IMPERIAL

HAVEN: Haptic And Visual Environment Navigation by a Shape-Changing Mobile Robot with Multimodal Perception

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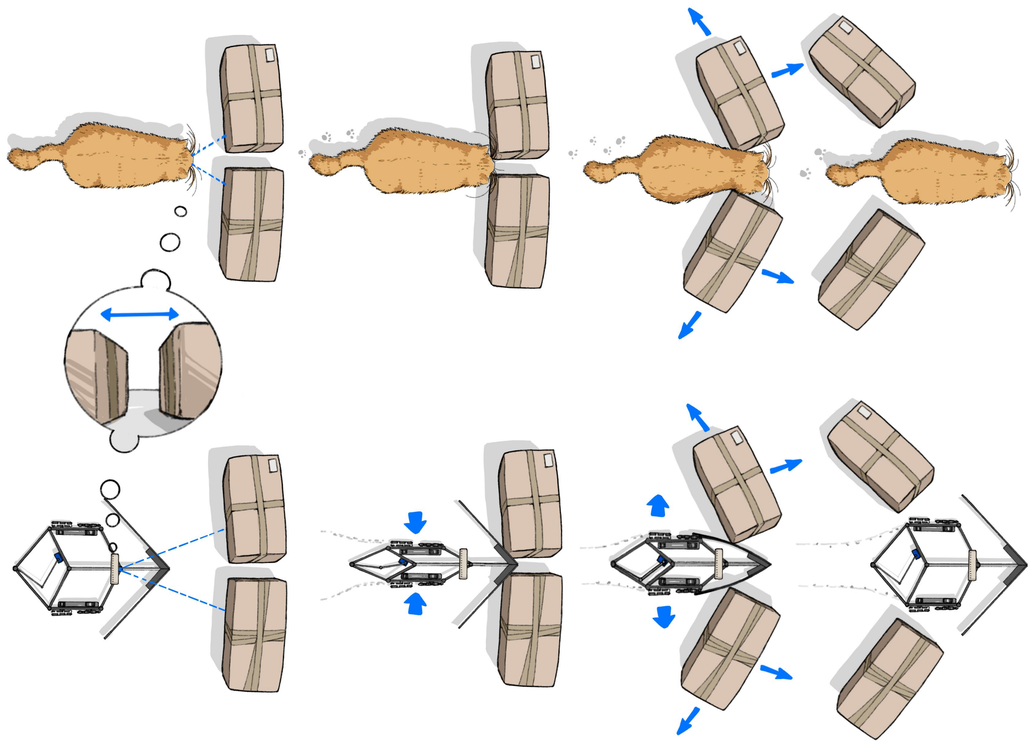
Introduction & Motivation

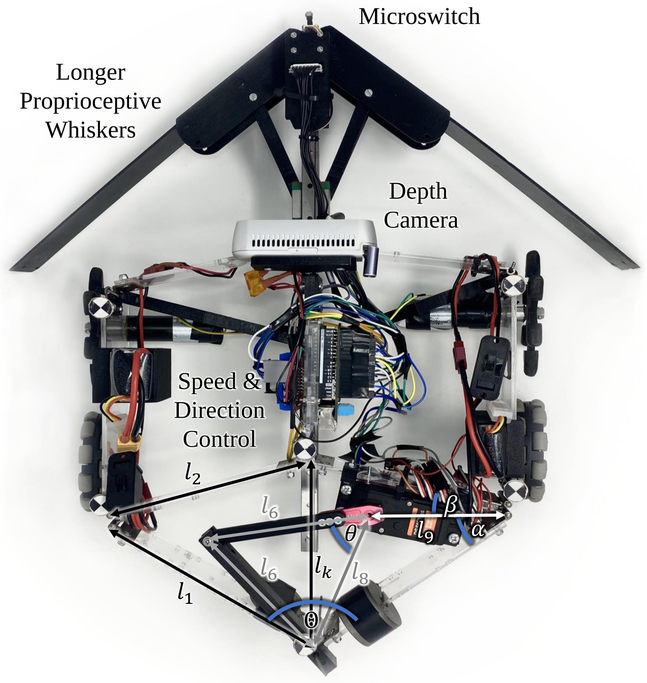
- Bio-inspired motivation: animals (e.g. cats) use multimodal perception (e.g. eyes, whiskers) and body adaptability.
- Problem: Most mobile robots are rigid and avoid obstacles where possible.
- Applications in obstructed environments (e.g. household, space, environmental, etc.).
- Goal: **Predictive, Reactive, and Active** robot navigation using multimodal sensing.



