Position Estimation by Registration to Planetary Terrain

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Introduction

- Autonomously localize rover on another planet using its sensor data and satellite image
- Generates local model using LIDAR and camera
- Correlates with satellite imagery
- No elevation data is necessary
- Accurate to 2 m

Advantages

- More efficient use of operators
- Travel out of communication range
- Absolute methods require infrastructure
- Relative methods drift over time

Current methods

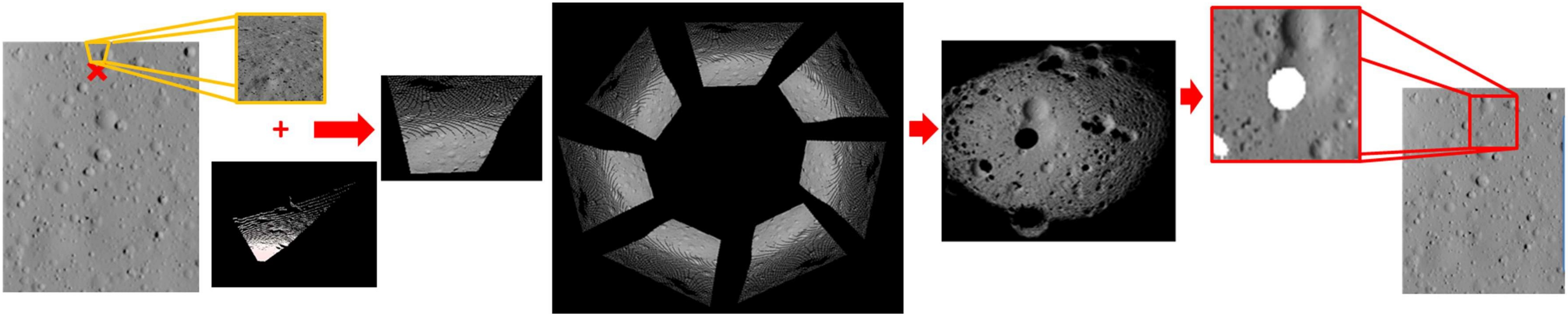
- Terrestrial robots rely on GPS
  - unavailable on other planets
- Non-GPS sensor-based localization
  - Maps are built ahead of time using SLAM
  - Assume route can be driven before map is needed

Current methods

- Planetary rovers used combination of relative localization and human input
- Mars Exploration Rovers
  - Lander localized using Mars Odyssey orbiter
  - Wheel odometry and Inertial Measurement Unit
  - Visual Odometry—high processor time

Overview

- Rover uses camera and LIDAR to capture images of surrounding terrain
- Creates colorized point cloud
- Projected into orthographic overhead view
- Cropped into small template, which is correlated with satellite imagery



Building the Panorama

- Cameras and LIDAR on rotating sensor head
  - Motion of camera and LIDAR is know to high precision
- Rotate rover chassis
  - Motion not know exactly
  - Reconstructed with visual odometry and iterative closest point algorithm
  - 75% overlap required

Generating the template

- LIDAR point cloud projected onto camera image to produce 3D panorama
- Rotated to world-frame orientation using rover attitude
  - Known from stars or sun and accelerometer
- Projected to overhead orthographic image
- Create 2D image with same resolution as map imagery

Estimating Rover Position

- Correlate orthographic template with satellite imagery
- Search area determined by guess of rover position and uncertainty
- Normalized cross correlation between template and map interest region
  - Modified to ignore blank areas in template

Experiments

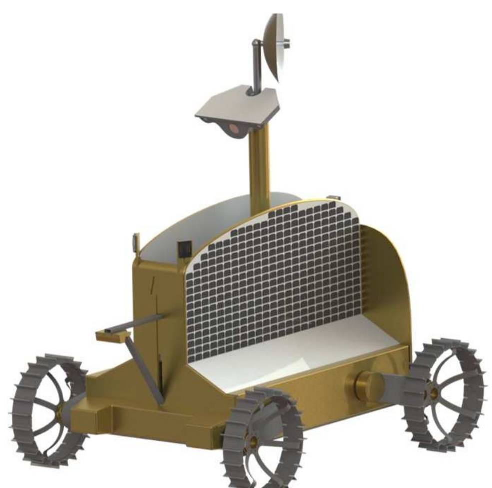
- Generated simulated datasets
- Tested accuracy and robustness under various conditions
  - Search area
  - Rover height
  - Lighting conditions
  - Map resolution
- Long term traverse

