Comparative analysis of different passive hazard mapping techniques

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Cologne, Germany

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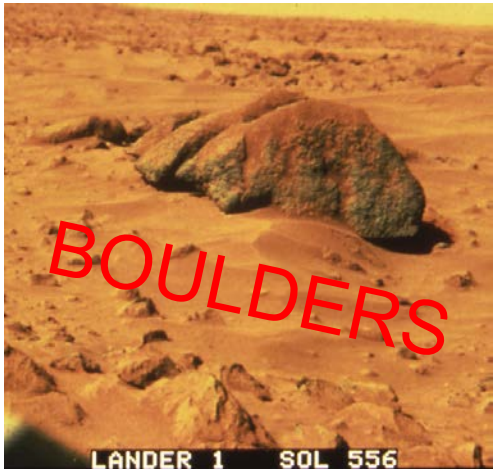

Landing challenges and hazards

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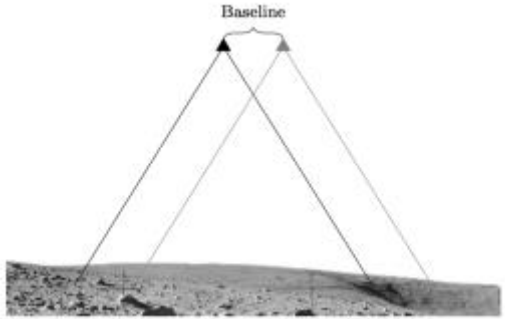
Stereo Vision

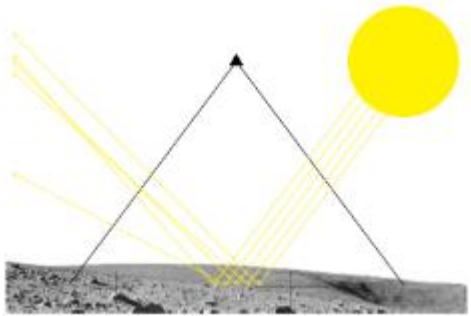


Ground-point projections in second image "*jump*" w.r.t. first image.

- Algorithm based on Woicke (2014)
  - Image correspondences have to be found
  - Distance towards ground can be computed from disparity
  - Image matching: Sum of squared differences
  - Quadratic fit for non-integer disparities
  - Post-filtering of DEM using median and linear regression filters
- Does not need additional inputs to recover DEM

(Woicke, 2014) Woicke, S. and Mooij, E., "A Stereo-Vision Based Hazard-Detection Algorithm for Future Planetary Landers" 11th International Planetary Probe Workshop, held June 16-20, 2014 in Pasadena, California. LPI Contribution No. 1795.

Shape from Shading

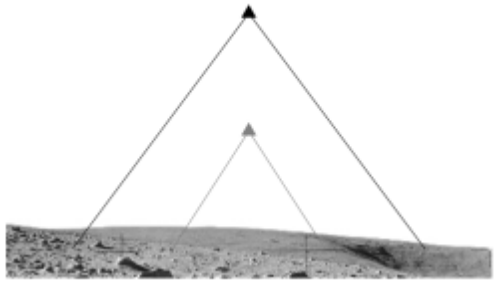


For most surfaces there is a unique value of reflectance and hence image intensity for a given surface orientation (Horn, 1977).

- Linearization of intensity function; as described by Pentland (1990)
- Algorithm:
  - Image x-direction and projection of Sun need to be aligned
  - Elevation computed in x-direction
  - Averaging of two DEMs, top-down and bottom-up
  - Filtering in y-direction to reduce line-artifacts in resulting DEM
- Knowledge of minimum and maximum elevation is required (or of two other points)

(Horn, 1977) Horn, B. K., “Understanding image intensities,” Artificial intelligence, Vol. 8, No. 2, 1977, pp. 201–231.
(Pentland, 1990) Pentland, A. P., “Linear shape from shading,” International Journal of Computer Vision, Vol. 4, No. 2, 1990, pp. 153–162.

Stereo from Motion



Assuming an elevation of the surface, it is determined if the projection of image 2 onto image 1 is equal.