Taking a bio-inspired approach from animals such as cats, we present a robot which uses visual and proprioceptive sensing to be predictive, reactive, and active in its locomotion and interactions.

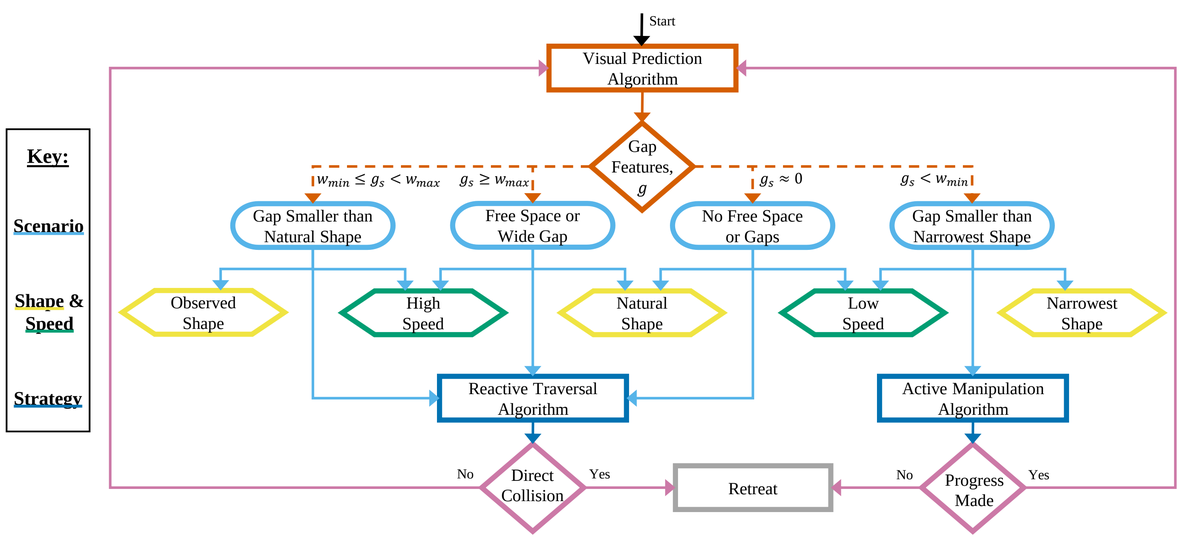
Design & Sensing

- Enhanced DeforMoBot (deformable mobile robot).
- Multimodal visual and proprioceptive sensing (depth camera and whiskers).
- Robot body shape controlled by single servo.



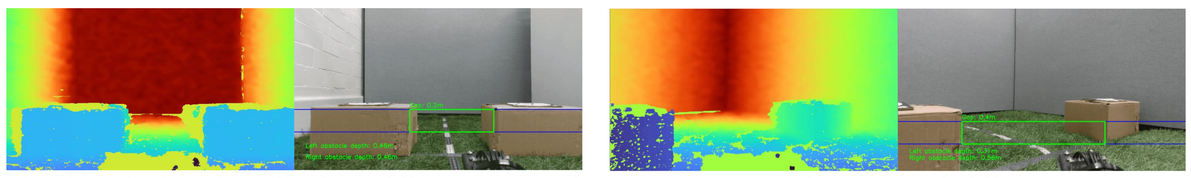
HAVEN Architecture

- HAVEN = Haptic And Visual Environment Navigation.
- Visual Prediction Algorithm identifies Gap Features and Scenario.
- Robot updates Shape, Speed, and Strategy (Reactive Traversal or Active Manipulation) based on scenario and sensor feedback.



Methods & Algorithms

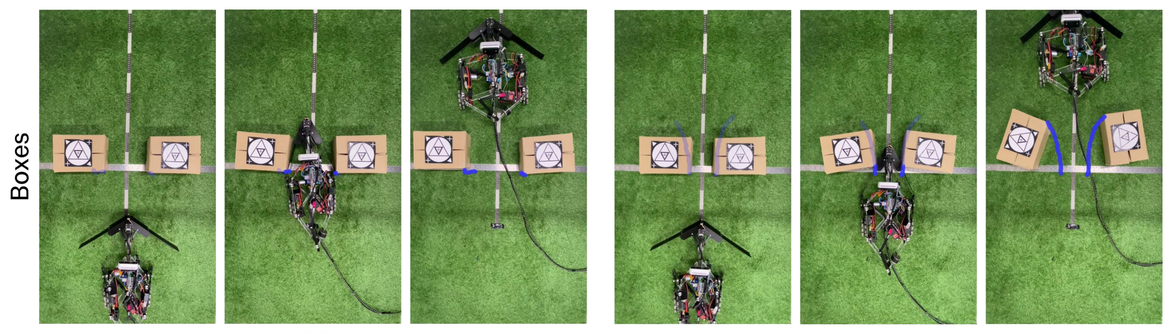
- Visual Prediction Algorithm: detect any obstacles and apertures using depth image analysis.
- Robot prepares body shape for traversal, adjusting servo angle (Φ) based on gap width (g_s).
- Proprioceptive whiskers trigger shape changes during traversal.