Simulation

- Used digital terrain map from Apollo 11 region
- Small rocks and craters added to rover view
- Generated using raytracer
- Generated camera, LIDAR, and satellite images

Experimental setup

- Lunar mission to find volatiles and ice
- Success defined as estimation within 2 m of actual location
- Camera and flash LIDAR on sensor head 1.5 m above the ground

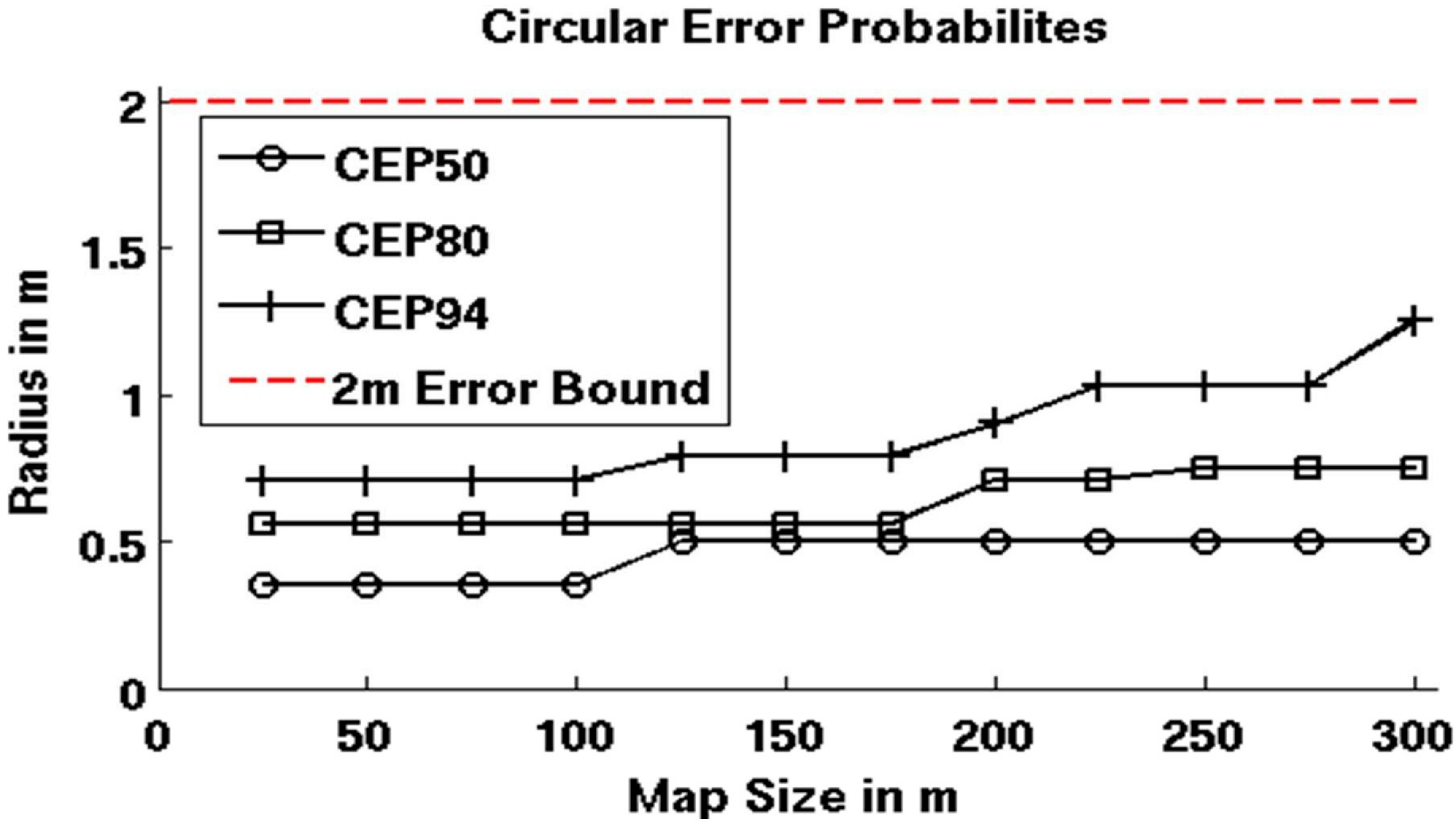


Experimental setup

- 800 m · 800 m section of the data at 0.25 m/pixel used as map
- Rover panoramas use 8 LIDAR camera image pairs over 360°
- Tested at 50 randomly chosen locations
- Angle of the sun could be adjusted