- Algorithm is based on the work presented by Xiong (2001)
- “Reverse” stereo vision
- Algorithm
  - 2nd image warped and downsampled
  - Cost function: Sum of squared differences
  - Quadratic fit
  - DEM smoothed by filtering
- Position and orientation of camera while talking pictures has to be known accurately
- Cannot reconstruct scene at and close to epipole

(Xiong, 2001) Xiong, Y., Olson, C., and Matthies, L., “Computing depth maps from descent imagery,” Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2001., Vol. 1, 2001, pp. I–392–I–397.

Requirements and Limitations

	Stereo Vision	Shape from Shading	Stereo from Motion
Terrain information required	☺	☹	😐
State of spacecraft has to be known	😐	☹	☹ ☹

	Stereo Vision	Shape from Shading	Stereo from Motion
Limited by altitude	☹	☺	☹
Limited by spacecraft design	☹	☺	☺

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Comparison

- Three hazard mappings
  - 1000 m
  - 500 m
  - 150 m

- DEM and hazard map compared to ground truth hazard map:
  - Slope
  - Roughness

- **Stereo vision**: baseline 2 m
- **Stereo from motion**: second image at ½ altitude
- **Shape from shading**: Sun elevation 15°

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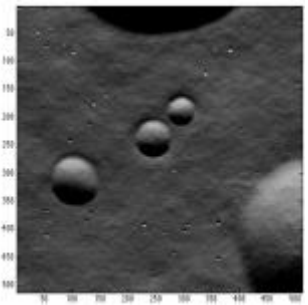
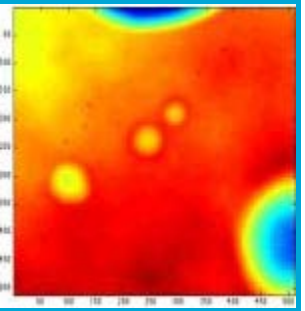
1000 m altitude

SV

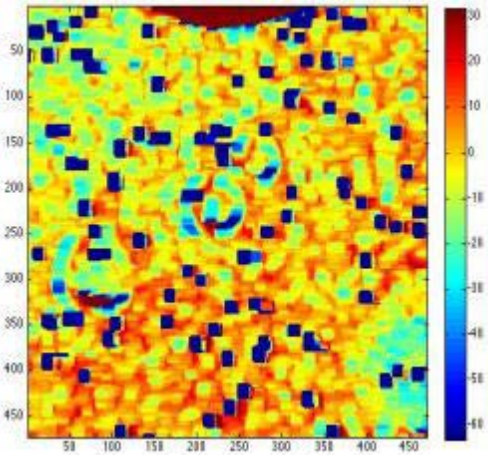
Median error	DEM	Slope	Roughness
SV	~~9.60~~	~~52.19~~	~~1.15~~
SfS	7.86	2.41	0.03
SfM	9.97	4.48	0.06

