MARVIN: Multimodally Advantaged Robotic Vehicle for Improved Navigation

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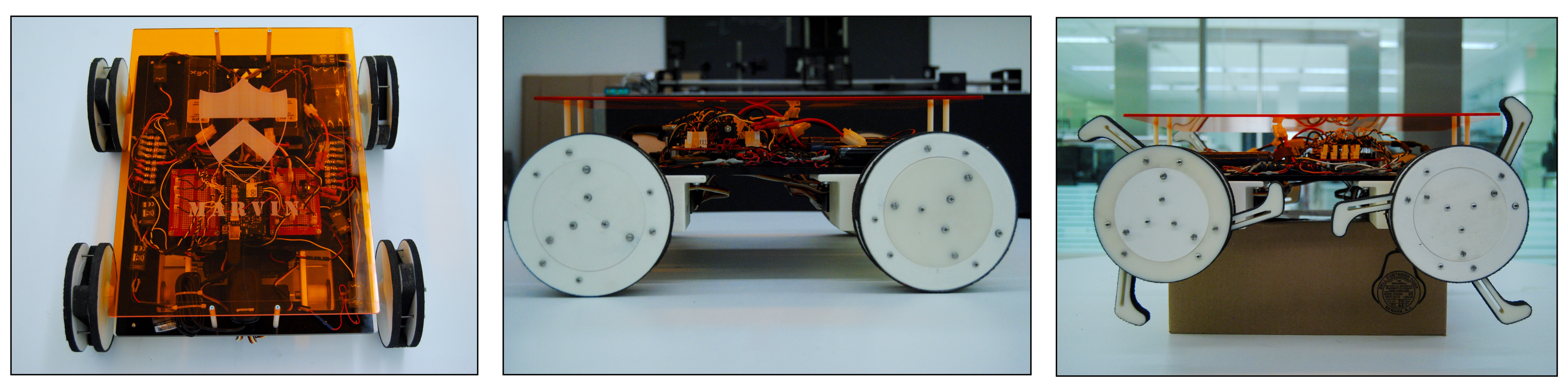
ABSTRACT

Wheel-legged hybrid robots combine the speed, stability, and power efficiency of wheeled robots with the versatility of legged robots. Here, we present MARVIN, a multimodal robot with several distinctive features: quick transition, well-defined wheel and leg modes, and flexible control through continuously variable leg length. Mode-specific cost functions are informed upon by data from real-terrain experiments. A least-cost path-planning algorithm over varied terrain then jointly optimizes over both modes.



MOTIVATION

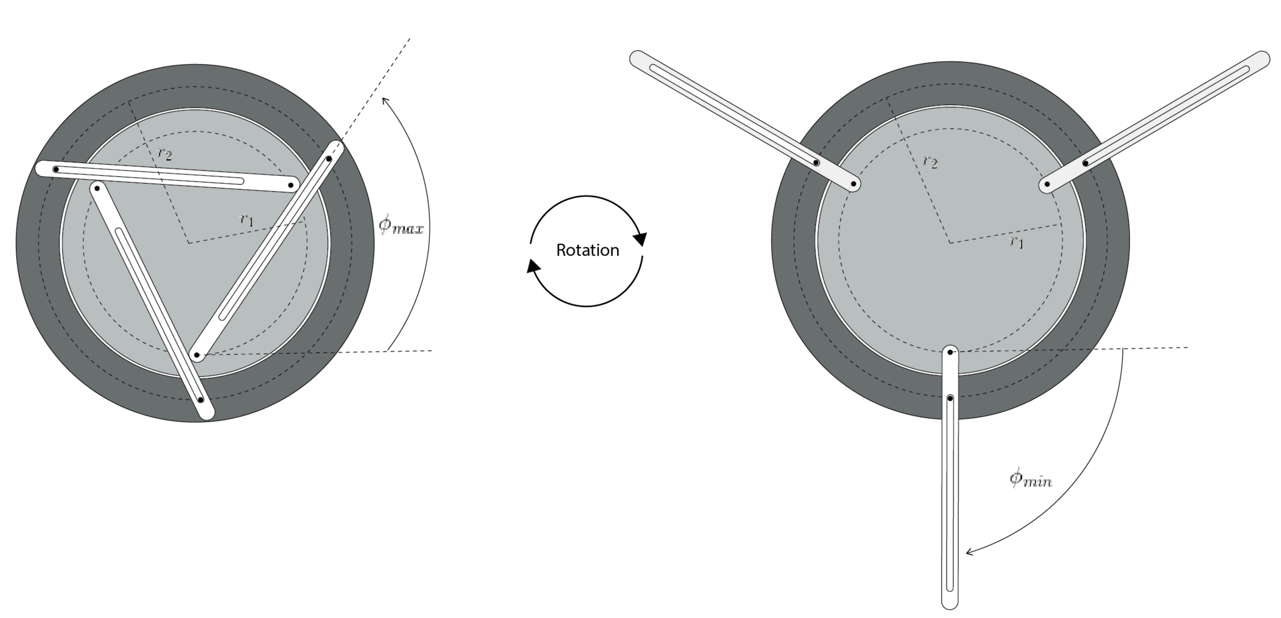
- Increasing demand for high-risk, diverse-terrain missions [1, 2].
- Robot mobility remains a major limitation [3].
- Room for valuable innovation: emerging field of intense research.

