National Aeronautics and Space Administration

FY25 Strategic University Research Partnership (SURP)

# Applying Human Certification Approaches to Autonomy Assurance


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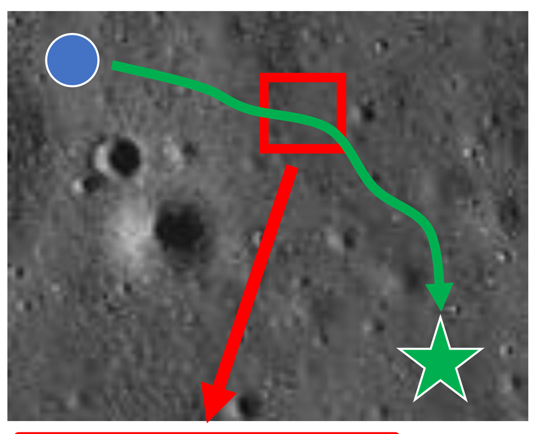
## Objectives

- ✓ Develop Stochastic Programming (SP) solver for autonomy verification and validation (V&V)
- ✓ Use the Endurance mission global path planning as proof of concept
- ✓ Develop effective system for creating and processing a probabilistic map for lunar terrain
- ❑ Remaining work: Test the system's feasibility as a basis for user-centered certification methodology and evaluation tools

## Background



**Using the Endurance mission as use case.**

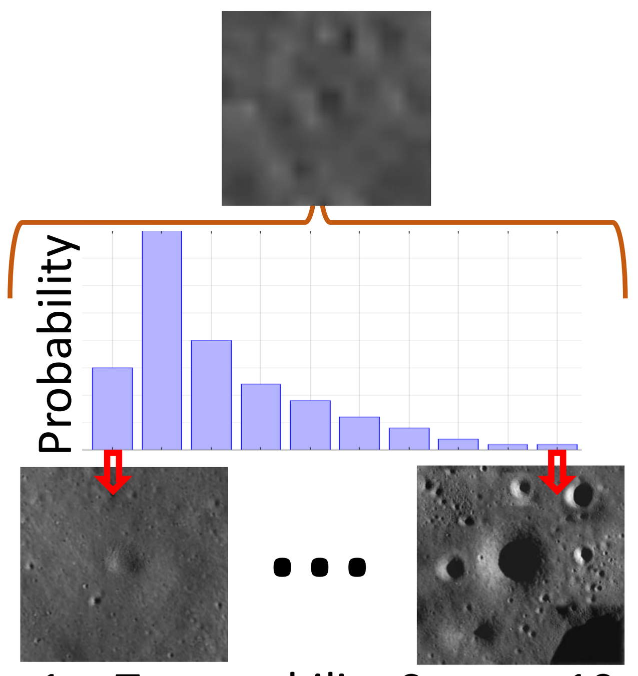
**Satellite imagery** can be used to path plan on the moon.

Satellite imagery is a "blurred version" of the real surface. (.5m/px max resolution)

**It would be useful to predict the unknown surface using the blurry satellite imagery.**

## Traversability Prediction Model

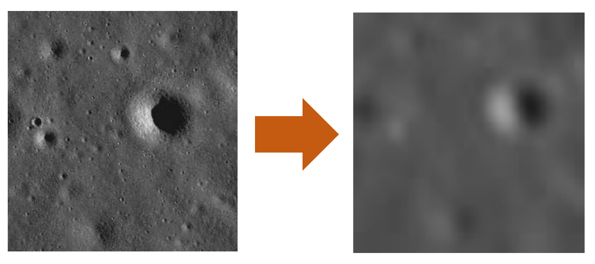
### Multiclass classification




1 <-Traversability Score-> 10

### CV labeling technique

**Score image** **Label image**



**Max resolution** **Blurred**

The model is trained knowing the true score but only seeing the blurred image.