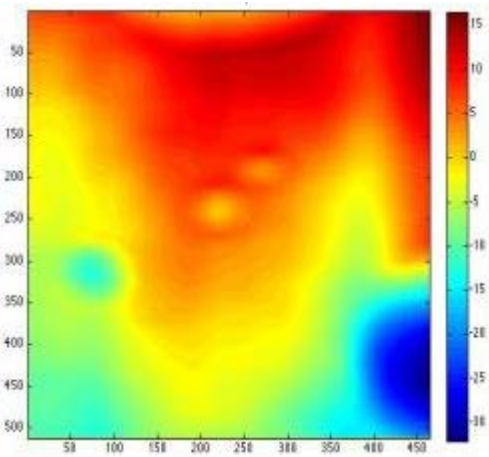


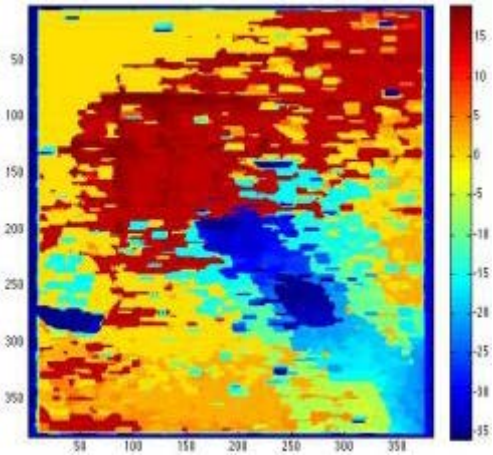
Input Image

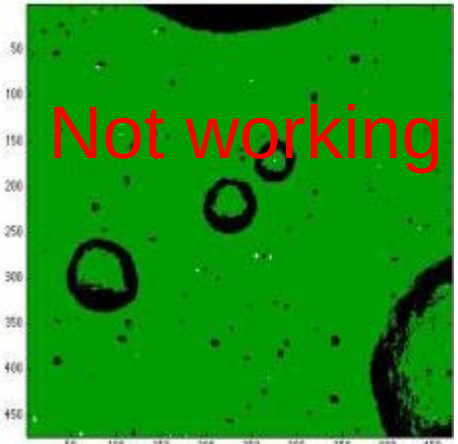


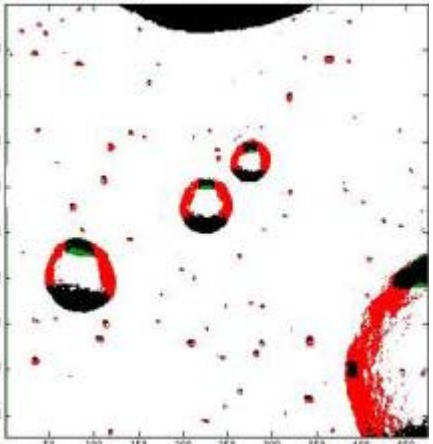
Ground Truth DEM

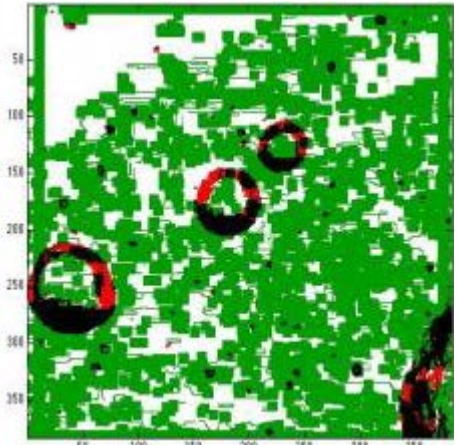












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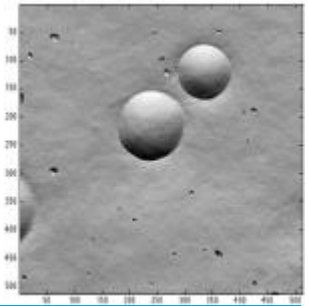
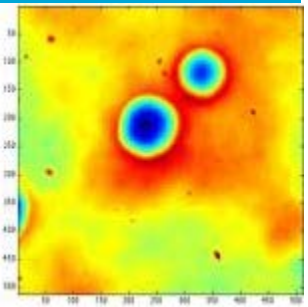
500 m altitude

SV

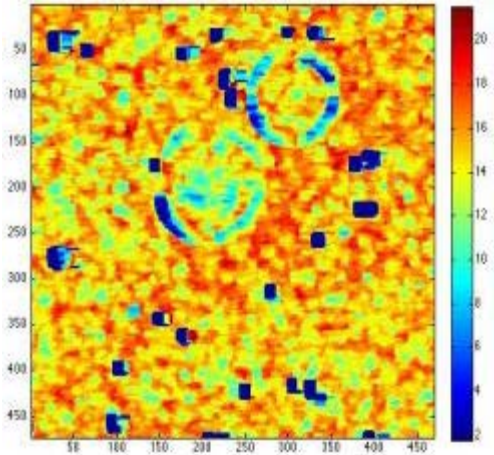
Median error	DEM	Slope	Roughness
SV	~~7.03~~	~~27.73~~	~~0.61~~
SfS	2.40	1.40	0.02
SfM	2.68	10.22	0.18