INNOVATIONS

- Fast, high-efficiency wheel transformation.
- Continuous transformations for variable terrain roughness.
- Enhanced path-finding routine using empirical cost model.

WHEEL-LEG DESIGN

•Two internal disks with radius r_1 & r_2, connected by N slotted legs.
•Legs retract to be fully contained inside the wheel perimeter.
•Actively adjusting the angular offset of the disks, ϕ, allows extension to be continuously controlled. Simple, with few D.O.F.'s.
•Leg-mode follows the popular Whegs (spoke-leg) design [4].



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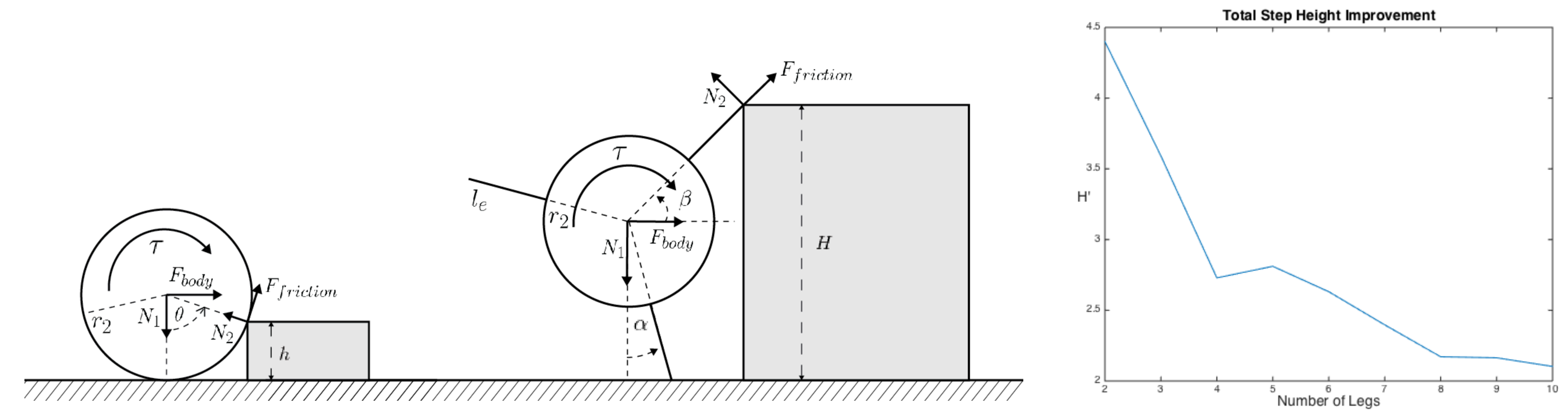
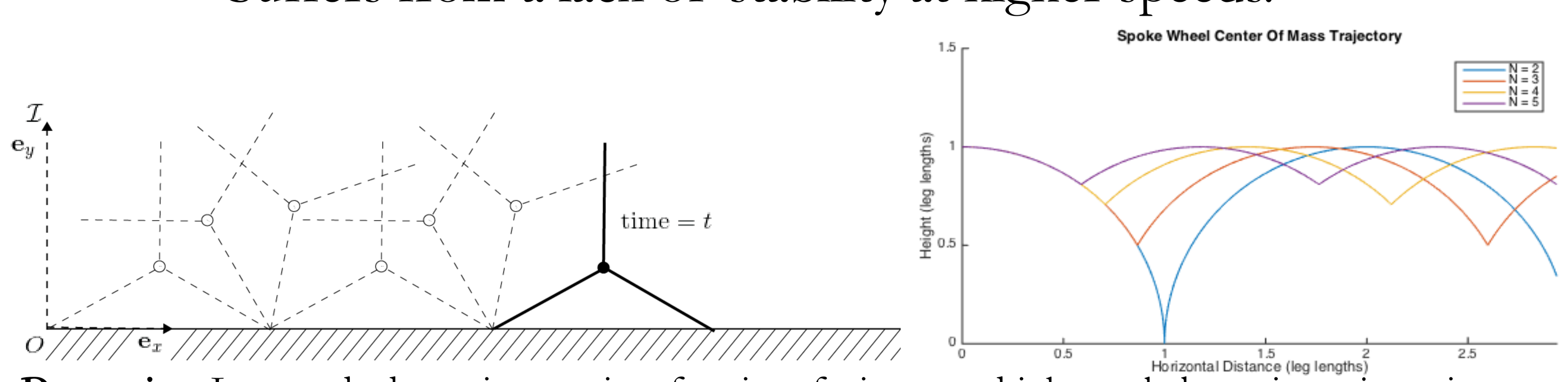
MECHANICAL ANALYSIS

