MAARCO—Multi-terrain Amphibious ARCtic explOrer

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Motivation

- Autonomous rovers have been used for exploring remote and inaccessible regions
- *Nomad* rover for data collection and survey of regions in Antarctica
- *Curiosity* and Perseverance in "search of life" missions on Mars
- Technological Gap 1: **Rovers are limited to flat and mostly uniform terrain**
- Technological Gap 2: **Rovers do not have amphibious capabilities**

Exploring the Arctic

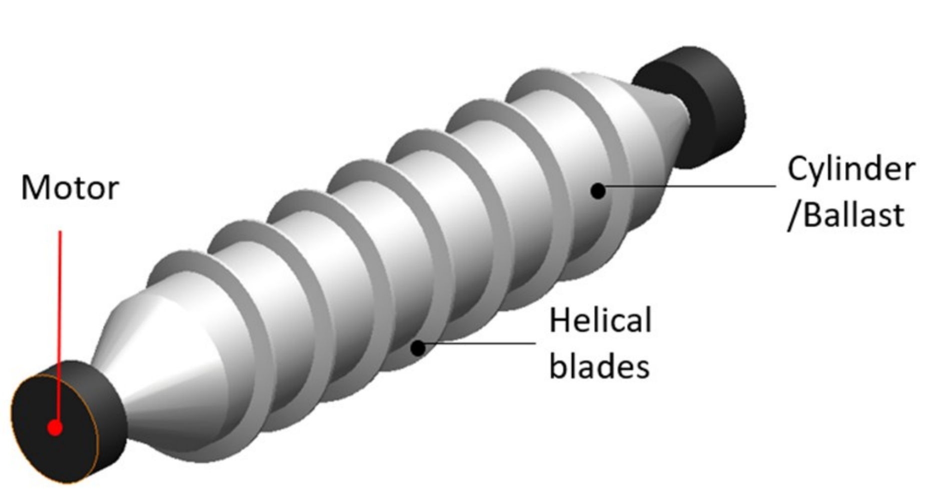
- The rapidly changing Arctic climate presents unique and heterogeneous combinations of terrains
- Snow, melting ice, partially-frozen lakes, wet/firm permafrost, sea ice, open ocean
- Rovers need to have multi-terrain and amphibious locomotion capabilities

Helical Drives

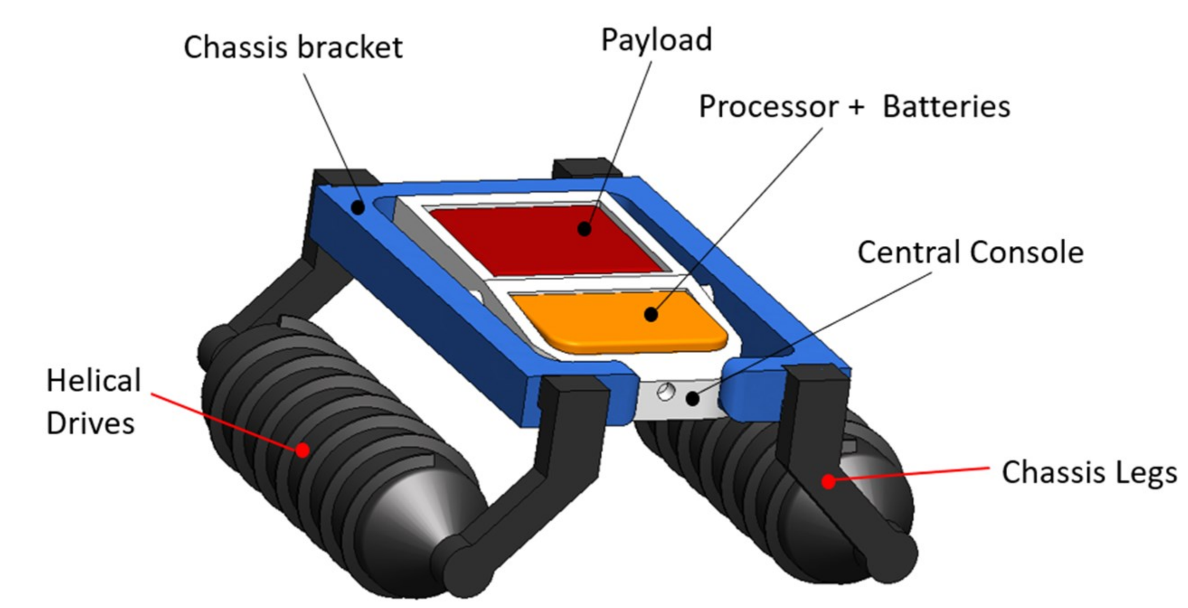
- Consist of screw-like rotating cylinders with helical blades
- A mechanically simple propulsion system that provides multi-terrain and amphibious locomotion capabilities

"All in One" propulsion Mechanism

- **In soft media**: Helical blades push surface medium backward to produce propulsion
- **On water**: Hollow central cylinders offer buoyancy and rotating blades produce propulsion
- **Under water**: Central cylinders are flooded with water and rotating blades produce propulsion

