A Stereo Vision Based Hazard Detection Algorithm for Future Planetary Landers

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International Planetary Probe Workshop, June 16-20 2014
Pasadena, California

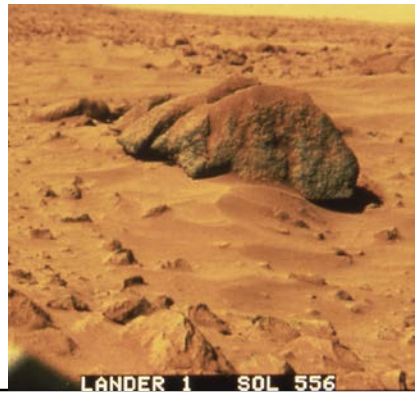
Hazard Detection and Avoidance (HDA)

Introduction

- Curiosity:
  - no HDA but landing region had to be flat (<15°) and free of rocks larger than 0.5 m.
  - landing ellipse 20 km x 7 km (110 km^2)

→ huge safe area needed

- Asses the safety of a landing region on-board during the descent
- Enabling landing in unsafe regions, targets interesting for science
- Orbiter data not accurate enough and terrain can change over time
- **Hazard detection increases the area accessible to landers and decreases the risk of a landing failure**

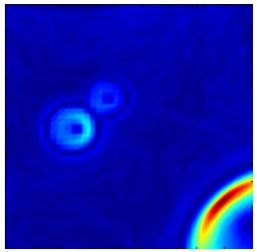


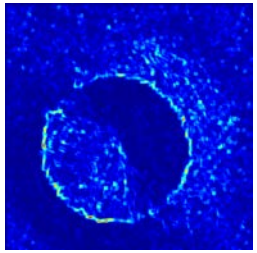
Boulder “Big Joe” a 2 m boulder directly next to the Viking lander, in an area which was considered to be safe!
Source: NASA

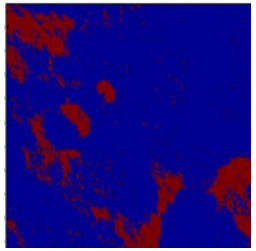
Hazard Detection and Avoidance

HDA principle

- Slope, roughness, illumination, and texture map are combined into a final hazard map
- Slope and roughness map require a Digital Elevation Model (DEM) as input
- Texture and illumination require an intensity image
- DEM can come from multiple sources
  - Active: LIDAR (scanning and flash/imaging LIDAR), radar (heavy, expensive, high power consumption, BUT DEM directly available)
  - Passive: Camera (light, cheap, low power consumption, BUT DEM has to be reconstructed)
- Hazard map is combined with fuel map, reachability map, etc., for final decision


