Review of Autonomous Technologies for a Crewed Exploration of the Lunar South Pole

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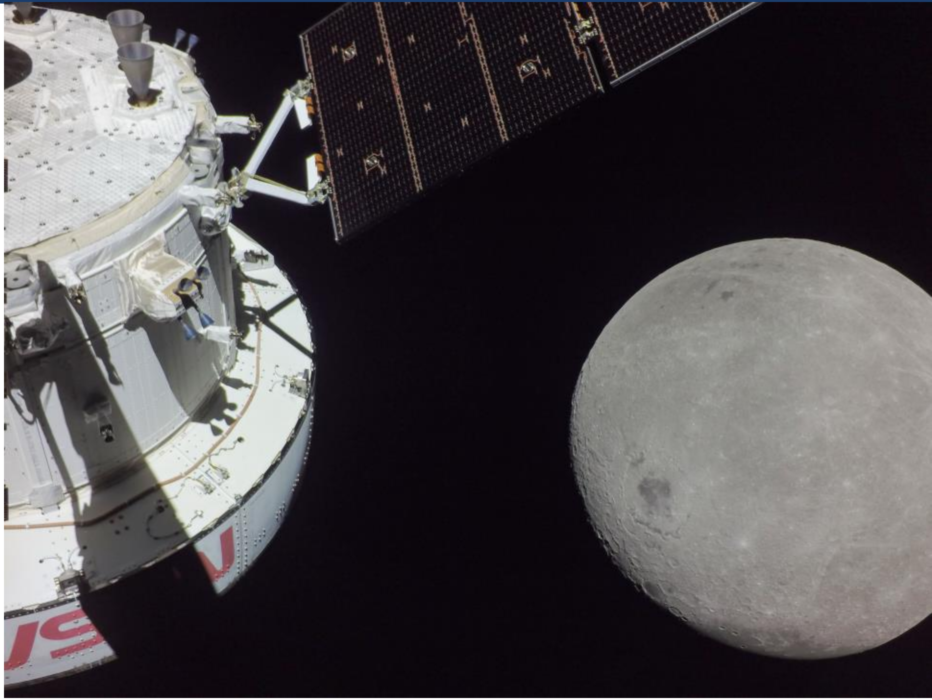
Artemis Program

- Artemis II – Crewed Flyby
- Artemis III – Crewed Landing
- Artemis IV – Landing and Lunar Gateway development
- **Artemis V** – Landing and **Lunar Rover delivery**



[1]

Introduction

What technologies are best suited to enabling autonomy in a lunar environment?

Conventional approaches will not work

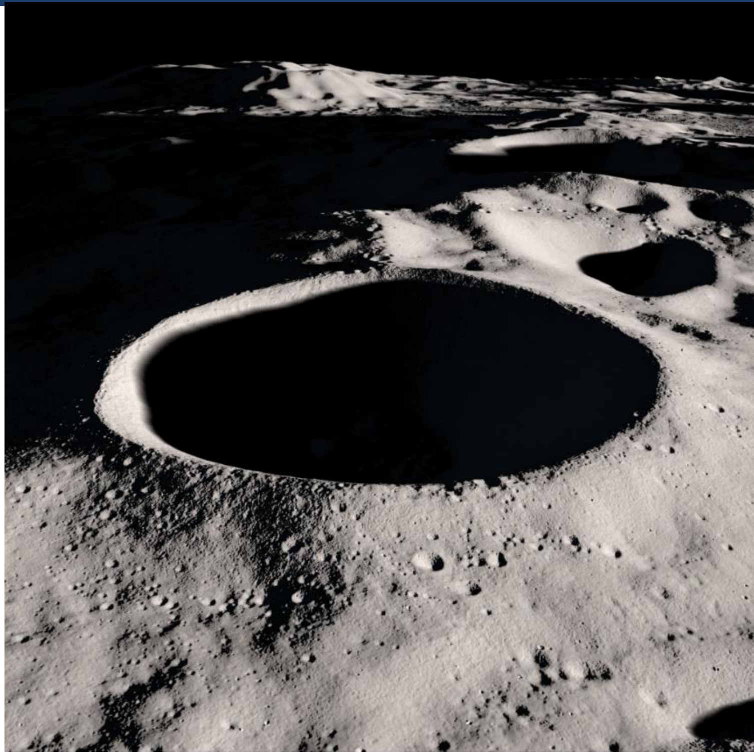
- No GPS
- No paved roads
- No streetlights

Where are we going?