Localization under variation in Search Window Size

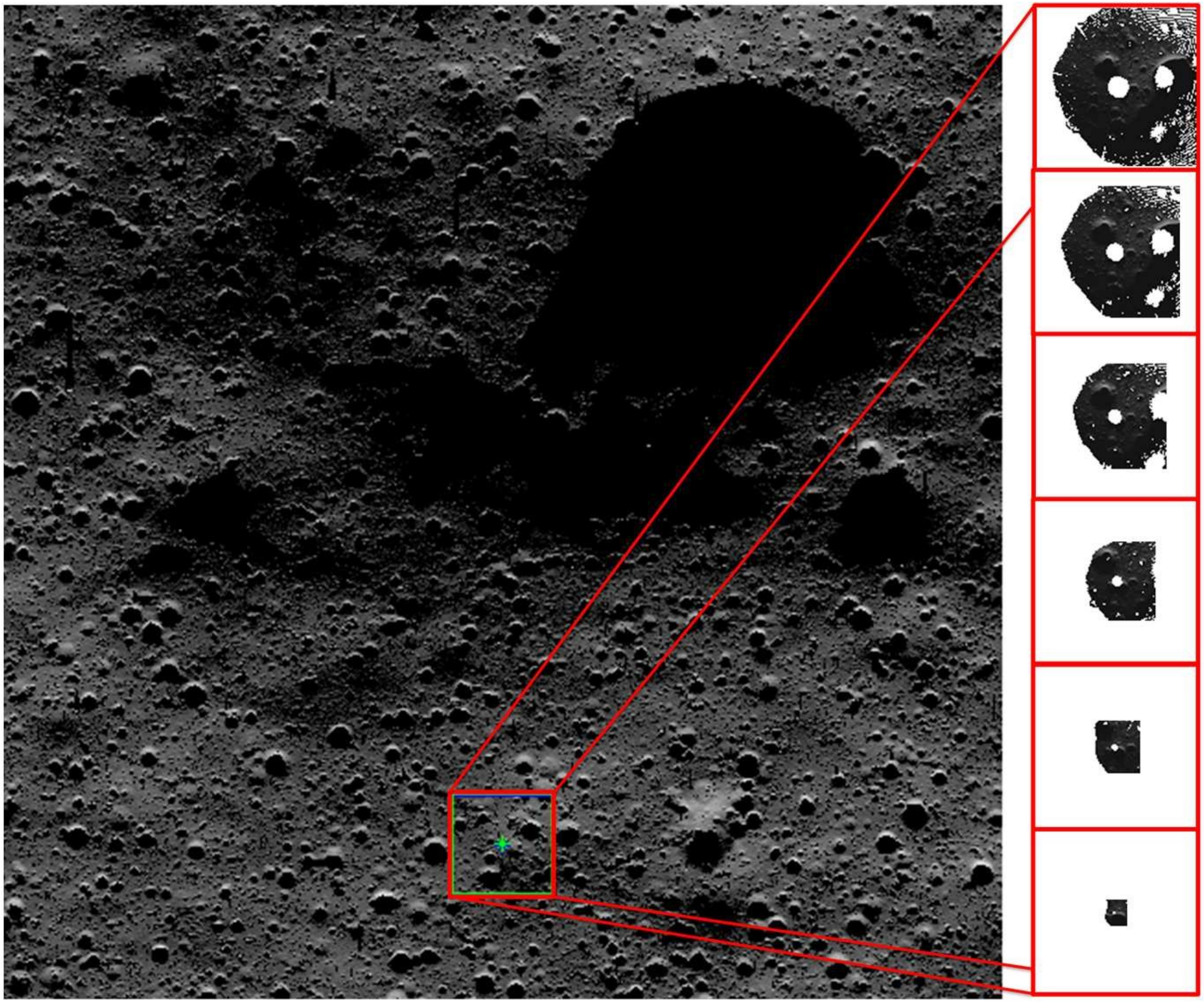
- Generate 15 m · 15 m templates centered on the rover
- For each location, square search window centered on rover in varying sizes
- Sizes ranged from 25 m to 300 m in 25 m increments
- Searched for location within the search window
- Analyzed using Circular Error Probability (CEP)