## CV Model Test Results

**Standard Image Processing**
Accuracy: 39.98% RMSE: 1.362

| True Class \ Predicted Class | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1423 | 748 | 433 | 184 | 59 | 16 | 4 | 0 | 0 | 0 |
| 1 | 529 | 608 | 532 | 400 | 165 | 54 | 9 | 2 | 0 | 0 |
| 2 | 210 | 364 | 469 | 561 | 410 | 147 | 41 | 4 | 0 | 0 |
| 3 | 86 | 213 | 351 | 495 | 597 | 308 | 131 | 17 | 2 | 0 |
| 4 | 30 | 88 | 206 | 359 | 536 | 605 | 323 | 94 | 16 | 0 |
| 5 | 16 | 37 | 81 | 153 | 381 | 685 | 593 | 264 | 40 | 0 |
| 6 | 4 | 25 | 50 | 94 | 180 | 445 | 791 | 549 | 155 | 0 |
| 7 | 0 | 5 | 21 | 27 | 80 | 166 | 420 | 951 | 419 | 25 |
| 8 | 0 | 0 | 2 | 3 | 7 | 24 | 62 | 419 | 1322 | 213 |
| 9 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 9 | 242 | 1721 |

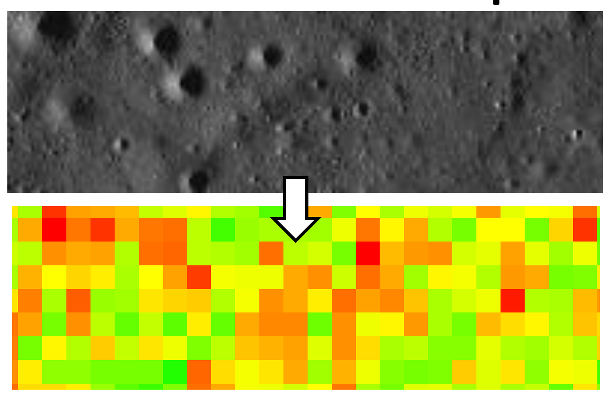
**Our CV Model**
Accuracy: 80.2% RMSE: 0.402

| True Class \ Predicted Class | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 2536 | 261 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 327 | 1605 | 301 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 5 | 354 | 1437 | 251 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 8 | 365 | 1385 | 267 | 1 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 8 | 303 | 1573 | 253 | 1 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 7 | 325 | 1622 | 213 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 1 | 9 | 332 | 1755 | 75 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 7 | 299 | 1694 | 29 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 254 | 2334 | 35 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 141 | 2114 |