- Most significant advantage due to legs is in step-climbing ability:
  - Increases effective wheel radius and improves geometry.
  - Theoretically climbs heights up to 4 x wheel mode max.
- Performance heavily depends on $r_1 : r_2$ ratio and N.



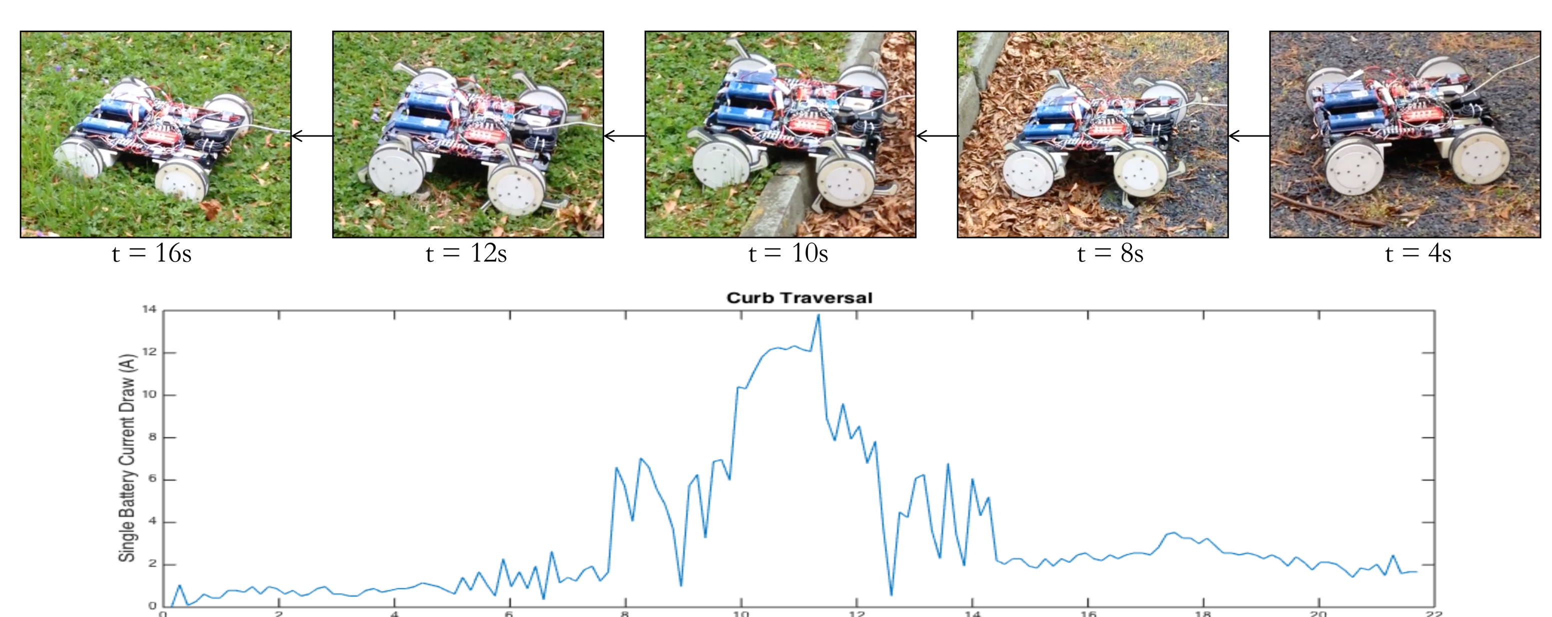
Mechanics: Legs allow robots to reach higher, achieving taller relative heights $H' = H/r_2$. By comparison, wheels typically have $h' = h/r_2 < 1$.

