Quadrupedal Robot Mobility on Mountainous Terrain

EXECUTIVE SUMMARY

Legged robots are gaining popularity as it has many advantages over wheeled robots. In general, wheeled robots are faster, cheaper, and easier to design, build, and control. However, legged robots outperform wheeled robots with their mobility, as legs are able to better transverse unanticipated terrain. However, as we move away from continuous to irregular surfaces, the uncertainties in each footfall increases substantially. Hence, the goal for legged robot design is one that can reliably navigate the complex contours of any given environment.

This research explores methods of improving the mobility of robots so that they can better climb steep and uneven surfaces such as that of a rocky mountainside. This project was inspired by the mountain goats' great maneuverability on rugged and elevated grounds. Accordingly, the goal of this study is to identify the underlying principles behind optimal surface grip and compliance for legged robots.

Following secondary research on the anatomy of the mountain goat, it was found that the lower limb plays a major role in its mobility. To test this finding, two main parts of the lower limb, the ankle and hoof, were further examined. The objective was not to exactly mimic the limb anatomy, but to understand and replicate its main mechanical properties.

The mountain goat's hooves allow it to better grip uneven surfaces. Each hoof has two toes that can move independently for flexible placement. Each toe has a soft sole that indents and conforms to irregularities, and a hard edge that cups rock ledges. Meanwhile, the ankle provides stability to the goat by increasing its terrain compliance. The goat's lower limb is remarkably flexible, allowing both linear and angular deflection of the hoof.

The mechanical design of the hoof includes a 3D-printed part with a soft material infill to resemble the sole. The design parameters were the hoof geometry and the sole material. A casting material that provides traction, elasticity, and surface hardness was sought for. On the other hand, in designing the ankle, flexible structures formed by bending thin spring steel rods were investigated. By varying the geometry of the design, different linear and angular stiffnesses along different axes were achieved.

Hoof and ankle prototypes were implemented on a quadrupedal robot developed by Ghost Robotics: the Minitaur. To gauge the performance of these designs, the Minitaur's existing rubber-stub feet was used as the baseline. Several tests were run to evaluate the mechanical properties of the hoof, ankle, and their assembly. Specifically, one of the Minitaur's four legs was used as a platform to determine the effective frictional coefficient of the hoof, which reflects surface grip, and the stiffness of the ankle, which reflects surface compliance. Increasing horizontal forces were applied to the hoof to obtain the effective frictional coefficient between the hoof and various surfaces. Next, increasing vertical forces were applied to the ankle, and the stiffness tensor matrix of each ankle design was determined by analyzing force-displacement relationships. Lastly, the performance of hoof-ankle assemblies was evaluated with both vertical loading tests and horizontal friction tests.

In conclusion, this study has demonstrated that increased surface grip and compliance on a legged robot can be achieved through replicating major mechanical properties of a mountain goat's lower limb. In particular, desired stiffness and friction coefficients can be obtained in an easily adaptable design through testing and iteration. Nevertheless, further work can be done to augment this study. Firstly, testing should be conducted to confirm that the designs are not only able to support the weight of the Minitaur, but also smoothly integrate with the walking gait. Next, the mountain goat can be further studied, particularly other aspects that lead to its mobility such as its body shape and flexibility, or its climbing behaviors. Lastly, the designs can be adapted to suit other situations (e.g., robots and terrains) where different stiffness and friction coefficients are required.

These findings supplement the ongoing research and development of legged robots. The benefits of designing a stable and robust mobile robot extend beyond ascending mountains to traversing desserts, surveying unsafe territory, and exploring other planets.

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