**Human Visual Analysis:**
23.7% accuracy 2.462 RMSE
**Random Guessing:**
10% accuracy

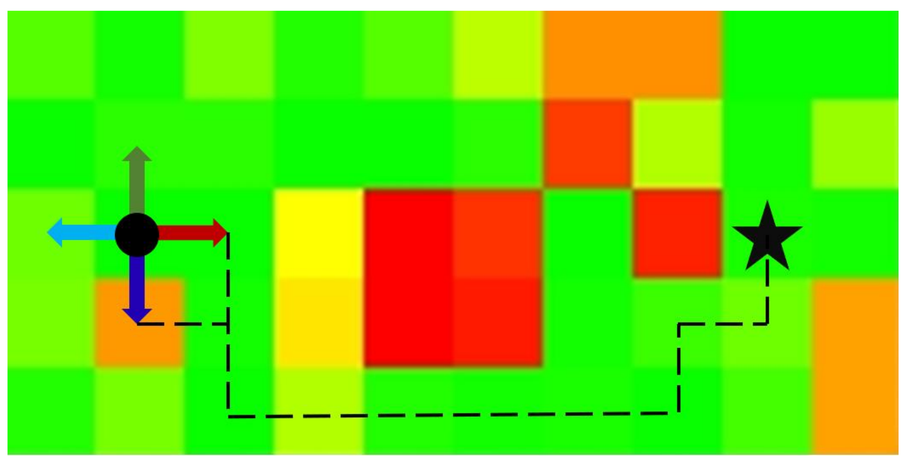
### Cost map

Apply model over larger areas to form **stochastic cost map**



## Stochastic Programming Path Planning

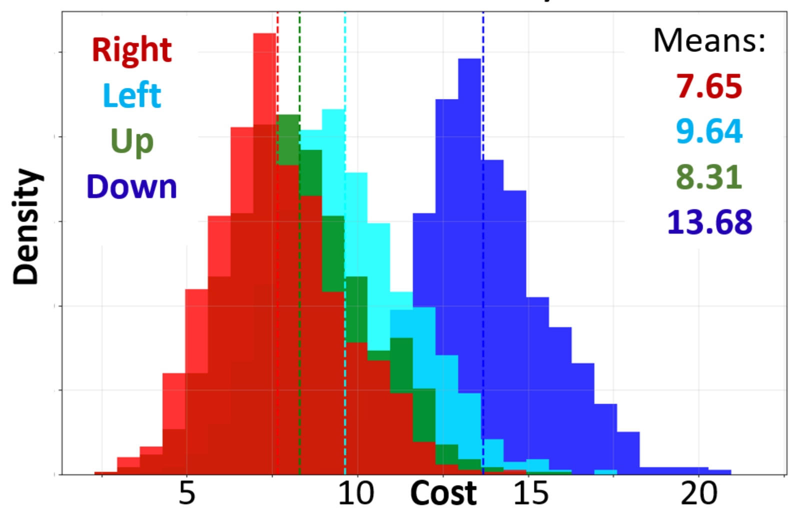
### Sample based decision making



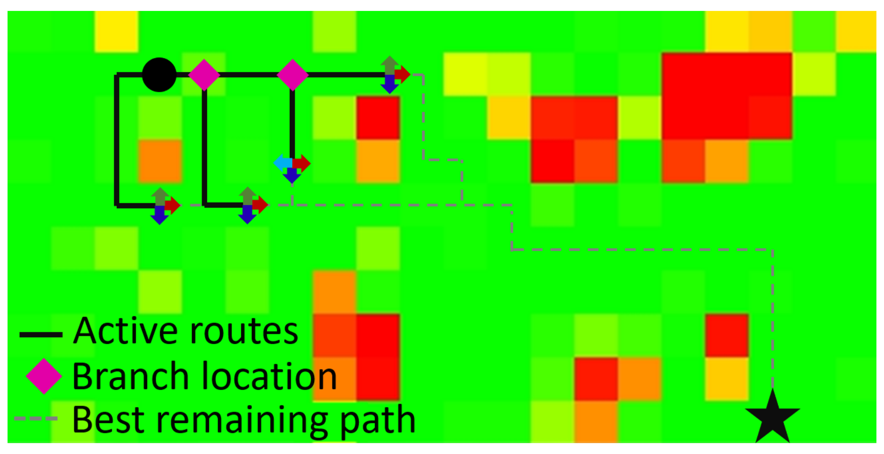
Enumerating all possible realizations is **intractable**. Instead:

- Identify possible moves from current position
- **Sample** a map from the stochastic cost grid
- **Compute** path cost for each move
- **Repeat** until move distributions are informative

