Simple field method to predict RHex locomotion performance in complex desert environments

NRI/INSPIRE #1514882: Legged Locomotion for Desert Research

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Introduction

Automated data collection could benefit desert research. Desertification is an increasingly severe problem in the southwest United States and around the world. Datasets with many repetitions of experiments close to each other in space and time, especially in response to a weather event, could lead to new scientific models of dune formation and movement [1]. RHex [2] performs well on complex terrain and offers a "plug-and-play" interface for scientists interested in taking data from multiple sensors simultaneously, offering a possible avenue to collecting this new type of dataset.

Figure: RHex at White Sands National Monument [3].

Locomotion on sand dunes is difficult and unpredictable. We tested RHex's locomotion performance in three deserts [4, 3] with dunes up to 29°, thin dune crests, and occasional bushes. While RHex could access every location on a dune when allowed to use an "easy" path up the lower-inclination crest, performance was unpredictable on steep inclinations. For example, we predicted that wider legs would always perform better, but found that while this was true on flat interstitial areas, on sufficiently high slopes they performed worse [4]. Since it is much slower to access the top of a dune via the crest than the steeper slip or windward faces, we are motivated to understand the unpredictable performance to improve locomotion and avoid predictable robot failures.

Experimental physics hints at a method to interpret locomotion performance. Recent robophysics experiments [5] revealed a scale-invariant empirical pattern predicting a dimensionless forward speed from the percent of the leg penetrating the sand. These experiments assumed rigid legs and flat, uniform granular media preparations, and the environments and robots were carefully controlled. However, our application uses compliant legs, a mix of ground inclinations, and no control of factors such as the volume fraction or particle homogeneity of the natural sand.

Extension to more realistic conditions produces a promising field assessment. We verified these results in a far less controlled environment to (1) account for leg compliance by allowing the leg length to vary; (2) predict current draw using only video from one high-speed camera to measure the leg penetration ratio; and (3) predict performance on inclines using leg penetration data from flat runs. **We anticipate that our extension of these results will enable us to predict locomotion performance on complex dune environments in the field in near real time using only a high-speed camera and data directly available to the robot.**

Methods

We simulated a sand dune with a 2.4x1.2m box filled to a depth of 8cm with play sand, which could be lifted at one end to create a desired inclination. Experiments were run on one of the two X-RHex model robots used in [3] and [4]. We varied two aspects of leg morphology and inclination, leading to eight conditions: wide or narrow legs, stiff or compliant legs, and 0° or 15°. In [5], a **dimensionless average forward speed** $\tilde{v}_x$ was predicted from the **leg penetration ratio** $\tilde{d}$, or the percent of the effective leg length penetrated into the sand. With the rigid legs in [5], the effective leg length is the length of the leg. We calculated the effective leg length for our compliant legs from the height of the robot when standing and supporting its own weight. Effective leg length therefore varied with leg compliance. In [5], the leg penetration ratio was calculated using a model of the granular media and robot leg. We used still images from high-speed video taken from the side as the robot ran across a level sandbox. Finally, we calculated both $\tilde{v}_x$ using time to travel the length of the sandbox and an alternative statistic **current draw** A in average amps per footstep, which is readily available on-board to the robot. In [5], $\tilde{d}$ predicted $\tilde{v}_x$ (intuitively, leg penetration predicted leg lengths traveled per second). **We verified the result in [5] in our system by predicting $\tilde{v}_x$ from our extended $\tilde{d}$, and demonstrated that A could be used as a proxy for $\tilde{v}_x$.**

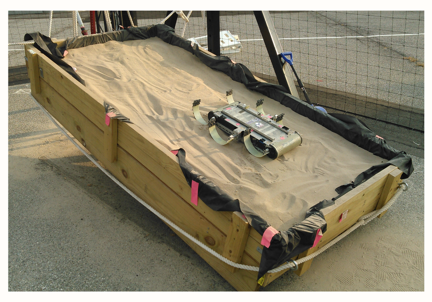

Figure: RHex in tilting outdoor sandbox.

Results

Since effective leg length varied with compliance, we only compare results from legs of the same compliance. In almost every case, for a given compliance condition, the legs with lower penetration ratio performed better. The exception was for stiff legs on level sand, but the difference in $\tilde{d}$ between the wide and thin legs was only 0.02 (as opposed to 0.09 for the compliant condition). In all cases, the same qualitative results between $\tilde{v}_x$ and A held, indicating that A could serve as a proxy for $\tilde{v}_x$. Below, $\tilde{d}$, $\tilde{v}_x$ and A are presented for RHex in the sandbox at 0 and 15°, with a commanded speed of 0.6m/s.

Table: RHex in sandbox at 0° inclination

Condition	$\tilde{d}$	$\tilde{v}_x$	A
Stiff, wide	0.26	0.42	170.37
Stiff, thin	0.28	1.50	123.70
Compliant, wide	0.22	1.03	122.24
Compliant, thin	0.31	0.42	239.53

Table: RHex in sandbox at 15° inclination

Condition	$\tilde{d}$	$\tilde{v}_x$	A
Stiff, wide	0.26	1.20	87.22
Stiff, thin	0.28	0.40	325.82
Compliant, wide	0.22	0.91	160.88
Compliant, thin	0.31	0.39	331.13

Happily, differences in leg penetration ratio appear to be exaggerated in their influence on performance on slopes, indicating that $\tilde{d}$ may be useful for predicting locomotion performance on slopes. Below, the results from RHex's average current draw per footstep are presented at 0 and 15° of inclination. The vertical bars are the standard error of the mean. Notice that compliance produced a larger difference in leg penetration ratio from leg width.

