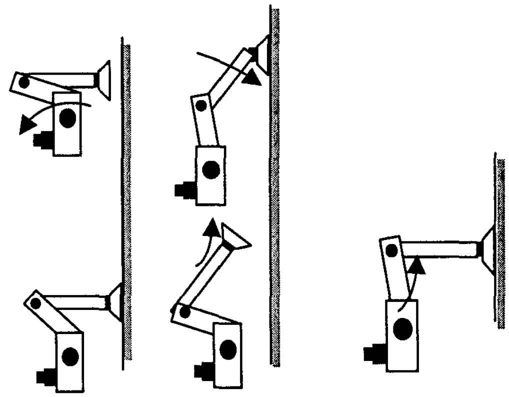


Fig. 4 Wall climbing configuration of the robot



-a- Leg movement. -b- Trunk movement.

Figure 6. Lift-Extend wall climbing gait

As in the walking, the wall climbing process can be accomplished by actuating two joints only of each leg. Also, there are two ways of joint actuation in the wall climbing, which are:

- Releasing the leg from the wall, by actuating the vertical hip joint (here it will be horizontal), and then, the hip horizontal joint (here it will be vertical) will be actuated to swing the leg to the new position. After that the hip horizontal joint will be actuated to adhere the suction pad to the wall for the movement of the trunk as simulated in Fig. 5. The trunk movement is accomplished through the co-operation of the four horizontal actuators. Here, the third link of the leg keeps perpendicular to the surface of the wall all the time, which helps in simplifying the controllability of the locomotion
- Releasing the leg from the wall, by actuating the hip vertical joint, and actuating the knee joint to extend the leg upwards, and then the hip vertical joint is actuated to return the foot to the wall, for the trunk movement. Fig. 6, here is one of the major advantages of the parallel actuation approach, where, the knee joints and the hip vertical joints for the four legs are coupled together to push-pull the trunk upwards.

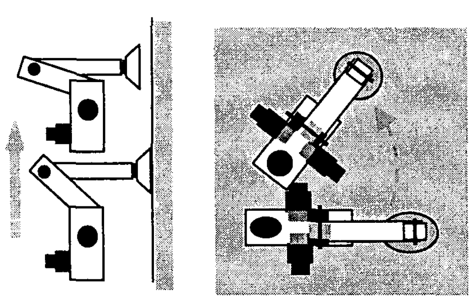


Figure 5. Lift-Swing wall climbing gait

V. GROUND-TO-WALL TRANSITION GAIT

The ground-to-wall transition consists of a series of integral procedures, which change the posture of the robot from ground-parallel position to wall-parallel position. In the locomotion of the living creatures, there are two ways to accomplish the transit gait; the first one is to move the trunk part-by-part from the ground to the wall, like in the lizards, which make use of the articulation of their bodies. While the other one is to regulate the trunk directly in the same footholds, like in the spiders, which have two-parted trunk and long, large in number, highly articulated legs.

In our robot, the trunk is one-parted, and the legs are four, with three joint of each. Hence, the transition gait was suggested to be in synthesised approach of both of the spider's transition gait and the reptile's transition gait. In the transition gait, the three joints are actuating with the assistance of the foot flexibility and several leg-movements and trunk-regulations will integrate to accomplish the process.

A. Leg Movement

To transfer the leg from the ground to the wall, the hip vertical joint is actuated to release the foot from the terrain. Then the knee joint is actuated to change the orientation of the lower link from being vertical to be in a horizontal plane. The hip horizontal joint turns the leg to the orientation, where the lower part becomes perpendicular to the wall surface. And the final step is the movement of the hip vertical join to push the foot against the wall. Fig .7 shows the simulation of all these steps.

