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Minimalistic, Dynamic, Tube Climbing Robot

Amir Degani, Siyuan Feng, Howie Choset, and Matthew T. Mason

Abstract— **This video shows the investigation of a novel minimalistic, dynamic climbing robot which can climb up tubes of different shapes using a simple dc motor. The motor moves an eccentric mass in a constant velocity. The location of the eccentric mass relative to the contact point determines the stability and the direction of the climbing motion. We present the analysis of this mechanism, simulation and experimental results.**

I. INTRODUCTION

In the Biorobotics lab and the Manipulation lab in the Robotics Institute at Carnegie Mellon University we have been developing a new kind of climbing mechanisms. These mechanisms use dynamic motions without any special attachment mechanism other than friction to climb.

This mechanism is an extension to the previously reported mechanism, called DSAC for Dynamic, Single Actuated Climber, which propels itself upwards by oscillating its leg in a symmetric fashion using a single actuator. This mechanism achieves dynamic, vertical motion while retaining simplicity in design and control ([1], [2]). The current mechanism is a miniaturized version of the DSAC which uses a similar motion to climb up inside tubes. Two main differences set aside the current mechanism compared to the planar DSAC mechanism. The first is that the current mechanism is not confined to the plane, and can climb inside tubes. The second difference is that instead of using a motor which continuously changes direction (symmetric oscillation), the current mechanism rotates in the same direction in a constant velocity. We will shortly describe the difference between this mechanism and previous vibrating climbing mechanism, then we will explain the underlying locomotion principle and will end with proof-of-concept experiments showing the robustness of this mechanism.

II. RELATED WORK

Other miniaturized tube climbing mechanisms have been previously proposed. These mechanism such as [3], [4], [5] use fibers or bristles at an angle relative to the climbing motion to produce anisotropic friction properties with the environment and to direct the mechanism. Since friction is low in a one direction, energy transferred into the system will transform into motion in the direction of lowest friction. Power to these mechanism is either generated using an external power source (e.g., [5]) or an internal vibrating mechanism. Unlike these mechanisms, our mechanism does not rely on anisotropic friction mechanism such as fibers but in fact uses regular isotropic friction. In our system the asymmetry comes from locating the moving mass above the most distal contact point. Not relying on anisotropic friction enables the operator to change the direction of motion, and to safely withdraw the mechanism when power is shut off.

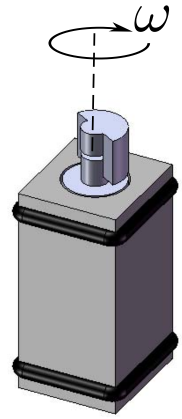

Fig. 1. CAD image of the miniature climbing mechanism

III. MODELING

Our climbing mechanism depicted in Fig. 1 comprises of a body, motor, eccentric mass and two o-rings. The motor rotates the eccentric mass in a constant velocity (ω) which generates an oscillating acceleration and force. The current design uses a square cross section body which, when climbing in a square tube, causes the mechanism not to rotate and helps us correlate these experimental results to previous planar mechanisms. We use o-rings in order to increase friction and to accuratly locate the contact points.

The oscillating force generated by the eccentric mass generates a torque around the contact points (o-rings), which in turn forms a stable periodic motion as can be seen in Fig. 2.

The location of the eccentric mass is crucial to the stability and the direction of climbing. In order for the mechanism to climb upwards the mass should be located distal to the upper o-ring. This will generate a torque around the upper o-ring that will enable upward climbing. On the other hand, if the eccentric mass is located below the bottom o-ring the mechanism will stably climb downward. Locating the eccentric mass in between the o-rings will cause an unstable climbing motion.

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A. Degani, Siyuan Feng, H. Choset and M. Mason are with the Robotics Institute, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA, USA `<adegani,choset,mason>@cs.cmu.edu`

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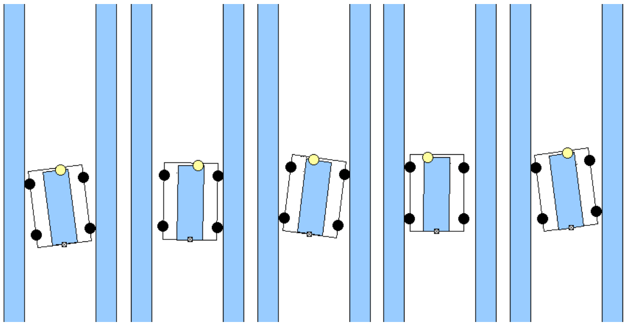


Fig. 2. Gait sequence of tube climbing mechanism from left to right. The oscillating force generated by the eccentric mass generates a torque around the contact points (o-rings), which in turn forms a stable periodic motion.