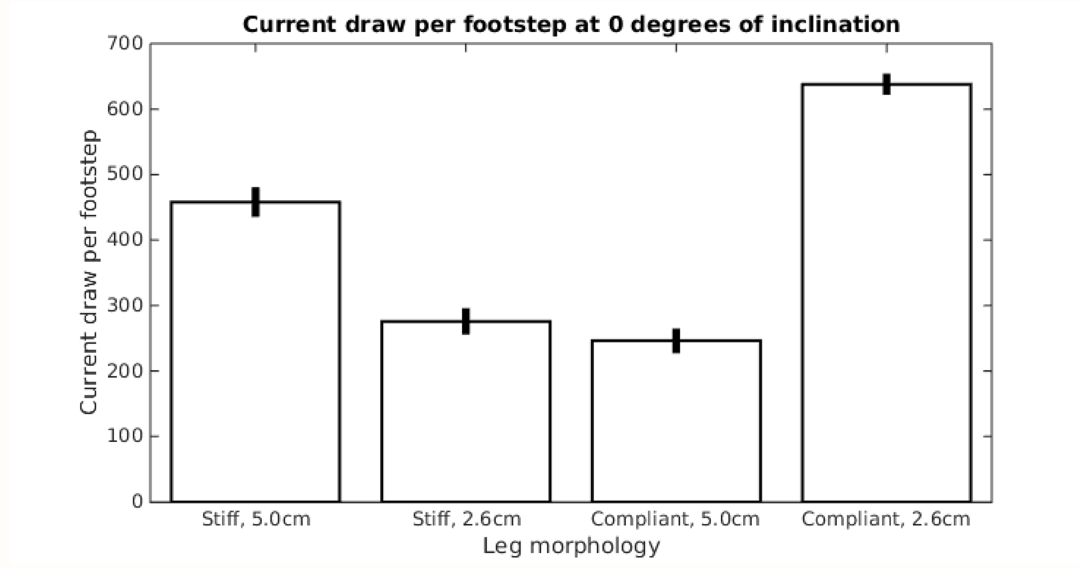

Figure: RHex in sandbox at 0°.

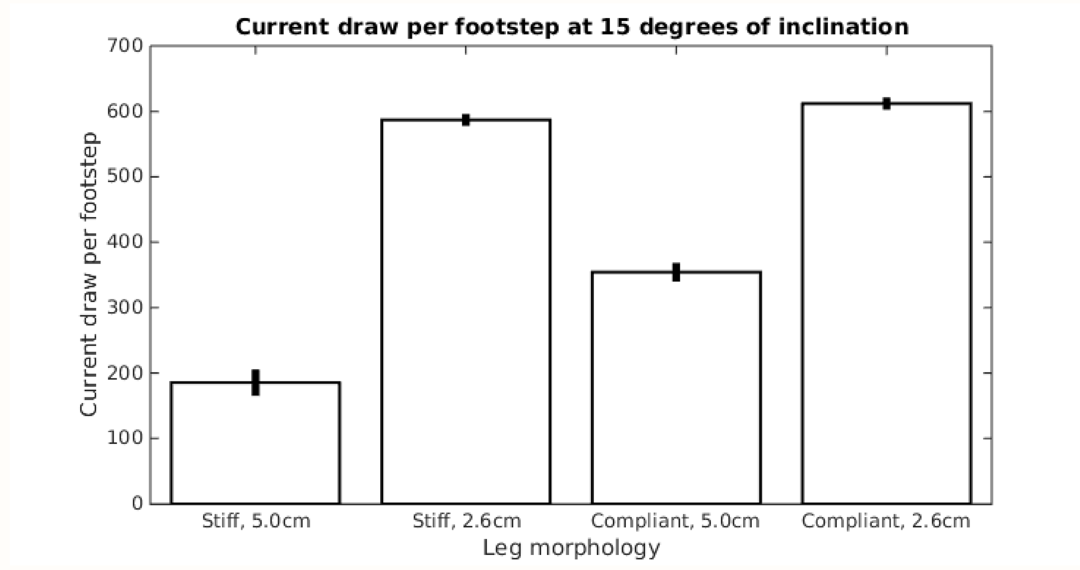

Figure: RHex in sandbox at 15°.

Conclusions

Dimensionless average forward speed can be predicted from the dimensionless leg penetration ratio on flat sand with rigid legs [5]. We extended this result to account for leg compliance and examined the predictive power of leg penetration ratio for speed on inclined ground and amps drawn per footstep. **We anticipate that RHex's locomotion performance on natural sand dunes may be predicted from its performance in flat areas with similar sand, enabling us to predict in near real time whether different morphologies, behaviors, or combinations thereof will improve performance.**

References

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