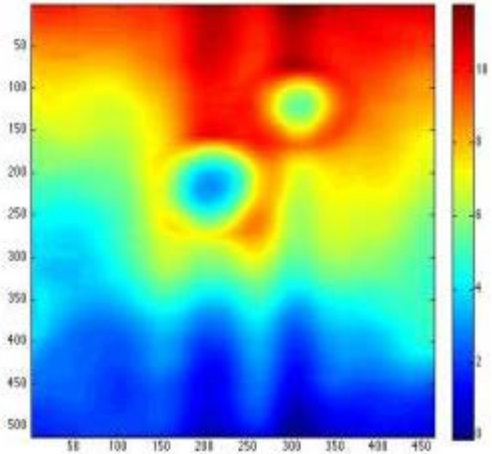


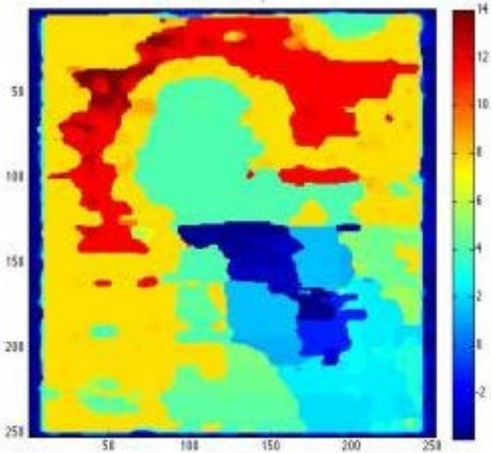
Input Image

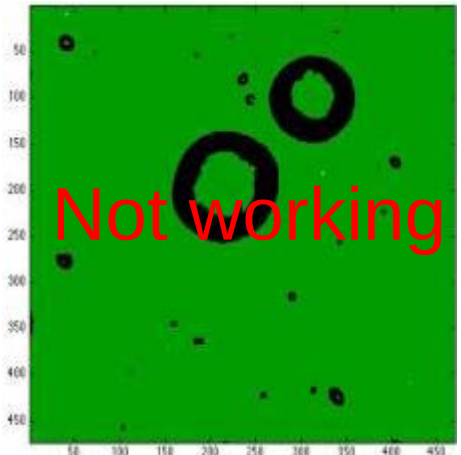


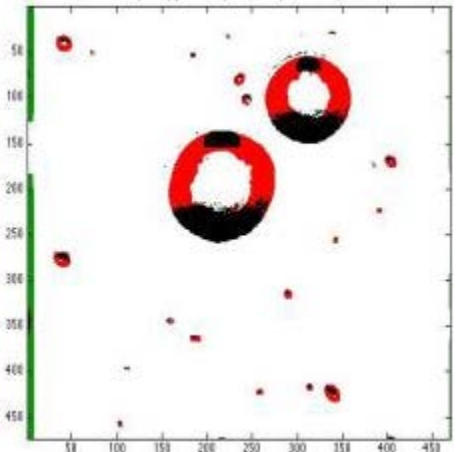
Ground Truth DEM

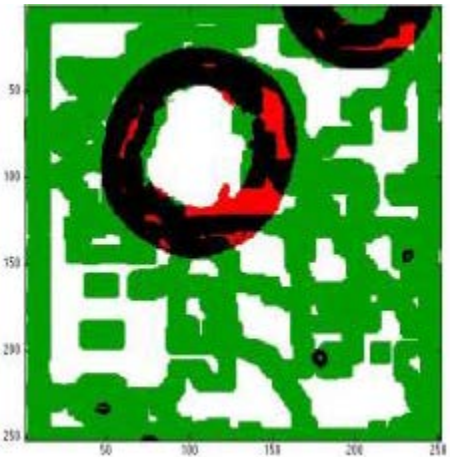












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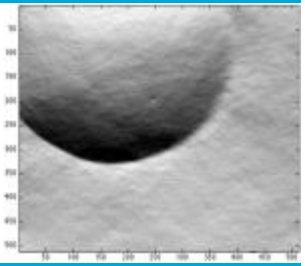
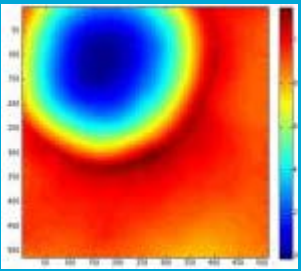
150 m altitude