Shackleton Crater, Lunar South Pole

Likely contains water ice and other volatiles due to permanent darkness

- Scientific interest
- Water to support human settlements

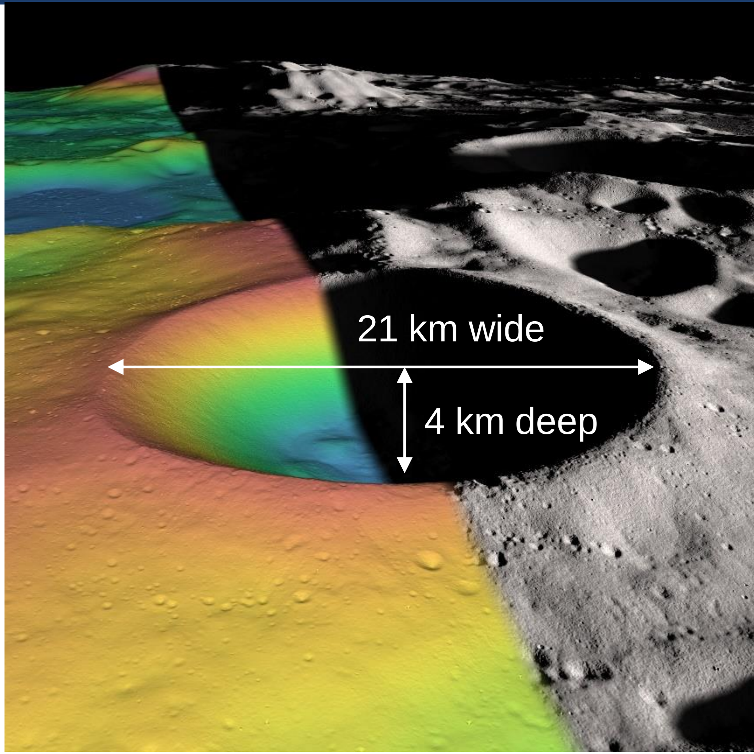


[2]

Exploration Challenges

- Uneven terrain
- Steep grades
- Vast distances

- No existing infrastructure
- Infrastructure is costly



[2] Lunar Reconnaissance Orbiter

Lunar Roving Vehicle (LRV)

[1]

Apollo 15

Apollo 16

Apollo 17

Proposed Lunar Rovers

NASA’s Lunar Terrain Vehicle (LTV)