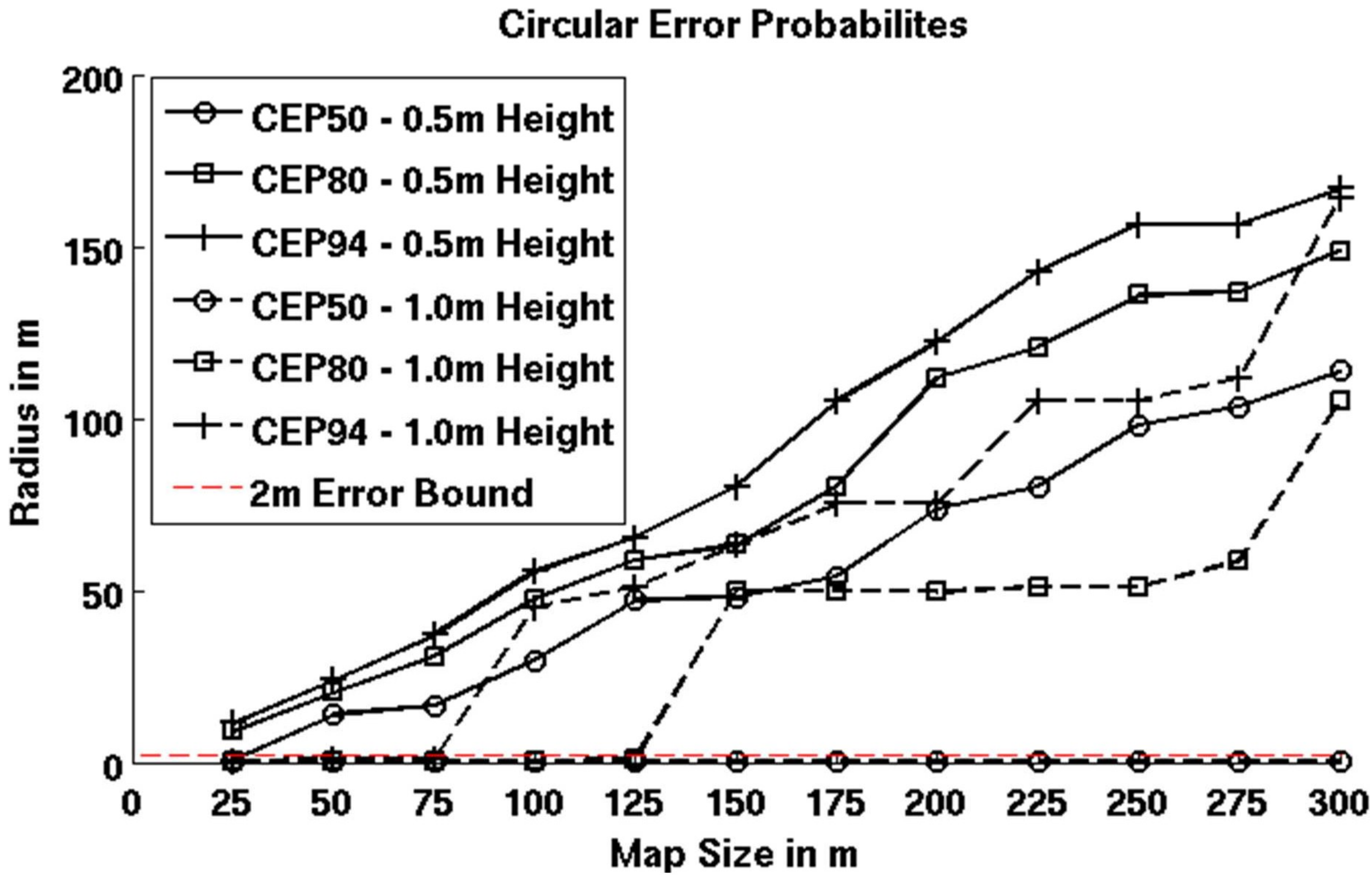


Circular Error Probabilites
CEP50
CEP80
CEP94
2m Error Bound
Radius in m
0
0.5
1
1.5
2
0
50
100
150
200
250
300
Map Size in m