slope


texture


illumination

Stereo Vision Hazard Detection

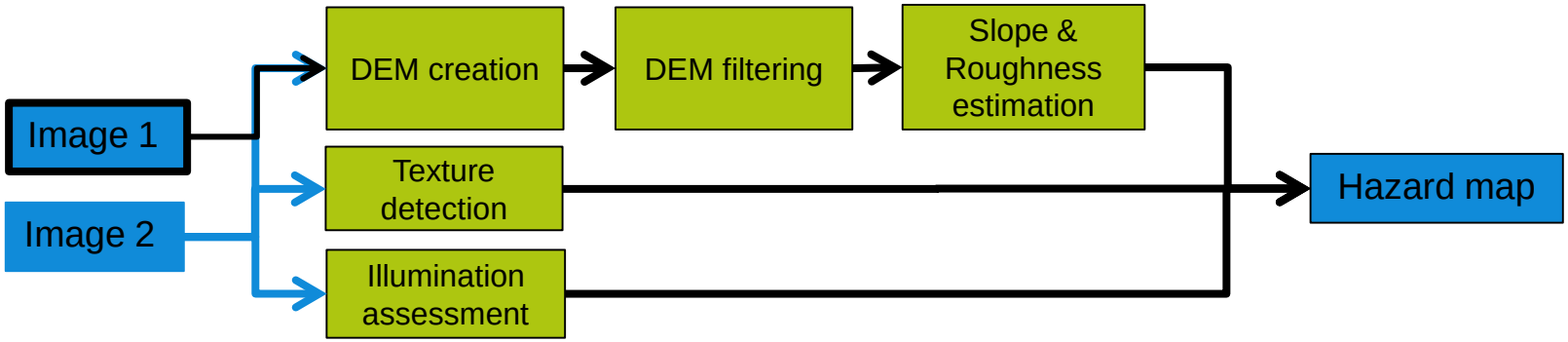
Algorithm

- Challenges:
  - Distance between observer and landing region far away >100 m
  - Scenes rather uniform as compared with terrestrial applications
  - Depth resolution of stereo vision is limited, obtaining sufficient vertical resolution is challenging
- The algorithm shall combine slope, roughness, illumination and texture information into a final hazard map
- Requirements:
  - Capable of detecting slopes larger than 15°
  - Roughness larger than 0.5 m
  - Execution time less than 2 s
  - Less than 1% wrong detections (a hazard is detected as a safe site)

Stereo Vision Hazard Detection

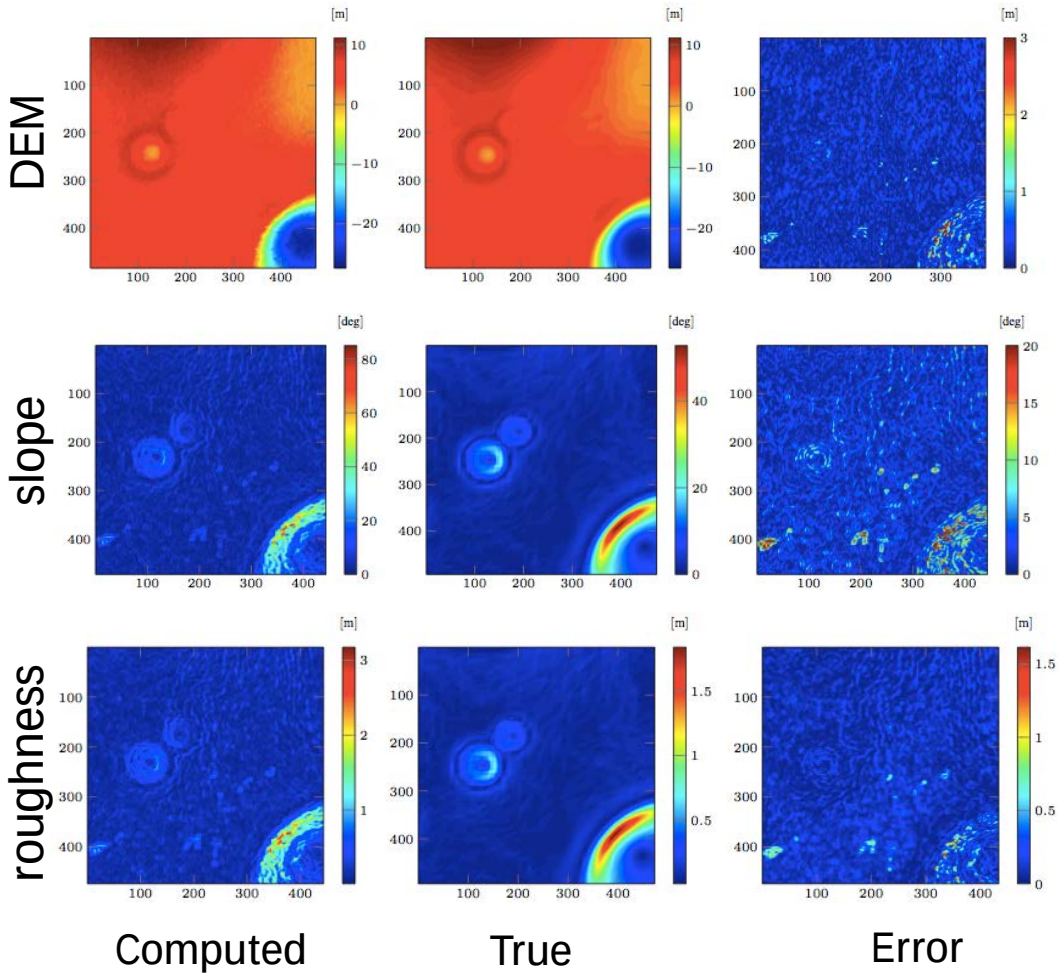
Algorithm

- **DEM** creation from stereo pair using block matching (sum of squared differences), but achieving non-integer disparities by parabolic fitting to overcome the problem of limited depth resolution
- **DEM** is filtered using linear prediction and median filter to remove outliers
- **Slope and roughness** are computed from DEM using a linear regression mean plane
- **Texture** is evaluated using histogram-based variance using one of the stereo images
- **Illumination** conditions are analysed using one of the stereo images