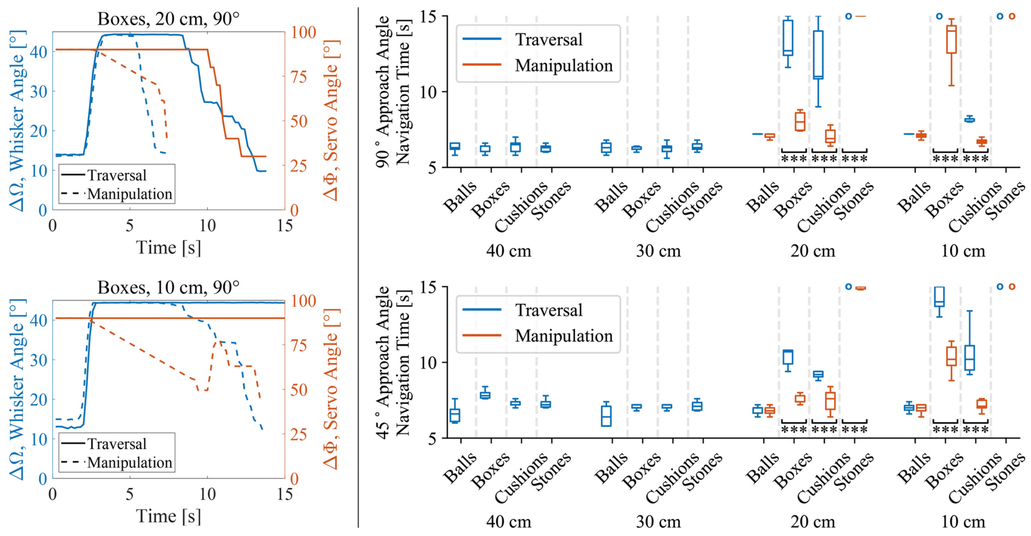
Visual Prediction Algorithm from different approach angles on various obstacles with different apertures. Left: Coloured depth images; Right: corresponding aligned depth-to-colour images with feature info.

Experiments & Results

- 480 trials across obstacles with varying physical properties (Balls, Boxes, Cushions, Stones) and gap widths (10–40 cm).
- Active Manipulation Algorithm had:
  → **Higher success rate** in narrow gaps.
  → **Average 32% faster** navigation time.
- Improvements in outdoor environments (gravel, tarmac, grass).



Robot manipulating and traversing obstacles using its shape-changing body.



Example angle measurements. Box plots comparing summary statistics.

Table: Comparison of Median Navigation Times

Angle	Algorithm	Gap	Balls	Boxes	Cushions	Stones	Gap	Balls	Boxes	Cushions
			20 cm					10 cm		
90°	Traversal		7.2 s	12.7 s	11.0 s	N/A		7.2 s	N/A	8.2 s
	Manipulation		7.0 s	8.0 s	6.9 s	15.0 s		7.1 s	14.0 s	6.7 s
	% Change		2.8 %	37.0 %***	37.3 %***	100.0 %***		1.4 %	100.0 %***	18.3 %***
45°	Traversal		7.0 s	10.7 s	9.2 s	N/A		7.0 s	14.0 s	10.2 s
	Manipulation		6.8 s	7.4 s	7.6 s	15.0 s		7.0 s	10.2 s	7.1 s
	% Change		2.9 %	30.8 %***	17.4 %***	100.0 %***		0.0 %	27.1 %***	30.4 %***

Results of paired two-tailed Mann–Whitney U tests where $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$.

Conclusions & Future Work

- HAVEN enables autonomous multimodal navigation and manipulation.
- Shape change + sensor fusion = enhanced agility and mobility.
- Future: further sensing modalities, machine learning, materials.

Paper & Video