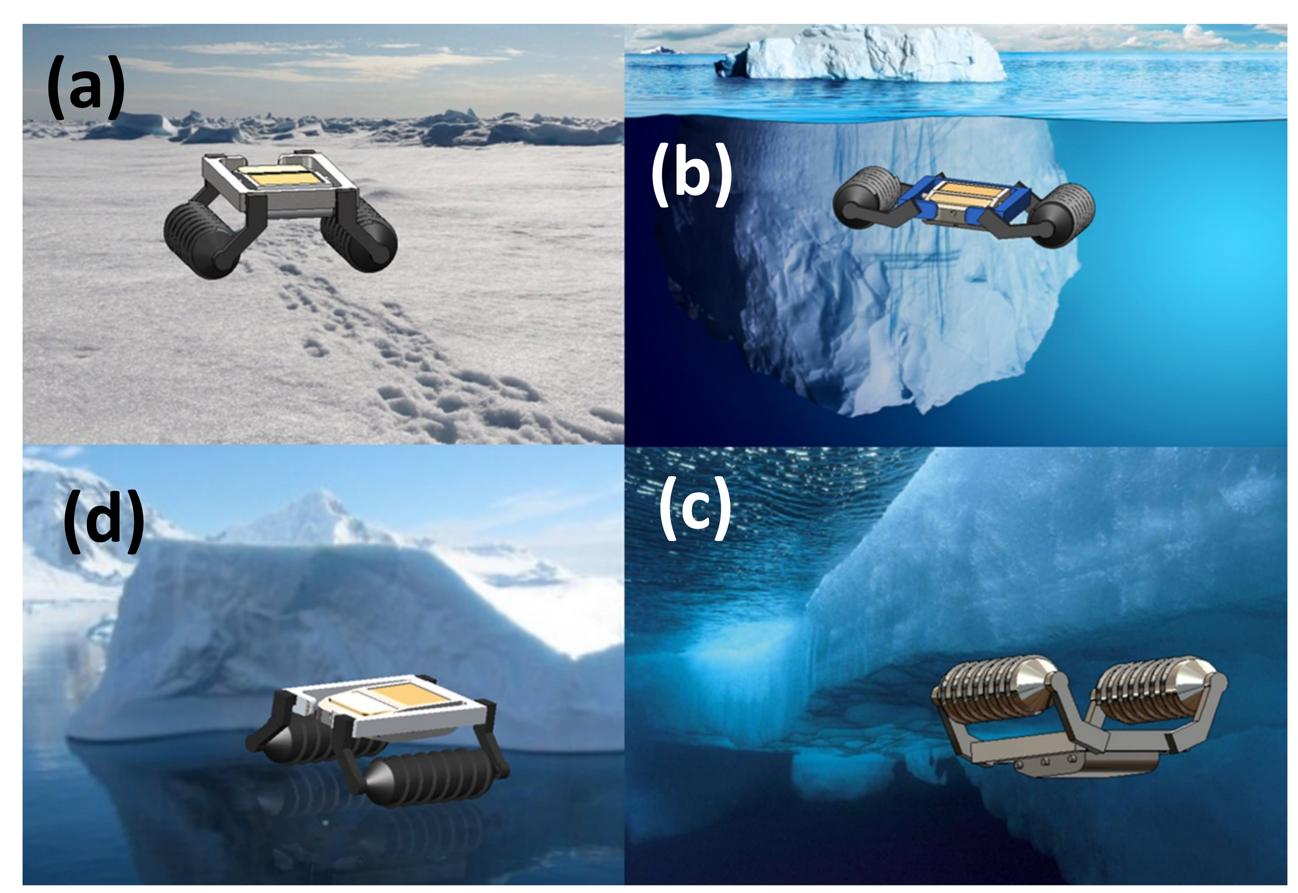


Proposed Rover



- The central console carries the payload, control and communication electronics, and energy storage components
- The helical drives can be empty, partially– or fully-flooded
- The small number of moving components and the simple design makes the rover easy to build and requires limited maintenance compared to more complicated systems like tracks—perfect for long range autonomous missions