[3] Artist Rendering

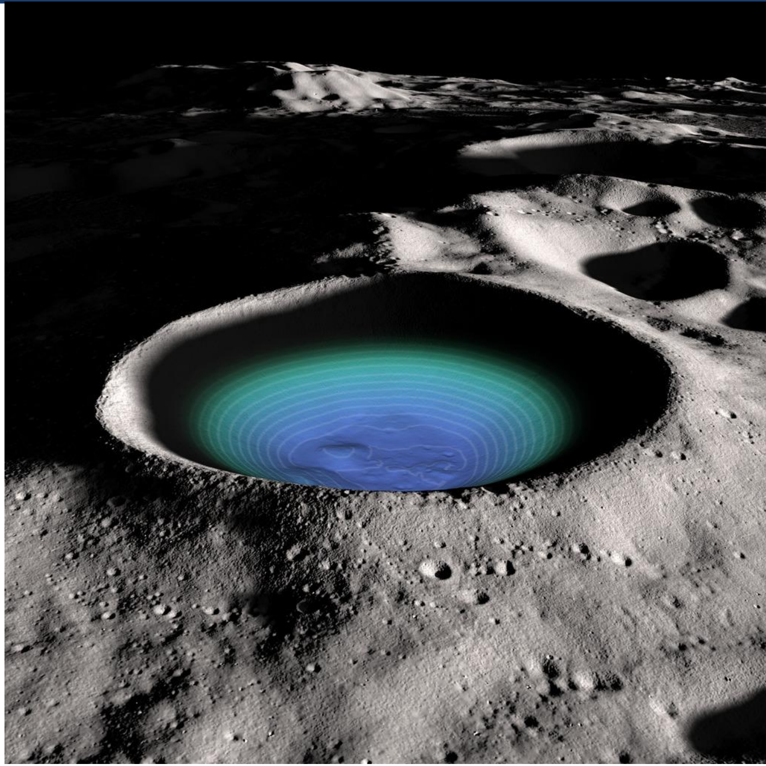
The Need for Autonomy

Safety

- Obstacle avoidance
- Stability control at speed
- Prepositioning

Future uses

- Bulk logistics
- Rescue missions



[2]

Challenges of Lunar Autonomy

Autonomous System Design Requirements

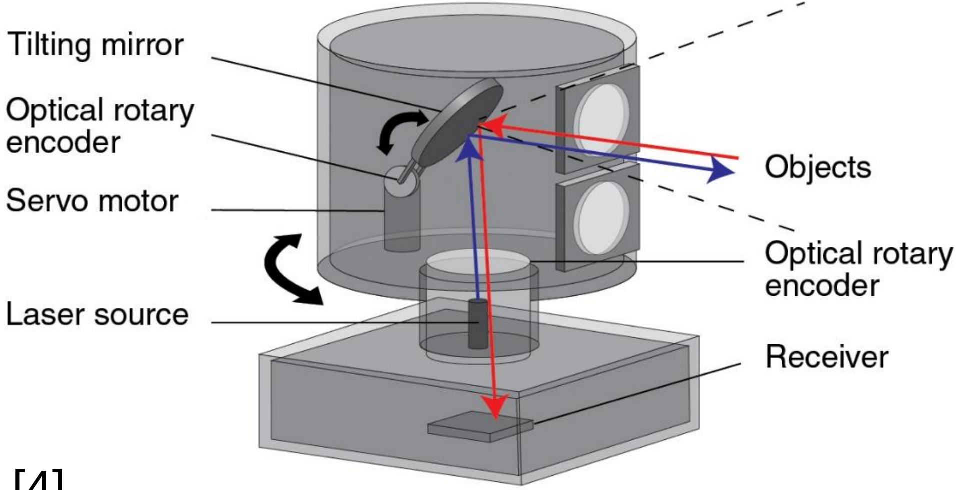
- Operate on the darkened crater floor
- Operate without external positioning or computing
- Maintain a high degree of safety in all environments

Enabling Technologies

- Light Detection and Ranging (LIDAR)
- Image Recognition
- Optical Flow Sensors

LIDAR

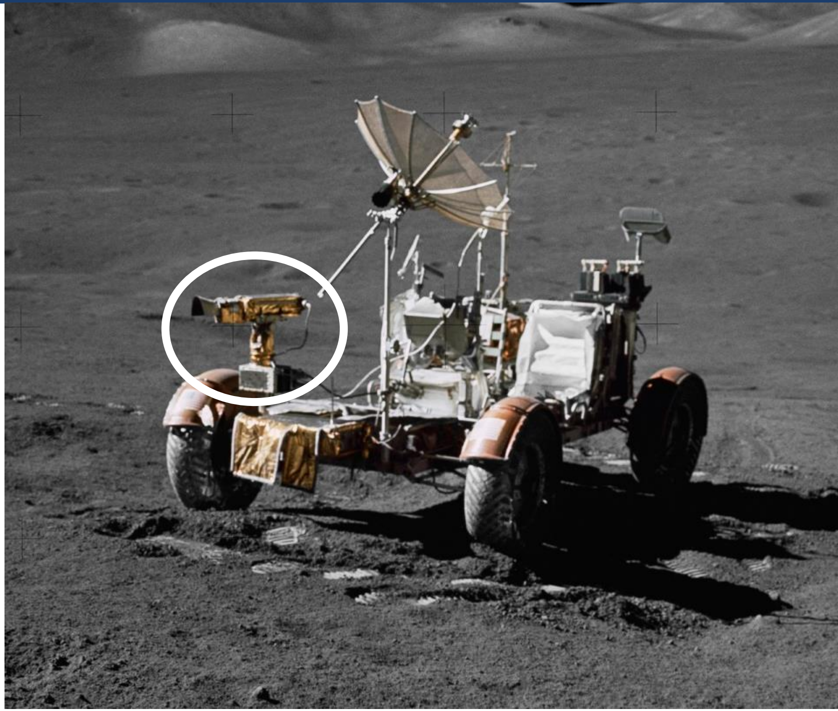
- Can operate in the dark
- Highly accurate up to 300 m
- Versatile and mature