Localization under Variation in Sensor Head Height

- Effect of template size on localization accuracy
- Higher head results in larger view of environment
- Size of template increased by 5 m for every 0.5 m increase in head height
- Height varied from 0.5 m to 3 m
- Template varied from 5 m to 30 m
- Tested in search windows 25 m to 300 m wide





Circular Error Probabilites
CEP50 - 0.5m Height
CEP80 - 0.5m Height
CEP94 - 0.5m Height
CEP50 - 1.0m Height
CEP80 - 1.0m Height
CEP94 - 1.0m Height
2m Error Bound
Radius in m
200
150
100
50
0
0
25
50
75
100
125
150
175
200
225
250
275
300
Map Size in m

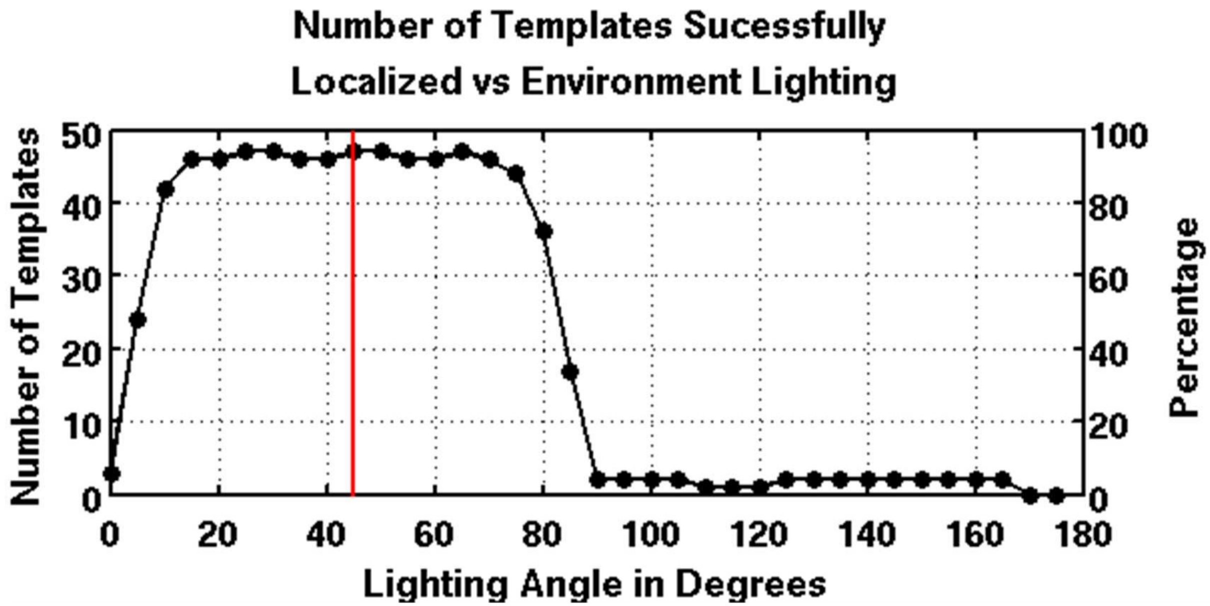
NUMBER OF TEMPLATES SUCCESSFULLY LOCALIZED WITH VARIATION IN ROVER HEIGHT AND SEARCH WINDOW SIZE .

Search Window	Rover Height (m)					
	0.5 m	*1.0 m*	*1.5 m*	*2.0 m*	*2.5 m*	*3.0 m*
100 m	12	48	50	50	50	50
200 m	8	38	48	49	50	50
300 m	7	32	47	48	49	50