SV

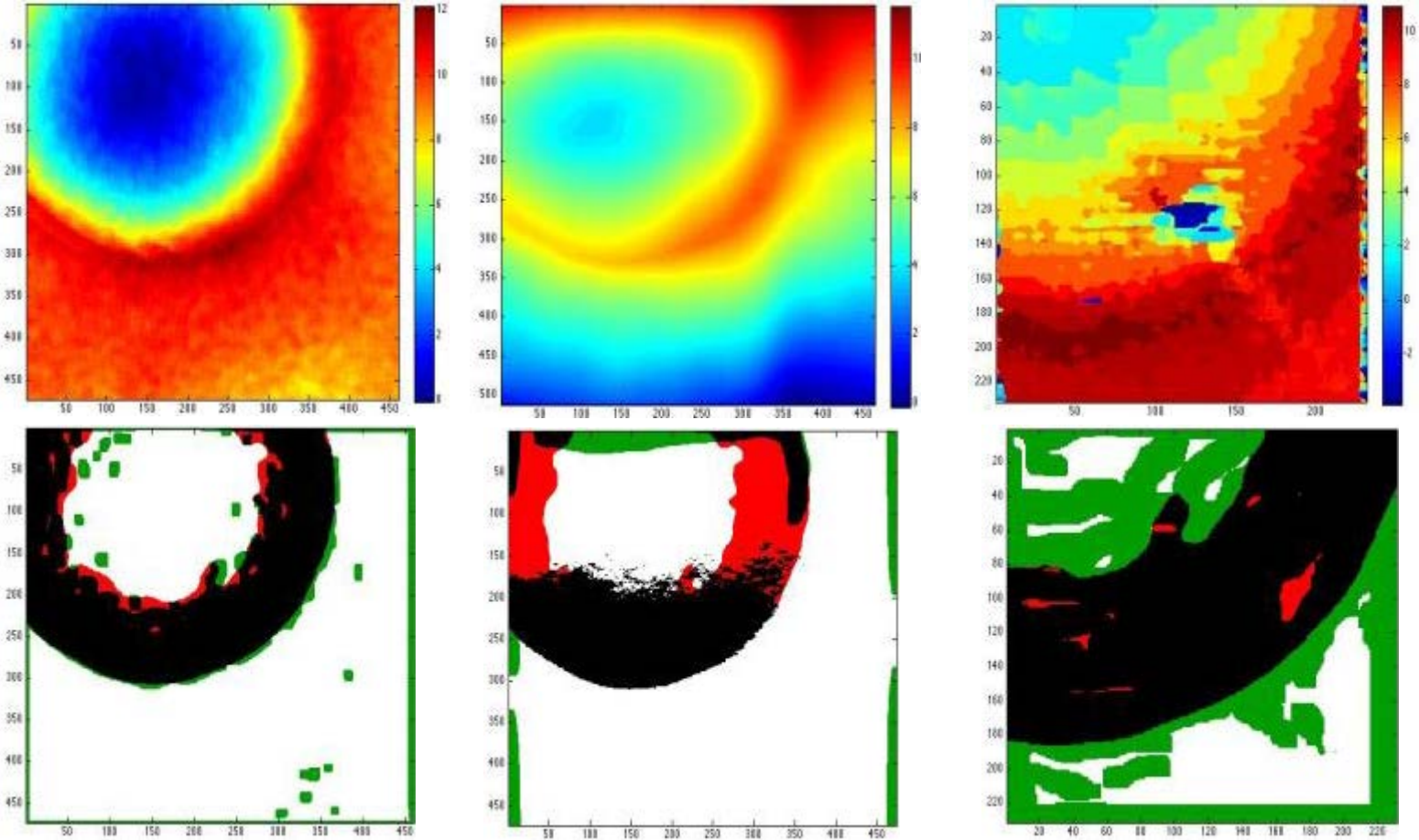
Median error	DEM	Slope	Roughness
SV	0.24	2.63	0.05
SfS	3.35	6.89	0.10
SfM	0.61	7.76	0.22



Input Image



Ground Truth DEM



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Conclusion

	+	-
SV	• Very good performance at low altitudes • Good boulder detection • Baseline known	• Very limited in altitude • Baseline limited by design
SfS	• Works at high altitudes	• Hazard maps not “standalone”
SfM	• Does work at higher altitudes than SV	• S/C state and orientation has to be known very well • Limited in altitude • DEMs noisy • DEMs in epipole cannot be reconstructed • DEM size smaller

→ Algorithms have to be selected based on mission scenario
→ Combination of methods (e.g., SfS at high altitudes, SV at low altitudes)

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