[4]

Image Recognition

- Low mass - can use existing engineering cameras
- Requires a pretrained model
- Requires an illumined area
  - Will reduce range



[5] Apollo LRV

Optical Flow Sensors

- Compares features between frames to determine motion
- Lightweight and compact
- Best used to validate other sensors

[6] SCARAB rover

Selection Criteria

- Mass
- Maturity
  - NASA Technology Readiness Level (TRL)
- Cost
- Accuracy

Selection Criteria		
Objective	Weighting Factor	Parameter
Mass	0.30	kg
Maturity	0.20	1-9
Cost	0.20	$
Accuracy	0.30	Reported
Overall Value		

Qualitative Score Assignments:	
Great	10
Good	7
Fair	4
Poor	1

Decision Matrix

Selection Criteria			LIDAR			Image Recognition			Optical Flow Sensors		
Objective	Weighting Factor	Parameter	Magnitude	Score	Value	Mag.	Score	Value	Mag.	Score	Value
Mass	0.30	kg	3.5	7	2.1	0	10	3	0.05	8	2.4
Maturity	0.20	1-9	7	10	2	5	0	0	6	5	1
Cost	0.20	$	100,000	3	0.6	0	10	2	200	6	1.2
Accuracy	0.30	Reported	Great	10	3	Fair	4	1.2	Poor	1	0.3
Overall Value											

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Cost	0.20	$	100,000	3	0.6	0	10	2	200	6	1.2
Accuracy	0.30	Reported	Great	10	3	Fair	4	1.2	Poor	1	0.3
Overall Value					**7.7**			**6.2**			**4.9**

Qualitative Score Assignments:	
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Poor	1

LIDAR

Impact

Near Future

- Safety
- Cost

Far Future

- Synchronization

Earth

[2]

Conclusions & Next Steps

Conclusions

- Autonomy is necessary to support future exploration
- LIDAR is optimal for navigation in lunar craters

Next Steps

- Combining multiple technologies increases reliability
- Validating LIDAR in the dusty lunar environment

References

[1] Johnson, N. Panorama View of Apollo 15 Lunar Surface Photos. Flickr. https://www.flickr.com/photos/nasa2explore/48299975991/in/album-72157635384998736/. Accessed Mar. 21, 2023.

[2] Wright, E. SVS: Visualizing Shackleton Crater. NASA Scientific Visualization Studio. https://svs.gsfc.nasa.gov/4716. Accessed Mar. 14, 2023.

[3] National Aeronautics and Space Administration, and NASA Johnson Space Center. Modification #1 to Amendment #1 to Lunar Terrain Vehicle (LTV) Special Notice - Update #1. sam.gov. https://sam.gov/opp/48c07a7cd6b24f54833397d5bad3dc14/view. Accessed Mar. 21, 2023.

[4] Renishaw plc. Renishaw: Application Note: Optical Encoders and LiDAR Scanning. *Renishaw*. https://www.renishaw.com/en/optical-encoders-and-lidar-scanning--39244.

[5] Williams, D. The Apollo Lunar Roving Vehicle. NASA.gov. https://nssdc.gsfc.nasa.gov/planetary/lunar/apollo_lrv.html. Accessed Feb. 19, 2023.

[6] Wettergreen, D. S., and Barfoot, T. D. Field and Service Robotics. *Springer*, 2016.

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