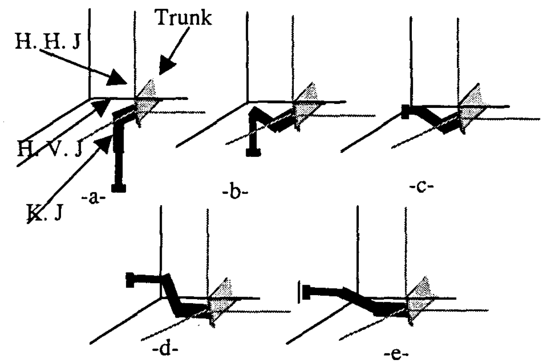


Fig. 7 Leg movement from the ground to the wall.
–a- on ground. –b- lift up. –c- lift, to be horizontally.
–d- swing towards the wall. –e- adhering to the wall.
to the swing towards the wall

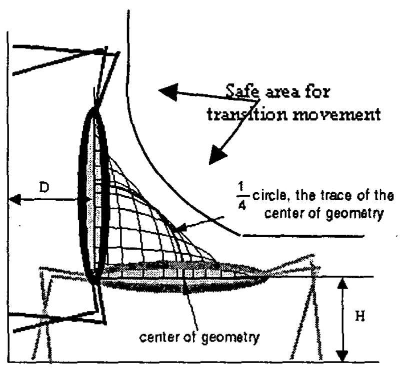


Fig 8. Trunk path, and the safe area for transit gaits

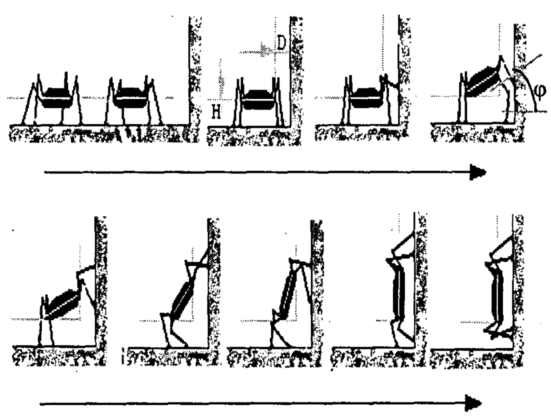


Fig. 9 Transit gait of the wall climbing robot

B. Trunk Movement

In the transition gait of legged robot, there are two unwanted probabilities; to hit the wall with its head, or to hit the ground with its tail. To prevent any of these two risks, the paths of head point and the tail point on the robot trunk were suggested primarily, and they will define the trajectory of the trunk. The head point will move on a vertical line, at a distance (D) from the wall, while the tail point will move on a horizontal line, at a height (H) from the ground. [2]. This approach has another advantage when the robot is to be used in a maendrous channel, where the safe area for transition gait can be derived easily from the equation of movement which is of the form of the equations of the ellipse. Fig. 8 shows the traces of several points on the trunk during the transition gait, and the safe area for movement.

C. Integrated Sequences

Before the transition gait starts, it supposed that the robot is walking on the ground. When it receives a signal that the distance between the wall and the front point of the body equals to (D), then it will stop walking, and starts to move to the wall. The first step is to move one of its front legs from the ground to the wall, as explained above. After that the body is to be regulated, with the help of the four legs, that it will make an angle (φ) with the ground level. Then the second leg is transferred to the wall, followed by the other regulation of the body, then the rear legs start to move forwards, one-by-one, while the body is still being regulated and the fore legs are still being shifted up. When the angle (φ) becomes (90) degrees, the trunk regulation will stop and the rear legs will be transferred one-by-one to the wall. At this point, the transition gait will be completed and the robot starts to climb up as illustrated in Fig. 9.

VI. CONCLUSION

Since it was targeting to solve the problem of the transit gait, the paper presented the mechanical configurations of a quadruped robot able to walk climb and to transfer from plane to another. For walking, the robot takes the mammalian, or reptile shape. In the wall climbing, it is re-arranged to be a spider like. And in the wall climbing, it moves in a special manner synthesized of both the spider and the lizard. The leg-movement-trunk-regulation approach has been analyzed. The advantages of the parallel actuation for the legged robot have been discussed, and the safe area for transition gait investigated.

VII. REFERENCES

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