Optical Kinematic State Estimation of Planetary Rovers using Downward-Facing Monocular Fisheye Camera

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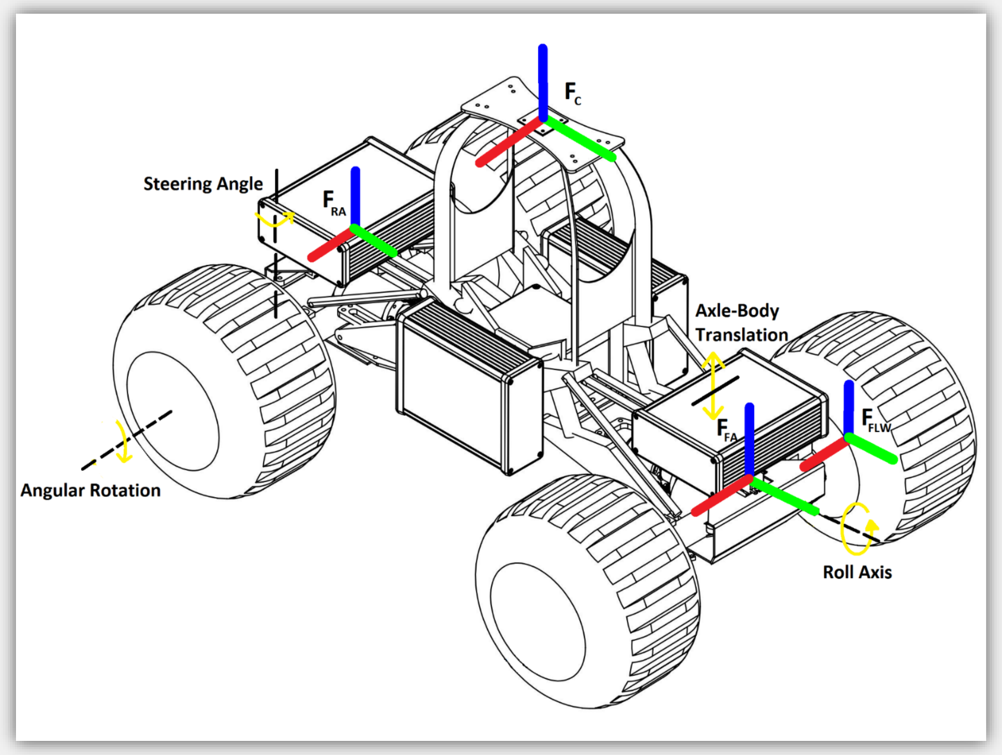
Motivation and Objective

- Kinematic state knowledge is critical to motion control and exploration, especially on rugged planetary surfaces.

- Existing methods employ a large suite of proprioceptive sensors (encoders, IMUs, potentiometers) that- (i) Are prone to mechanical and electronic failures (ii) Require thermal isolation (iii) Have sensor wires prone to bending, flexing and wear (iv) Hinder mass, size and power limitations.
- Vision algorithms were used sparingly in the past, but current technology points to full fledged vision systems in future missions.
- **Objective:** **To develop a vision system that provides kinematic state knowledge, using a single camera.**

Kinematic Model

- The AutoKrawler is a four-wheel, double-ackermann steered rover specialized to traverse adverse terrain.

