Optimizing grip and speed of robotic goat feet using 3D printed parts

Nathan Flatau
Mentored by Dr. Sean Gart
Science and Mathematics Academy

Introduction

Autonomous robots (AR) need to traverse many complex terrains for tasks like surveillance and search and rescue. Their ability to traverse sloped surfaces and uneven landscape is challenging with current technology. Most AR's use rubber nubs for feet because they are lightweight, durable, and stable. However, the foot shape varies from canines to birds to tridactyls to goats. Research conducted on movement and grip of 6-legged robots, when climbing vertical building surfaces, revealed that gait and body morphology, like foot shape, were most important when improving climbing (Spenko et al., 2008). It is predicted that an AR's speed will improve when the factors of stability, grip, and foot shape are combined. The design of an AR's foot should also factor in cost, surface type, and incline climbing. Other factors to consider include increasing the contact patch of the foot. A contact patch is the portion of the foot that is in actual contact with the surface and is important for reducing slippage. The purpose of this project was to design, test, and optimize the grip and speed of a robotic foot. The foot type chosen was based on a goat's hoof. Designs were 3D printed and prototypes were tested on an inclined vs flat surface and rocky vs smooth terrain. The results were then processed through MATLAB a data analysis software to generate results.

Materials and Methods

Figure 1 shows the rubber nub used as a baseline for most research and development on AR feet. This was used to test against other design prototypes to measure improvement throughout this project. For all testing, the feet prototypes were attached to a mechanical arm that would oscillate the foot up and down while moving forward according to specifications for an autonomous robot. The robot arm sensors used within this project included a speedometer (m/s) and a force meter (N).

Figure 1 (right): Rubber nub model that is being used to test against the multiple different designs throughout this project as this consistently performs well without much error and is very easy to produce while having a low cost which makes it ideal to use for projects like this.

Previous research developed a robotic foot as shown in Figure 2. This design was made of polylactic acid (PLA) plastic and was a modification of an actual goat's hoof with two split toes and a heel to absorb the force of the impacts when running on the different surfaces to limit the damage the design took.

Materials and Methods (continued)

The original foot designs (Figure 2) characteristics of the two split toes inspired other designs. All prototypes were developed using Fusion 360, a computer design software and then were 3D printed.

Figure 2 (left): Original foot design with hollowed out toes and the ankle directly attached to the rest of the model which was found to be very unstable as well as cause breakage with the direct connection with little flexibility in the toes in terms of movement around objects.

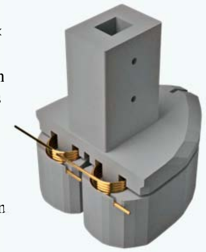


Figure 3 (right): Prototype one featuring a 0.5" × 0.8" × 1.2" connection piece. In which torsion springs were used in combination with a snap fit connection between the ankle and the toes themselves for which the springs would allow the toes to expand while maintaining the home center position after expanding when going over or around an object. This was in combination with the removal of the spring and a decrease in the size of the ankle connection as it proved to be too bulky to work in the design.

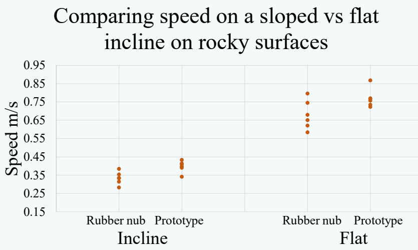
Figure 4 (left): Prototype two. After testing with the spring design and finding out the springs were inconsistent in operation and instead replaced with a dense rubber filling in between the toes and the ankle to allow for flexibility as well as a Thermoplastic Polyurethane (TPU) plastic cover on the bottom of the toes in order to increase the friction between the toes and the ground which should increase the grip the model has with the ground.

Figure 5 (right): Prototype three. This included thick rubber in between the ankle and the toes for grip that was inspired by research into desert locusts grip when jumping (Woodward & Sitti, 2018). This was done to increase flexibility in the movement of the toes as well as increasing the grip the prototype maintains with the ground when running.

Testing included attaching prototypes to a mechanical arm and then simulating running on a smooth surface (wood) and a rocky surface. Each surface was also tested laying flat and on an incline.

Each prototype was observed and tested with the mechanical arm. Prototypes one and two failed, but prototype three were successfully tested. The final prototype (Figure 5) was tested against the rubber nub for six trials each of flat and smooth, incline and smooth, flat and rocky, and incline and rocky terrain.

Results



Graph 1 (right): Graph displays differences in speed between the rubber nub (Figure 1) and prototype three (Figure 5) under various test conditions. The final prototype was faster in both rocky conditions. All tests were run for six trials.

On the flat and smooth surface, the rubber nub ($M = 0.89$, $SD = 0.02$) was faster than the prototype ($M = 0.80$, $SD = 0.02$) by 0.09 m/s. On the inclined smooth surface, the rubber nub ($M = 0.56$, $SD = 0.02$) was also faster then the prototype ($M = 0.30$, $SD = 0.19$) by 0.26 m/s. Along the flat rocky terrain, the rubber nub ($M = 0.68$, $SD = 0.09$) was slower than the prototype ($M = 0.77$, $SD = 0.06$) by 0.09 m/s. On the inclined rocky surface, the rubber nub ($M = 0.33$, $SD = 0.04$) again was slower than the prototype ($M = 0.40$, $SD = 0.03$) by 0.07 m/s. When looking at grip, the rubber nub failed on two of the trials as it slipped when attempting to run up the incline, but the prototype never slipped once.

Conclusion

The final prototype successfully passed each trial in grip. It also outperformed the rubber nub in rocky conditions on surfaces that were flat and on an incline. Also, when looking at grip, the rubber nub slipped twice when traversing the rough terrain whereas the model never did during the trials. This fulfilled the purpose of this project which was to optimize the grip and speed of a robotic foot. Further studies can continue to look at increasing the speed along the smooth surfaces as that is where the prototype lacked behind the rubber nub. Additionally, further prototypes could be created that would investigate improving durability and strength when running.

References

Spenko, M. J., Haynes, G. C., Saunders, J. A., Cutkosky, M. R., Rizzi, A. A., Full, R. J., & Koditschek, D. E. (2008). Biologically inspired climbing with a hexapedal robot. *Journal of Field Robotics*, *25*(4-5), 223–242. https://doi.org/10.1002/rob.20238

Woodward, M. A., & Sitti, M. (2018). Morphological intelligence counters foot slipping in the desert locust and Dynamic Robots. *Proceedings of the National Academy of Sciences*, *115*(36). https://doi.org/10.1073/pnas.1804239115