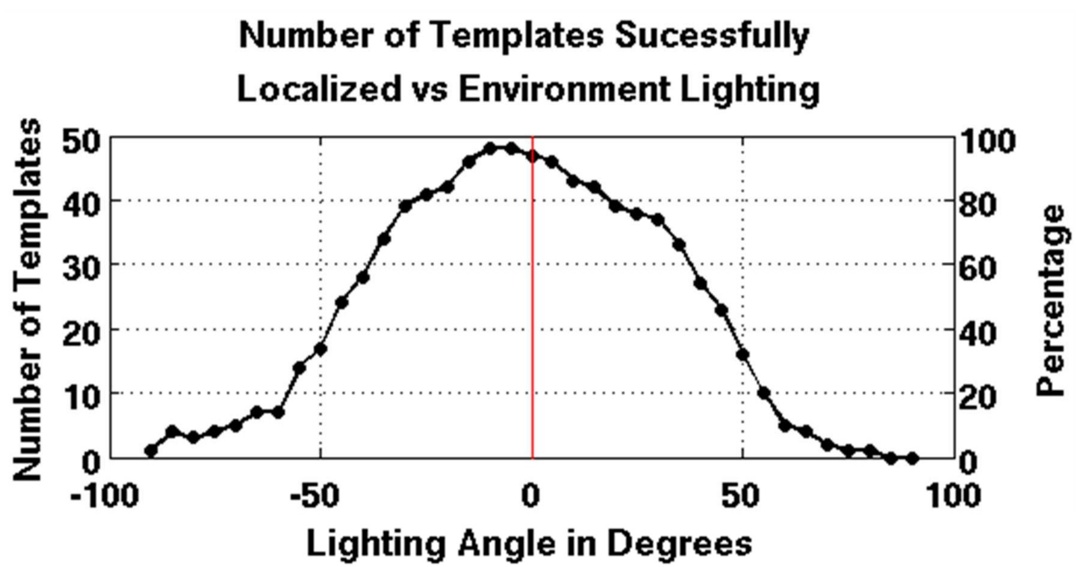
Localization under Variation in Lighting

- Examines effect of difference in angle between satellite image and rover image on the robustness of the localization
- Lighting angle of map was varied to simulate mismatch
- Two sets of templates: polar and equatorial
- Orthographic views generated with varied lighting for equatorial and polar conditions