- Leg-mode dynamics are similar to those of a rimless wheel [5].
- Operating this way, however, incurs significant costs:
  - Places larger requirements on motor torques.
  - Robot losses energy from COM oscillations.
  - Suffers from a lack of stability at higher speeds.

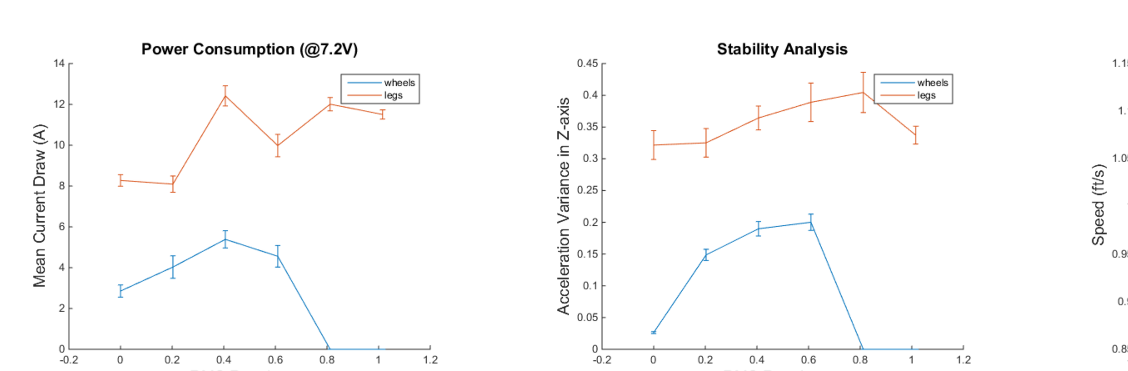


Dynamics: Leg-mode dynamics consist of series of pivots, and inherently bumpier trajectories

EXPERIMENTAL DATA



Natural Terrain: Trial-runs over various terrains show that legs allow MARVIN to successfully traverse difficult environments such as paths with curbs, tall grass, leaf piles, sand, etc. The spike in current draw when using legs to overcome a curb illustrate the cost of this benefit, however.



Artificial Test Field: Experiments in a controlled environment attempt to draw a more concrete relationship between wheel and leg performance with respect to terrain roughness. There was only enough data collected in this study for a coarse analysis of trends (see cost function), but this is a rich area for exploration and improvement.