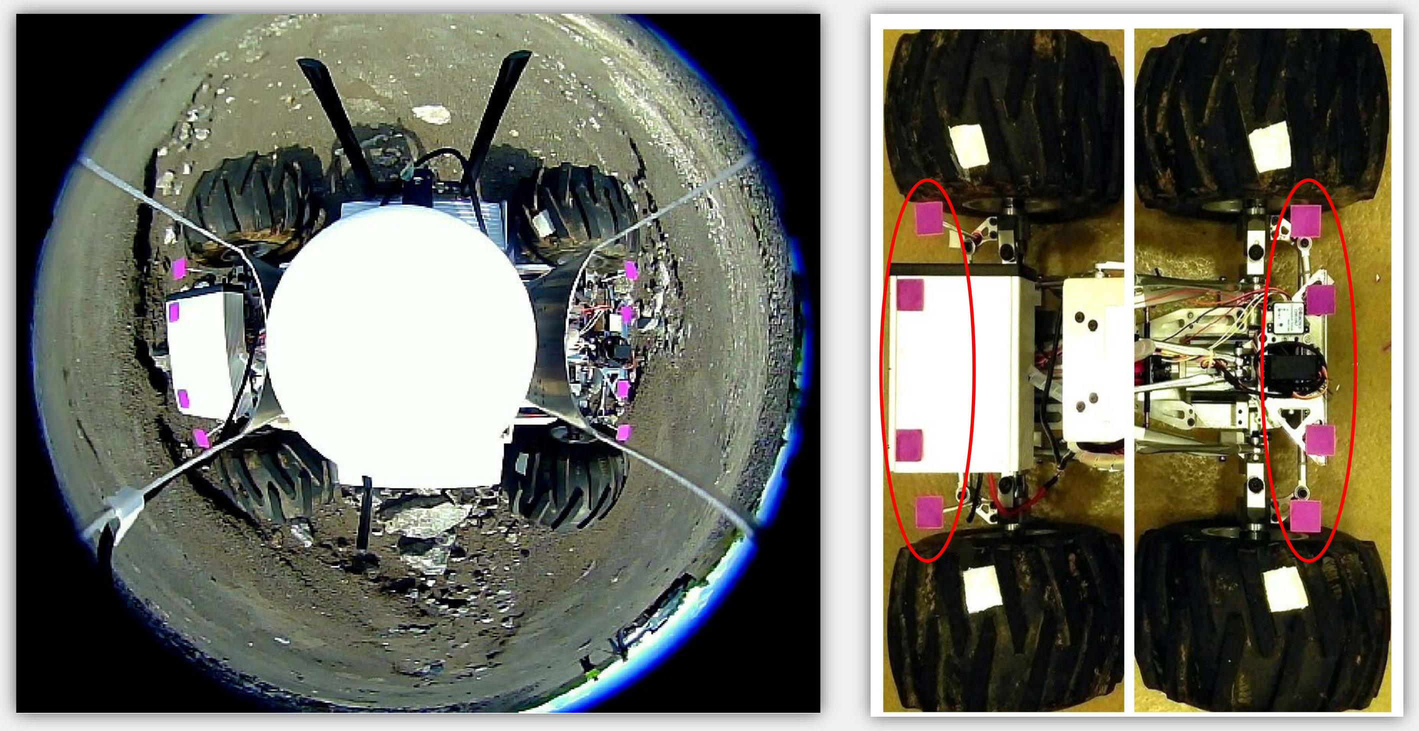


- The degrees-of-freedom estimated are 10 in total:
  - Axle roll and Axle-Body translation - ψ_F, ψ_R and d_F, d_R
  - Two steering - λ_F, λ_R
  - Four angular rotations- θ_{FL}, θ_{FR}, θ_{RL}, θ_{RR}

Approach

Camera Model:

- We choose an omnidirectional **fisheye** camera and design a robust, minimally occluding camera mount.
- Upon calibration, we map 2-D pixel positions to **world 3-D coordinates**, assuming certain kinematic constraints. The estimation algorithms use these coordinates as inputs.



*Camera field-of-view with minimally occluding camera mount **(left)**. Colored fiducial markers and checkpoint markers visible **(right)**.*

Axle Configuration (ψ_F, ψ_R, d_F, d_R):

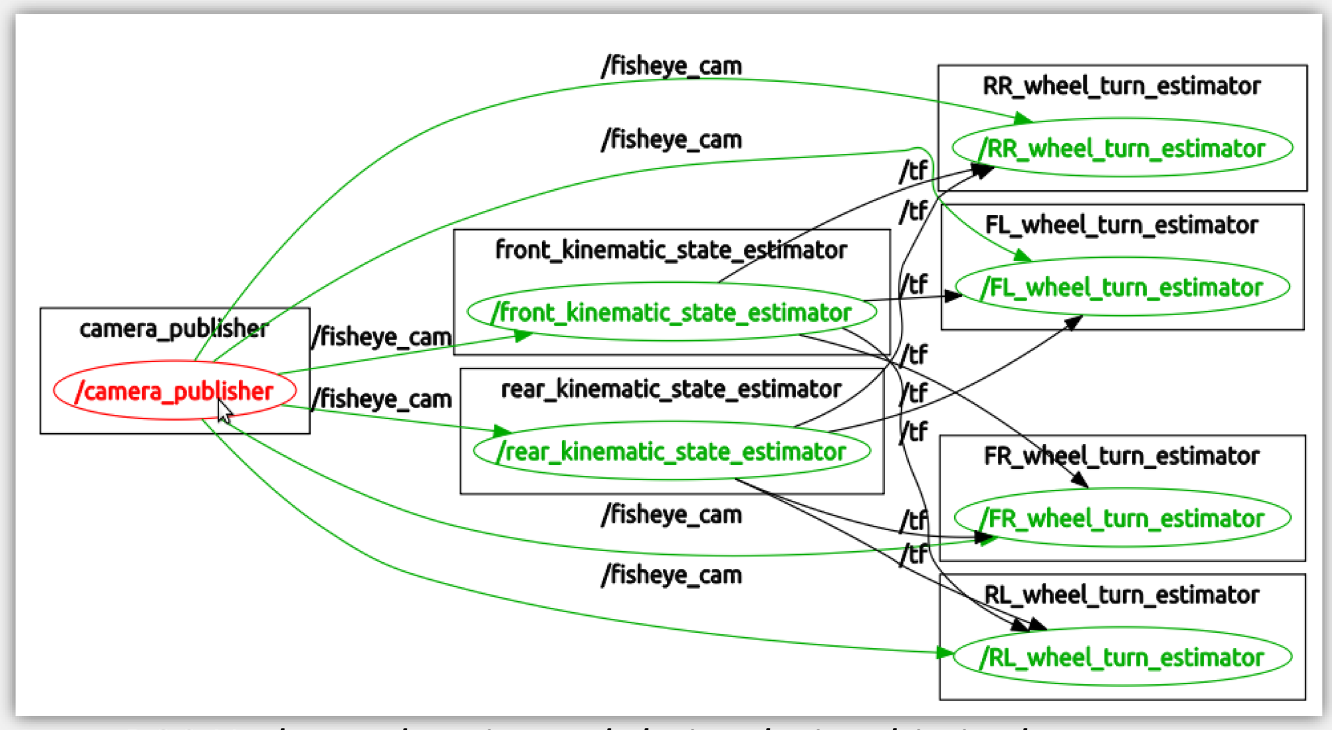
- We track world-coordinates of **fiducial markers** on defined planes of the axles to give roll angle and body-frame distance.

