Frequency of Cyclic Water Pumping as a Drag Reduction Mechanism for Robot Locomotion in Submerged Granular Media

Jenna Atencio*, Caitlin Le*, Shivam Chopra, Prof. Nicholas Gravish

Department of Mechanical and Aerospace Engineering
University of California, San Diego

Goal

To investigate cyclic water pumping as a drag reduction mechanism using robo physical experiments that imitate the burrowing sand octopus.

Introduction

- **Granular media** (e.g. sand)
  - Composed of solid macroscopic particles
  - Challenges: varying **packing fraction** and increasing force required to dig with increasing depth

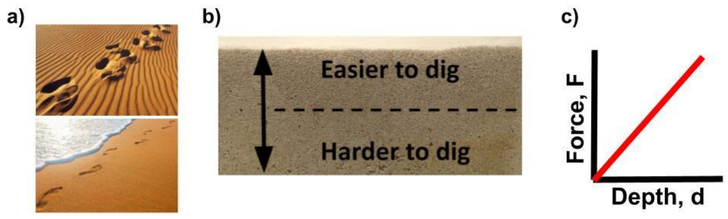

Figure 1: a) Footsteps on loosely packed sand (top) and densely packed sand (bottom), b) Depth dependent packing of sand, c) Linear relationship between depth and force required to dig

- Inspiration: **The sand octopus**
  - Naturally burrows in sand using **granular fluidization**
    - Water is forcefully sprayed into the sand below the octopus, loosening the sediment, making it easier to burrow

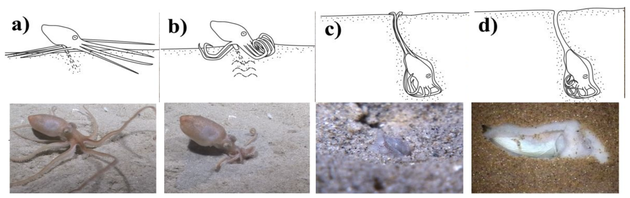

Figure 2: Sand octopus using granular fluidization to burrow[1]

- **Implementation** of the sand octopus burrowing technique:
  - Test different jetting frequencies to establish the relationship between frequency and depth achieved

- Potential **Applications**: Biological and environmental studies, anchoring, underground exploration, etc.

Method

We tested the vertical displacement of a nozzle for different frequencies of cyclic water pumping to fluidize the sand.

- Is there an optimal frequency for cyclic pumping that results in the largest displacement?

EXPERIMENTAL SETUP

- The nozzle undergoes a constant force from the weight of the supporting frame, and can only travel in the vertical direction.
- The water pump is repeatedly turned on and off to create cyclic water pumping, controlled by the microcontroller.
- The frequency of this cycle is changed and the displacement achieved by the nozzle is measured.