COST FUNCTION

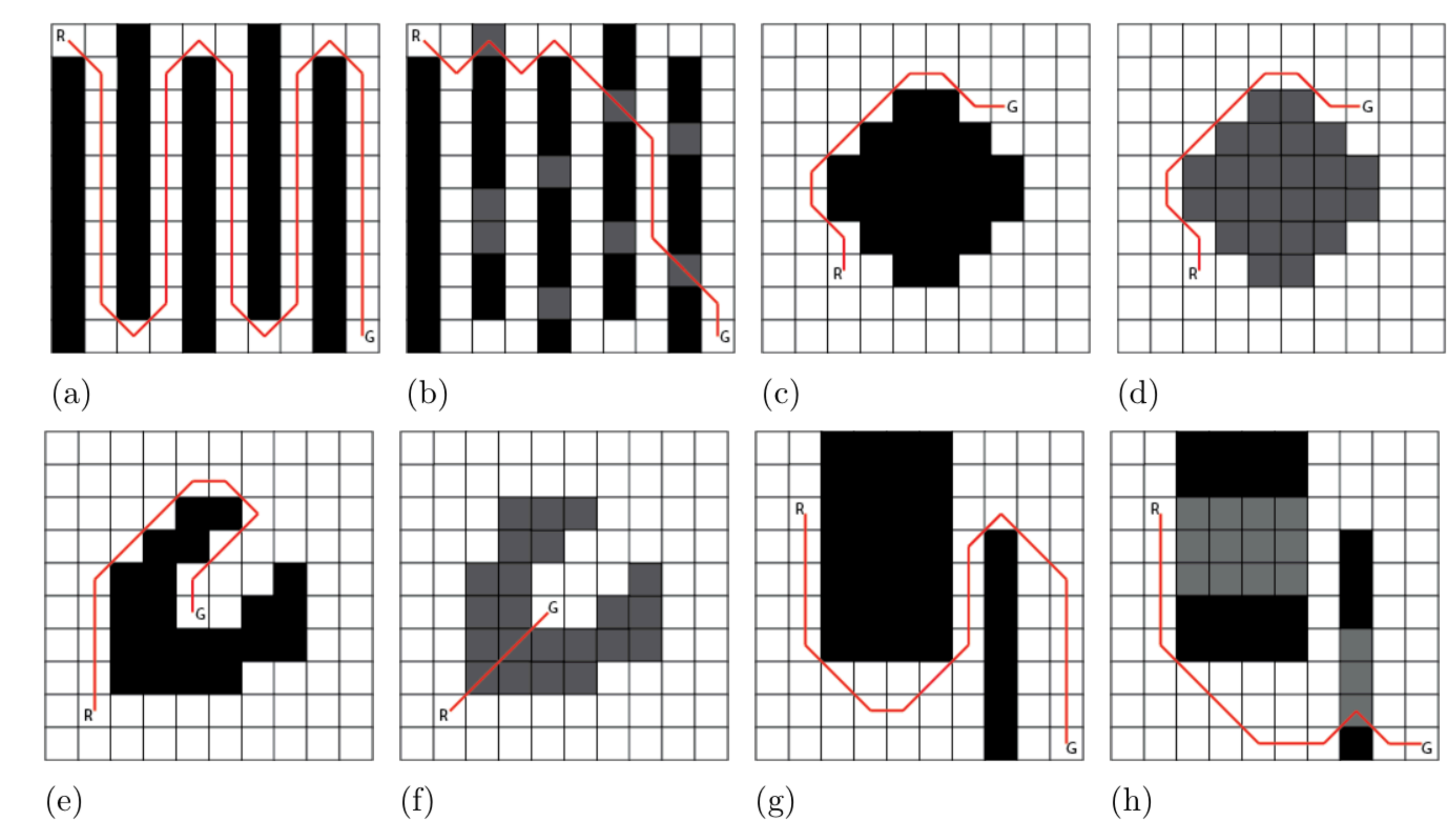
Average ratios between wheels and legs:

- Power → 2.3 : 1
- Stability (accel. variance) → 4.7 : 1
- Speed → 1:1 (at low overall speeds)

Cost function: $G = \mathbf{x}^T\mathbf{P}$, where $\mathbf{x}$ is the empirically determined vector of cost ratios [2.3, 4.7, 1], and $\mathbf{P}$ is a preference-weighted vector, $[p_1, p_2, p_3]$, where $\sum p_i = 1$.

LEAST-COST PATHS

- Path selection space is broadened under hybridization.
- Legs can traverse some areas that are otherwise blocked to wheels.
- Cost functions are empirically calculated.
- Least-cost paths are determined through the A* algorithm.



Hybrid Path Planning: Simulated optimal paths calculated by A* when normal (left) vs. hybrid costs (right) are considered. Normally non-traversable obstacles (black) are transformed to passable but expensive areas (gray). A hybrid planner picks between taking easier but longer vs. shorter but harder paths.

SUMMARY

- MARVIN was designed, built, and successfully tested in 7 months.
- MARVIN demonstrated superior navigation over varied terrain.
- Original elements performed as theoretically derived and designed .
- Derivations, like step climbing improvements, tested experimentally.

INDICATED DIRECTIONS FOR IMPROVEMENT

- Reduced weight and complexity with fewer motors.
- Reduced average actuation loads with ratchets or clutches.
- Improved stability with coordinated gait control.
- Automated path finding equipped with vision capabilities.

REFERENCES: [4] R.D. Quinn, J.T. Offi, D.A. Kingsley, R. E. Ritzmann. Improved mobility through abstracted biological principles. *Intelligent Robots and Systems*, 2002. IEEE/RSJ, pgs 2652–2657 vol.3, 2002. [5] M. J. Coleman, A. Chatterjee, A. Ruina. Motions of a rimless spoked wheel: a simple 3d system with impacts. *Dyanamics and Stability of Systems*. pages 139–160, 1997.