Rover Configurations



(a) Roving (b) Swimming (c) Under-ice crawling (d) Boating

Terrestrial Locomotion Dynamics

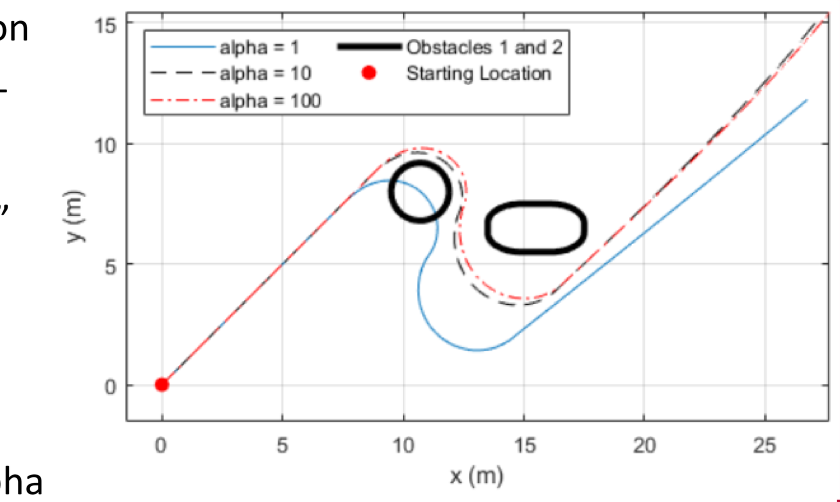
- The roving motion of helical drives on soft and/or fluid medium is characterized by both nonholonomic and holonomic constraint dynamics
- A pair of helical drives rotating in opposite directions generates propulsion through constraint motion between the helical blades and surface medium
- A low-fidelity dynamic model based has been developed
- The model accounts for both 'slip' (holonomic) and 'no-slip' (nonholonomic) constraint dynamics
- The model uses torque acting on each helical drive as inputs to control angular speed of the helical drives

'Slip' vs 'No-slip'

- The model uses Baumgarte's stabilization method to characterize the slipping motion of helical drives on soft media
- The method decreases "constraint drift" via the equations:

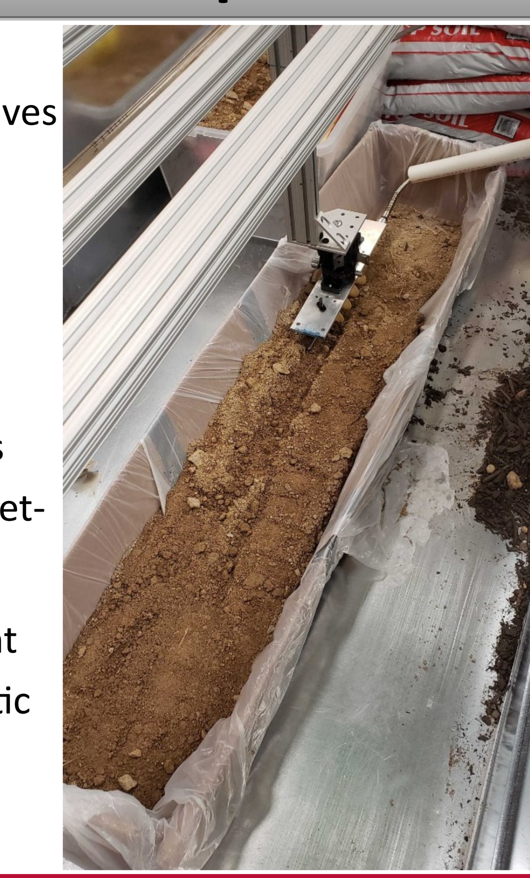
$$\dot{\varphi} + \alpha\varphi = 0$$

where nonholonomic constraints are imposed by the drive on the ground and alpha is the feedback control parameter for the position constraint violations.



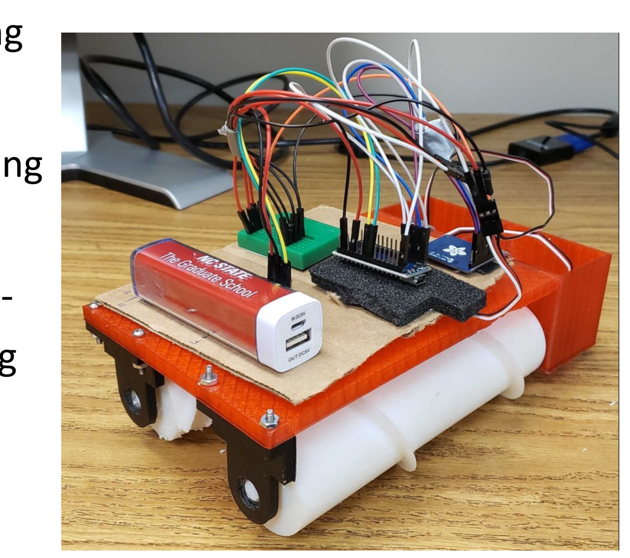
Lab-Scale Experimental Setup

- An experimental rig is being developed to validate the terrestrial locomotion dynamic model of the helical drives
- A singular helical drive is guided to move along the x-direction using a friction-less rail
- The constraining forces acting along the y– and z–direction are measured using a six-degree load cell
- The location and rotational speed of the helical drive is measured using encoders on board the experimental set-up
- Performance of various helical drive designs in different substrates mimicking the ground conditions in the Arctic will be estimated using the experimental setup



Work-In-Progress & Future Work

- 1:5 scale prototype design and fabrication
- Validation of terrestrial locomotion dynamics using lab-scale experiments
- Validation of underwater propulsion dynamics using water tunnel setup
- Development of an optimization framework to derive design, control strategy, and energy budgeting as a function of Artic mission requirements
- Formulation of Arctic survey missions
- Design and Fabrication of a full-scale rover
- Validation of full-scale rover in field conditions



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