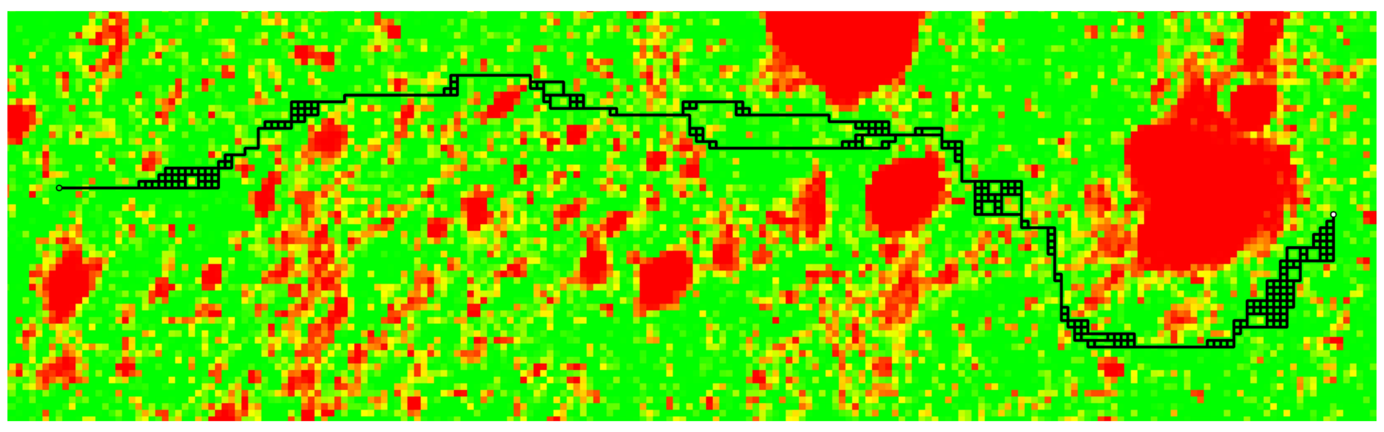
Path cost distributions by initial move



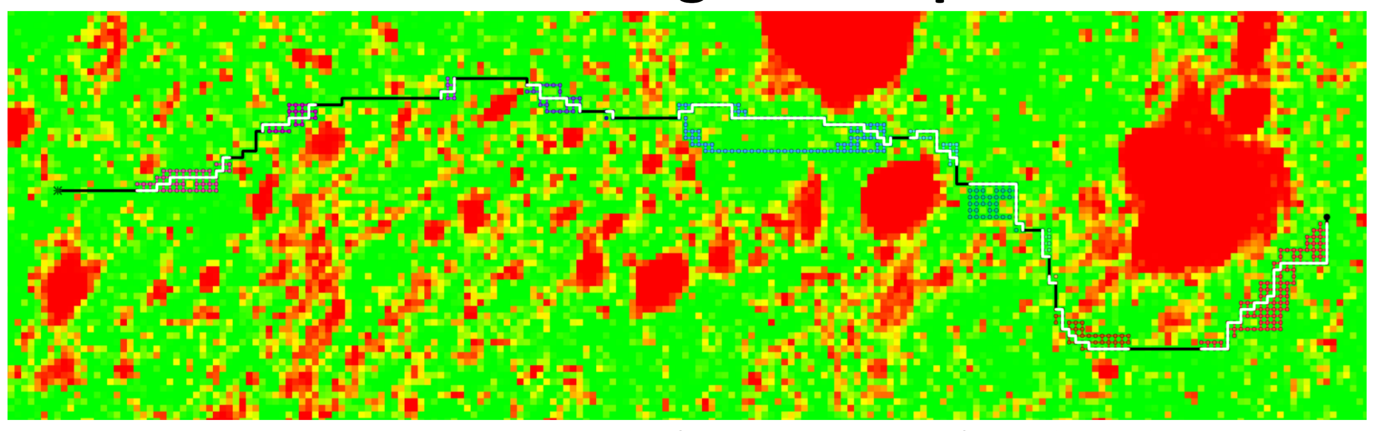

### Iterative decision making




- If sampling limit reached before confidence threshold → **branch** paths
- Use stochastic branch-and-bound to **prune** weaker frontier nodes
- **Repeat** until goal is reached
- Produces a **graph structure** of similar-confidence paths



### Solving the Graph

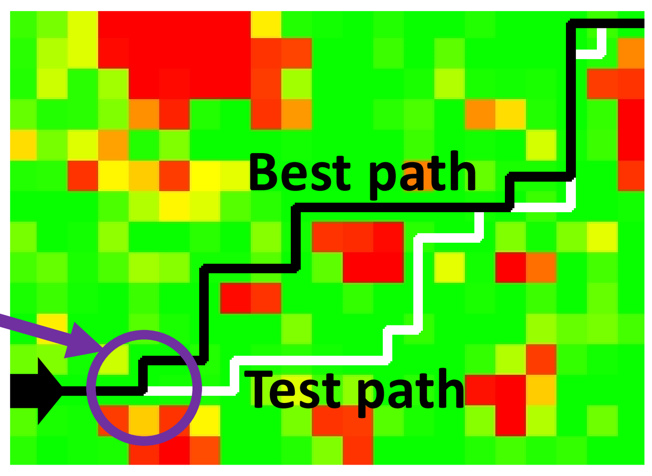


- Split graph into **islands** (node clusters) and **bridges** (connections)
- **Solve islands** using more samples than the first pass
- If confidence is still below threshold, choose by expected value of path distributions
- Produces a single uncertainty-aware **best path**

### Probabilistic decision analysis

- Use this framework to evaluate autonomy decisions probabilistically
- Compare each decision to other available options

"*Best move is 63% likely to result in a better path"





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## Publications:


Garrett Schueller, John-Paul Clarke, Alessandro Pinto, "Analyzing Lunar Imagery Using Computer Vision Models to Improve Path Planning," presented at the 2025 ASCEND Conference, July 22–24, (Control ID 4239449, Paper AIAA-2025-4028).


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