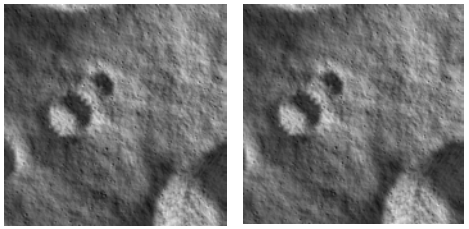


Stereo Vision Hazard Detection

Results



- Results for 2 m baseline and 200 m altitude, nadir-pointing spacecraft
- DEM well reconstructed, errors are only local. Maximum error 3 m, average error <0.5 m
- Small errors from DEM propagate to roughness and slope map, but no new errors are introduced



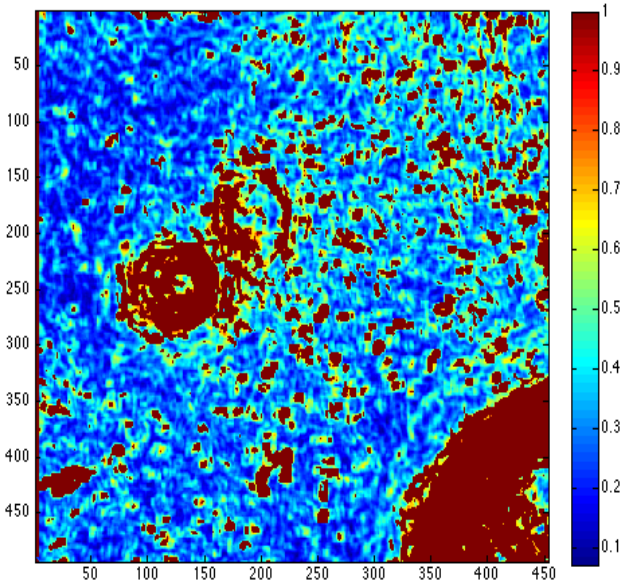
Input images[1]

[1] Input images produced using PANGU Planet Surface Simulation Software developed by the Space Technology Centre at the University of Dundee, Scotland

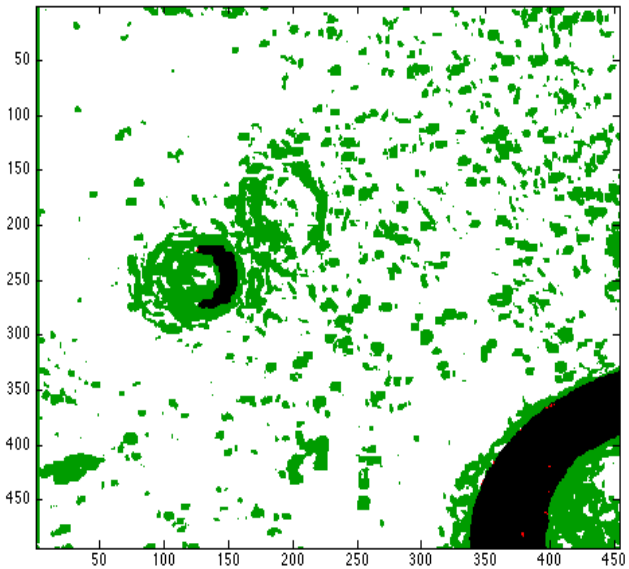
Stereo Vision Hazard Detection

Results

- Almost no wrong detection. Wrong detections are inside or next to detected hazard.
- Some false alarms (mainly due to texture detection)
- Hazards are detected correctly



Hazard map



Hazard mapping error

Red = wrong detection
Green = false alarm,
Black = correctly detected hazard
White = correctly detected safe site

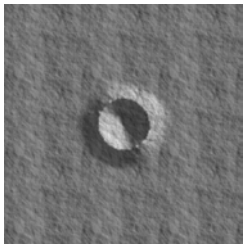
Sensitivity Analysis

Correct Detections

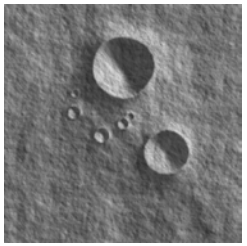
- Assume 60% correct detection is minimum(threshold)

