MARVIN: Multimodally Advantaged Robotic Vehicle for Improved Navigation

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\textbf{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.

\textbf{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.

\textbf{INNOVATIONS}

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

\textbf{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, $\phi$, allows extension to be continuously controlled. Simple, with few D.O.F.'s.
- Leg-mode follows the popular Whegs (spoke-leg) design [4].

\textbf{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 $r_1 \cdot r_2$ ratio and $N$. 

\textbf{EXPERIMENTAL DATA}

\textit{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 illustrates the cost of this benefit, however.

\textit{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.

\textbf{COST FUNCTION}

Average ratios between wheels and legs:
- Power $\rightarrow$ 2.3 : 1
- Stability (accel. variance) $\rightarrow$ 4.7 : 1
- Speed $\rightarrow$ 1:1 (at low overall speeds)

\textbf{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.

\textbf{REFERENCES}


2. Enhanced path-finding routine using empirical cost model.

3. Fast, high-efficiency wheel transformation.

4. Continuous transformations for variable terrain roughness.

5. Enhanced path-finding routine using empirical cost model.