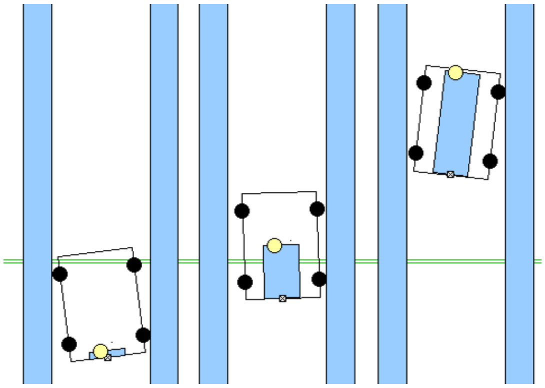


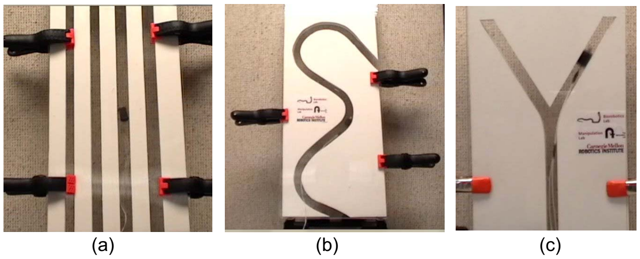
Fig. 3. Simulation of three mechanisms with different location of eccentric mass. a) below the bottom o-ring, b) in between the two o-rings, c) above the top o-ring. Green line shows initial vertical placement of the three mechanisms. When the eccentric mass is located below the bottom o-ring the mechanism will stably climb downward. Locating the eccentric mass in between the o-rings will cause an unstable climbing motion. When the eccentric mass is located above the top o-ring the mechanism will stably climb upwards.

We have simulated and verified these results using WorkingModel2D (Design Simulation Technologies, Inc), planar simulator and the 3-D Open dynamic engine (ODE) simulator. A snapshot from the WorkingModel2D simulator showing the importance of the location of the eccentric mass is depicted in Fig. 3.

IV. EXPERIMENTS

We have tested our mechanism in a few scenarios all climbing vertically upwards. As previously mentioned, when using a round cross section mechanism in a round tube the mechanism naturally rotates due to the angular momentum of the eccentric mass. In order to overcome these rotations in our experiments we have build a square cross section mechanism that climbs inside square tubes. We note that the circular mechanism can climb well even though it rotates, however, in order to correlate the results to previous, planar mechanism, we have chosen to use the square mechanism.

The velocity of the mechanism climbing inside a square tube is approximately $\frac{1}{4}\frac{\mathrm{m}}{\mathrm{sec}}$, which correlates to about 20 body lengths per second. It can carry approximately 20gr which is approximately five times its body weight.



(a) (b) (c)

Fig. 4. Various shaped tubes. a) variable width, b) S shaped tube, c) Y-Junction shaped tube. In all these shaped tubes the mechanism climbed considerably well. In the narrowest tube (leftmost of (a)) the mechanism climbed very slowly since the clearance between the mechanism and the tube was small. In the S-shaped tube the tether slowed down the climbing rate.

To show the mechanism's climbing robustness we have tested it in a variety of shaped tubes, these include: 1. four different widths square tubes with 2mm increments in width, 2. S-shaped tube, 3. Y-shaped junction (see Fig. 4). In all of these different shapes, the mechanism climbed well. In the narrowest tube (leftmost of Fig. 4(a)) the mechanism climbed very slowly since the clearance between the mechanism and the tube was small. In the S-shaped tube the tether slowed down the climbing rate.

V. CONCLUSIONS AND FUTURE WORKS

To conclude, we have shown how a very simple, minimalists, mechanism can be used to propel itself up inside tubes using dynamic motions. We have discussed some important parameters that change the behavior of the climbing robot. The robot can climb robustly and carry a few times its own body weight. In future work we intend to further analyze the mechanism and find the exact ratios which optimize climbing stability and velocity. We will try to build a tetherless mechanism in order to more easily climb inside tight environments.

Finally, although this project was not application driven, we believe that this mechanism might be helpful in a few application, such as search and rescue and the medical field. We intend to show proof-of-concept experiments in these fields.

VI. ACKNOWLEDGMENTS

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