Steering Angle (λ_F, λ_R):

- We fit a 2nd order polynomial to convert world-coordinate marker distances to steering angle.

Wheel Angular Rotations (θ_{FL}, θ_{FR}, θ_{RL}, θ_{RR}):

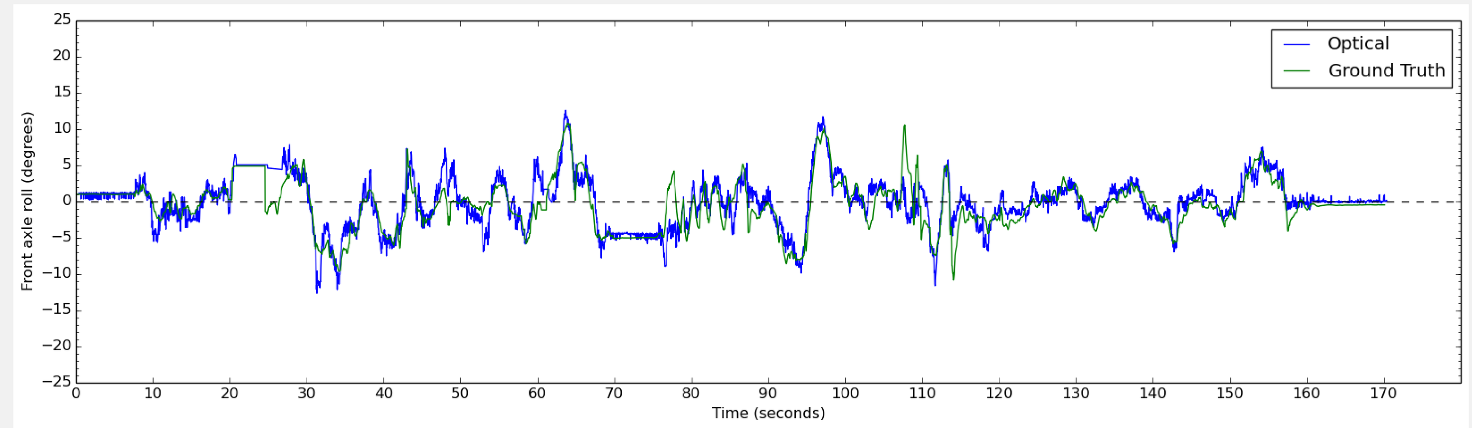
- ***Lucas-Kanade* Optical Flow** is performed on all four wheels, invariant to axle tilt and steering, to obtain angular rotations.
- A checkpoint marker prevents drift in wheel rotation readings.