Equatorial

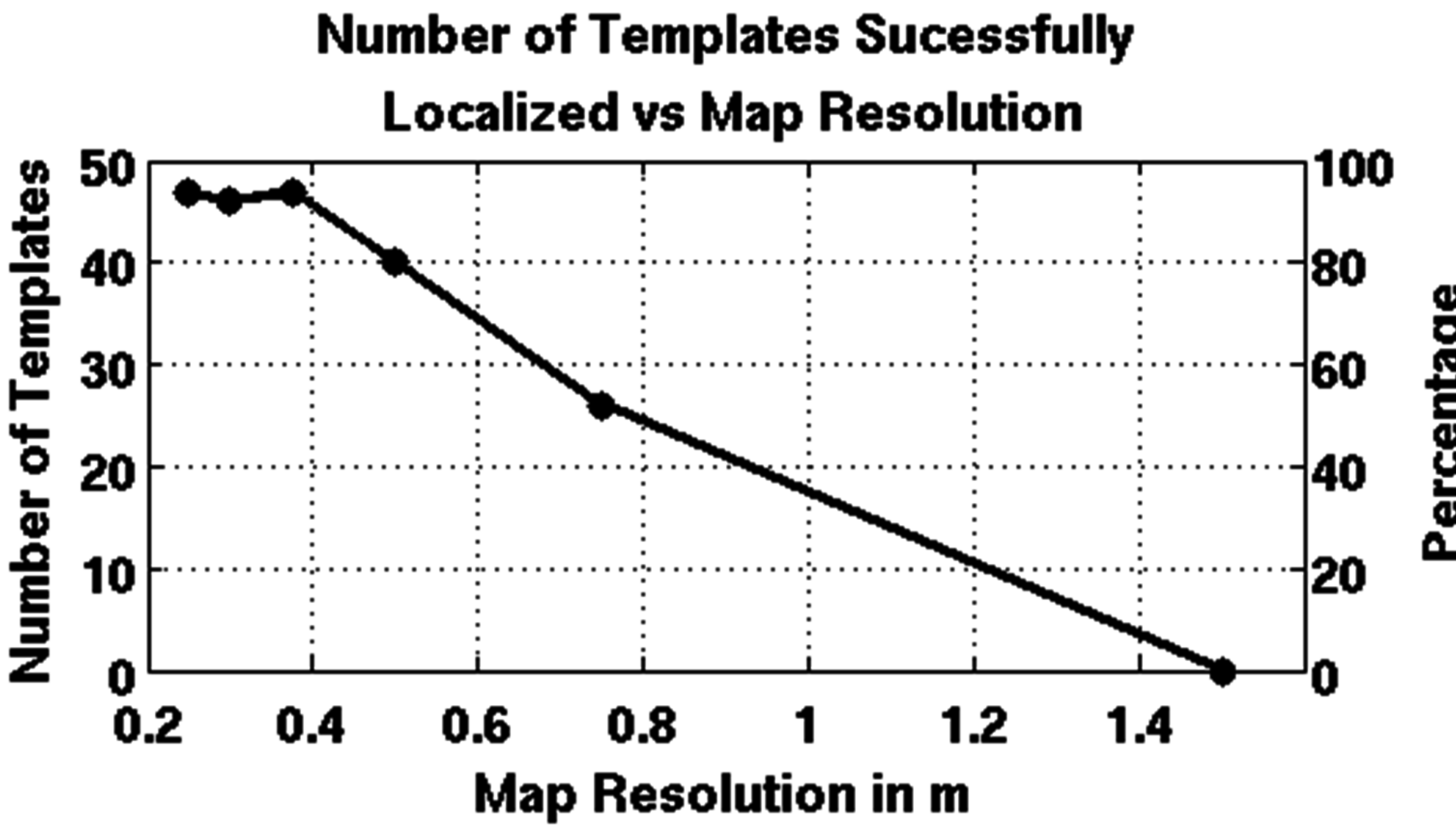


Polar



Localization under Variation in Map Resolution

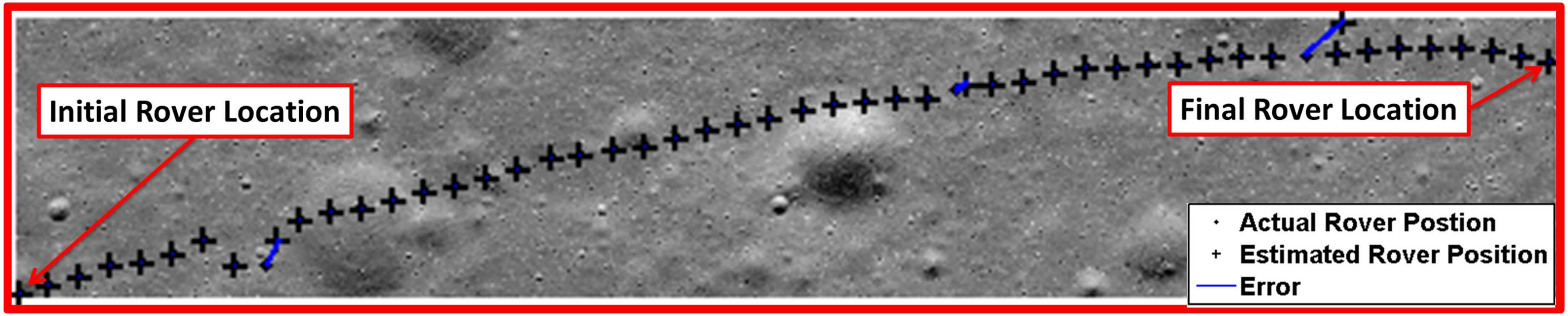
- Examines localization performance as a function of overhead map resolution.
- Templates generated at resolutions from 0.25 m (original) to 1.5 m
  - 15 m template is 10 to 60 pixels across
- Map downsampled to match templates
- Localized in 300 m search window


Number of Templates Sucessfully
Localized vs Map Resolution
Number of Templates
Percentage
Map Resolution in m
0
10
20
30
40
50
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1
1.2
1.4

5 km traverse to an interest Region

- Simulates long range travel using localization
- Two points 5 km apart were chosen and a path planned between them
- Points sampled every 100 m to generate 50 intermediate points
- Points shifted randomly
- Localized in 300 m search window

- Successful in 47/50 attempts
- Mean error of 0.53 m



Conclusion

- 94% probability of better than 2 m accuracy under nominal conditions
- Accuracy degrades with reduced template size, increased lighting angle, and decreased map resolution
- Probability increases with number of pixels in the template
- Performs well when map and rover lighting angle are within 30°
- Accuracy decreases with map resolution and increases with rover height

Future work

- Use template information content to determine likelihood of successful localization
- Field experimentation
- Effects of weather conditions in Earth-like environments
- Effects of sensor noise and cailibration
- Interactions between localization schemes and on-line planning and control

Questions?