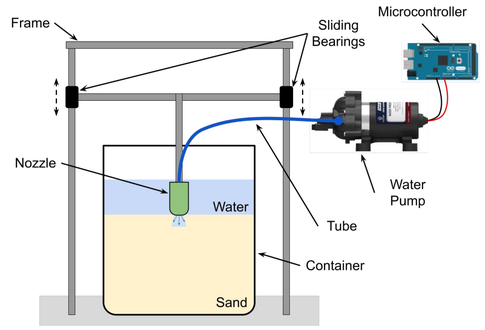

Figure 3: Experimental setup

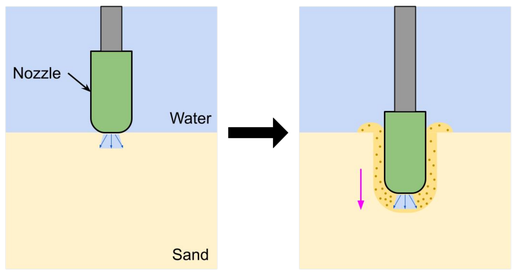

Figure 4: Fluidization of nozzle

QR Code 1: Video of fluidization demonstration

QR Code 2: Video of 10 hz cyclic pumping trial

Results

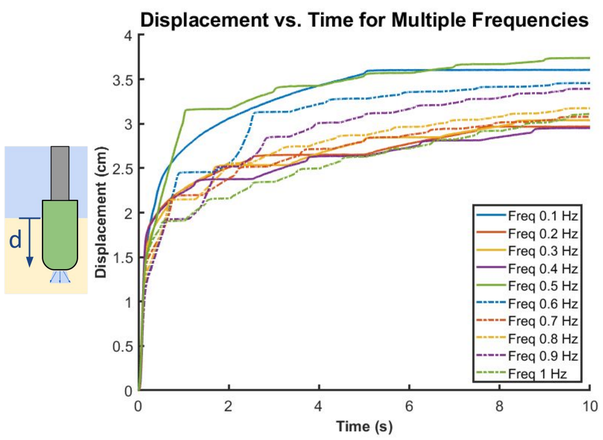

Figure 5: Plot of displacement of nozzle vs. time of multiple frequencies

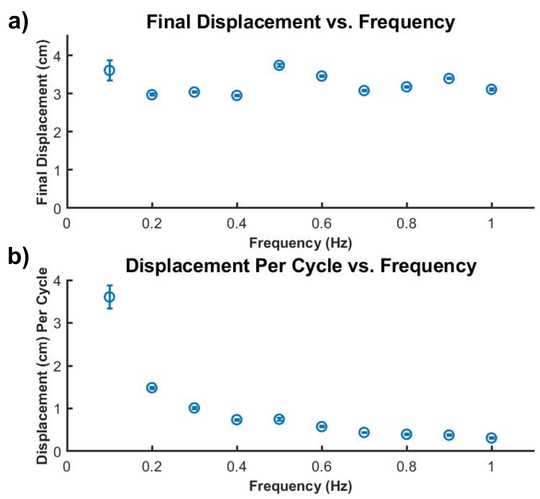

Figure 6: a) Plot of final displacement of nozzle vs. multiple frequencies, b) Plot of average displacement per cycle vs. multiple frequencies

Discussion

- **Frequency of cyclic pumping does not affect final displacement.**
  - It may be possible that at even higher frequencies than the ones tested, a lower final displacement may be observed, due to a decrease in pump output and thus a lesser flow rate.

- **Lower frequencies resulted in a greater average displacement per pulse.**
  - This is helpful for robots that are limited in the number of cycles they can perform.

- Overall, fluidization is helpful in moving into granular media, but the frequency of cyclic pumping does not have an effect on the final displacement, unless the frequency disturbs the pump's flow rate.

Conclusion

- Granular digging can be challenging, but our test of 10 various pumping cycles in submerged media resulted in a **significant reduction** in the force required to dig.

- Pumping frequency had **no effect** on the final penetration depth.

Future Work

- Our next step is to implement a cyclic water pumping mechanism on a burrowing robot.

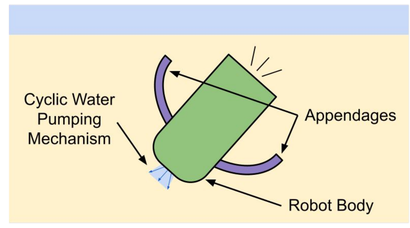

Figure 7: Burrowing robot with cyclic water pumping mechanism and appendages

Acknowledgements

Thank you to our mentors from the Gravish Lab: Shivam Chopra, Mentor. Prof. Gravish, Mentor. Prof. Tolley, Mentor.

Thank you to our GEAR program mentors: Ved Vakhari, GEAR Mentor. Lisa Trahan, GEAR Lead. Alejandra Arguelles, GEAR Lead.

Thank you to our funding source, ONR grant number N00014-20-S-B001.

References

[1] Montana, Jasper, Julian K. Finn, and Mark D. Norman. "Liquid sand burrowing and mucus utilisation as novel adaptations to a structurally-simple environment in Octopus kaurna Stranks, 1990." Behaviour 152.14 (2015): 1871-1881.

QR Code 1: Video of fluidization demonstration

QR Code 2: Video of 10 hz cyclic pumping trial