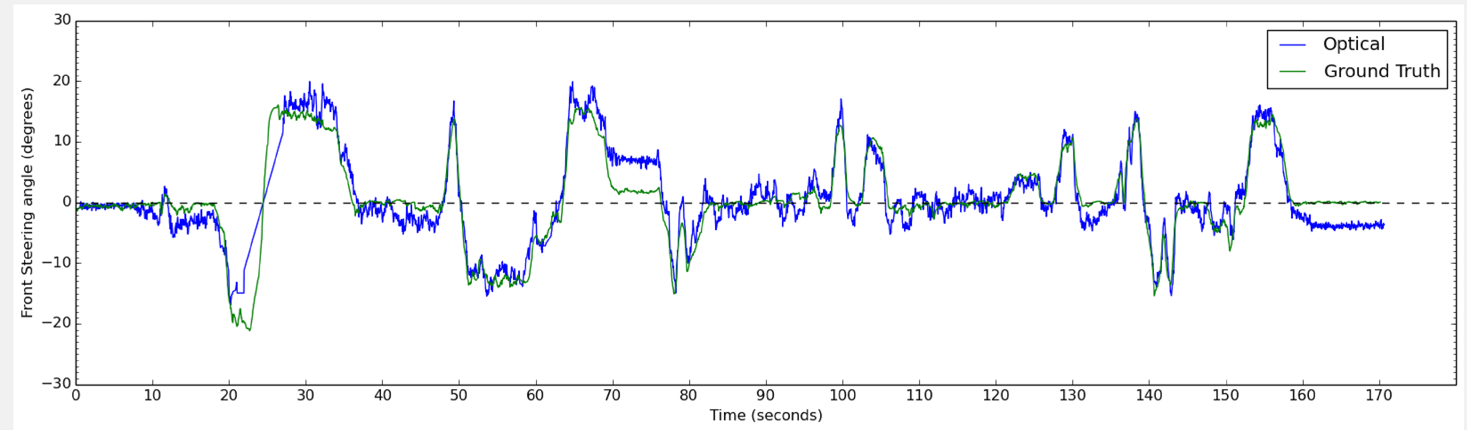
ROS Nodes and topics and their relationship in the system

Results

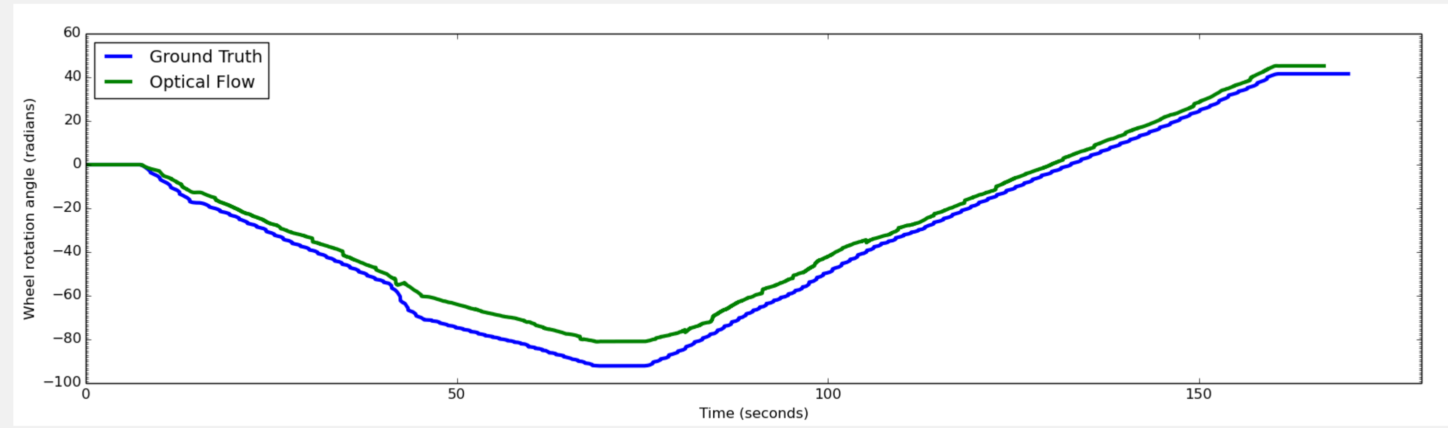
- The system was evaluated on datasets generated from field experiments conducted in a lunar analogue site.
- Ground truth data was obtained from IMUs, potentiometers and motor encoder on-board the rover.



Graph 1: **Front axle roll** computed by optical method compared with IMU ground truth



Graph 2: **Front steering** computed by optical method compared with potentiometer ground truth



Graph 3: **Wheel rotation angle (rear)** computed by optical method compared with motor encoder ground truth

Dataset	Duration (secs)	Axle Roll MAE		Steering Angle MAE	
		Front	Rear	Front	Rear
Dataset 1	82	1.65°	1.51°	2.49°	1.98°
Dataset 2	170	1.41°	1.32°	2.40°	2.49°
Dataset 3	257	2.41°	1.97°	1.86°	2.55°

Table 1: Mean absolute error of obtained data

Conclusion and Future Work

- Results show close agreement between estimated data and ground truth, thus validating the approach.
- Future work includes optimization of algorithm to run on-board the rover and making optical tracking invariant to illumination and shadowing.

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References

[1] D. Scaramuzza, A. Martinelli, and R. Siegwart. "*A flexible technique for accurate omnidirectional camera calibration and structure from motion*" (ICVS'06)

[2] Bruce D Lucas, Takeo Kanade, et al. "*An iterative image registration technique with an application to stereo vision*" (IJCAI , volume 81)