→Baselines ≤2 m are possible for altitudes of ≤200 m

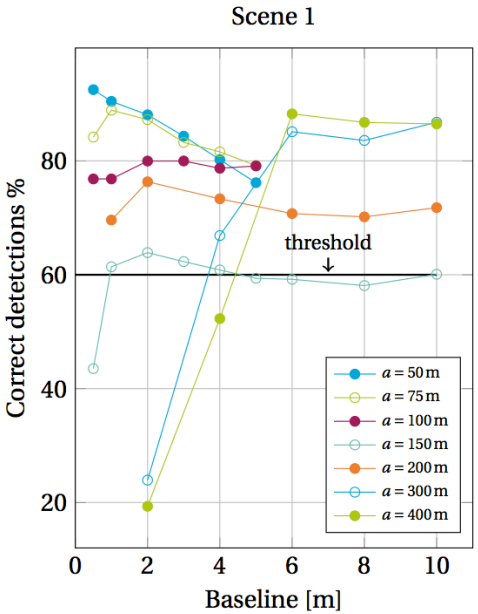
- Higher altitudes would require larger baselines
- Larger baselines could be synthetically created (stereo-from-motion techniques)
- 2 – 2.5 m baselines are considered to be the maximum feasible based on current designs

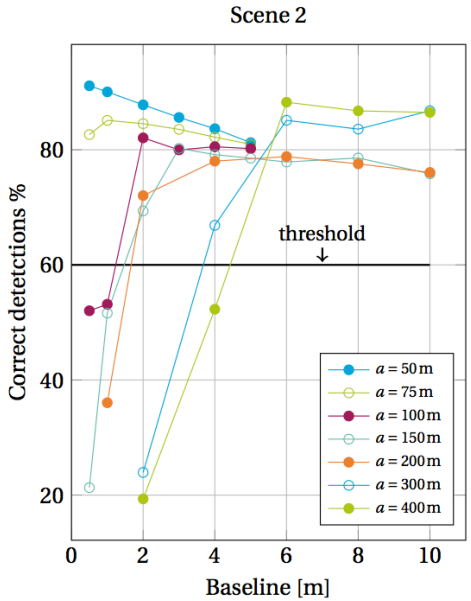


Scene 1



Scene 2

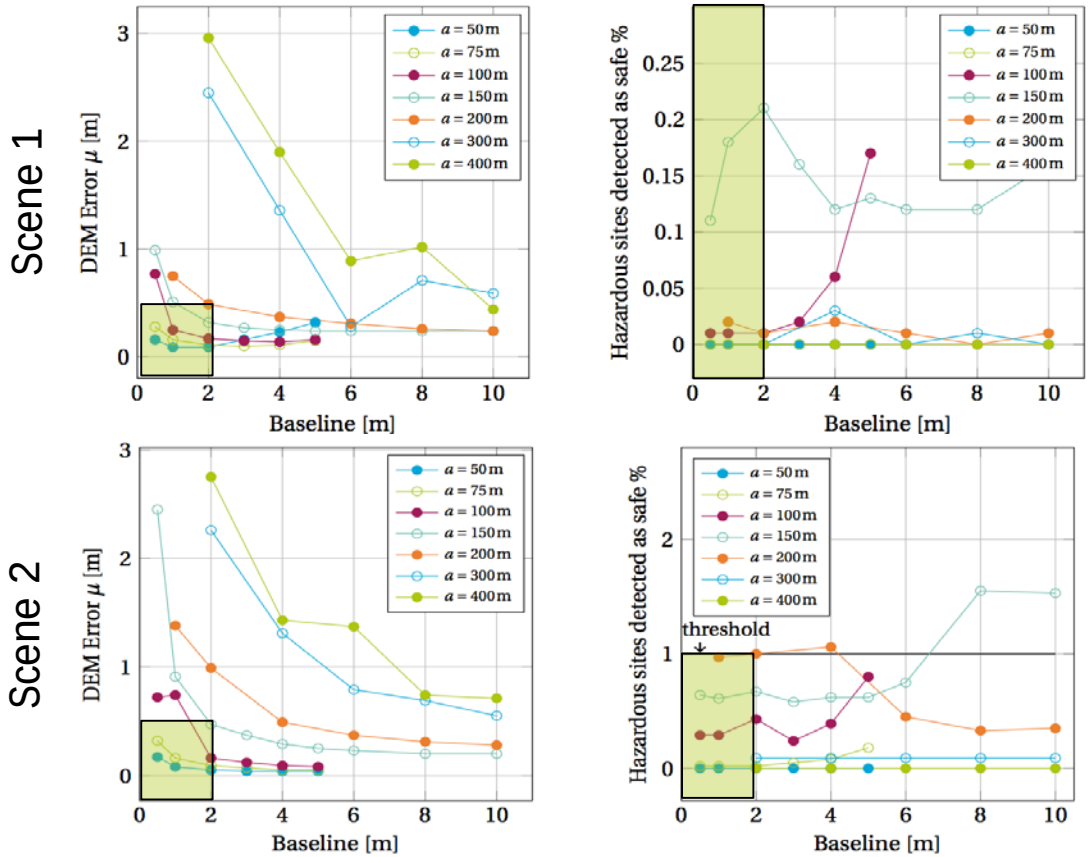


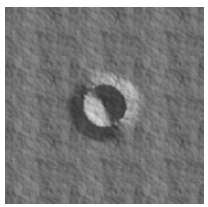


Sensitivity Analysis

DEM Error and False Detections

From altitudes ≤200 m baselines ≤2 m are possible with DEM errors ≤ 0.5 m and less than 1% false detections





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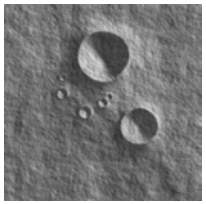


Scene 2

Sensitivity Analysis

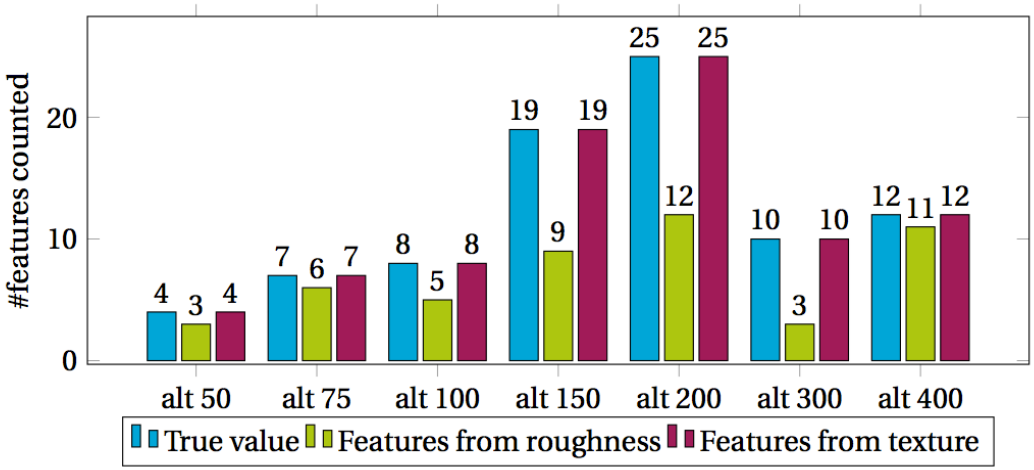
Rock Detection

1. Rocks are counted in the real scene
2. Texture and roughness detection is executed
3. Detected rocks are counted

➔ Texture detection always detects all rocks, roughness detection detects approximately half of the rocks

➔ BUT roughness can determine rock height while texture detection cannot

Texture detection and roughness should be combined for optimal rock detection!



Conclusions

- Stereo-vision based HD possible from altitudes ≤200 m at baselines of 2 m
- Higher altitudes possible, when larger baselines can be used
- Rocks detected very well (combing texture and roughness detection)
- Landing in hazardous terrain possible → increase in science return
- Stereo vision can detect hazards, which are too small to be detected from orbiter data
- HDA increases the area accessible by landers
- HDA decreases the risk of a landing failure

→ HDA is a must for next-generation planetary landers
→ Stereo vision is a very suitable candidate