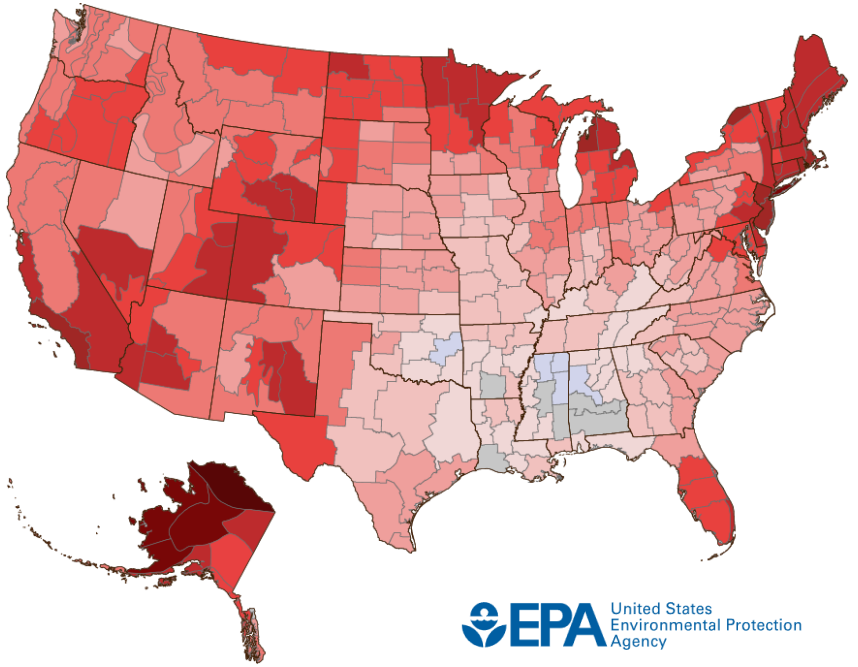
Climate Resiliency and Long-Term Surveillance of Nuclear Facilities and Repositories

Using Aerial and Ground Mobile Platforms



"Sustainably manage addressing severe weather events."

FRTR Spring 2022 Web Meeting

Anthony Abrahao <aabrahao@fiu.edu>
Leonel Lagos <lagosl@fiu.edu>

Miami, Florida

Florida International University

A vibrant, 58,000 student-centered public research university located in Miami, Florida.

Among the largest Hispanic-serving institutions in the U.S. and is designated a Minority-Serving Institution.

As a top-tier research institution, research is a major component in FIU mission.

Long-Term Surveillance of Nuclear Facilities and Repositories using Autonomous Mobile Systems

2019 – 2020 (MSIPP)

Sebastian Zanlongo (Post Doc)
Abdulmueen Alrashide (BS)
Joel Adams (BS)
Samanta Rodrigues (BS)

2020 – Current (DOE-EM)

Joel Adams (PhD)
Thi Tran (BS)

2020 – 2021 (DOE-LM)

Eduardo Rojas (BS)

2021 – Current (MISPP)

Maria Sotolongo(PhD)
Hiba Kahlil (BS)
Javier Figueroa (BS)

2022 – Current (DOE-LM)

Shawn Cameron (MS)

Basic Framework
Navigation
Localization
Perception
Indoor Facilities
Lidar Video Fusion

Tank Farm
Robust Navigation
Terrain Traversability
Mapping

Rifle Disposal Cell
Photogrammetry
Lidar
Unmanned Aerial Vehicle

WIPP
Digital Twin
Machine Learning
Virtual Reality
Augmented Reality

Rifle Disposal Cell
Climate Resilience
Autonomous Ground Platforms
Ground Penetrating Radar

Environmental Robotics

Informative Path Planning
Risk-Awareness
Semantic Mapping

FIU Applied Research Center

U.S. DEPARTMENT OF ENERGY | OFFICE OF ENVIRONMENTAL MANAGEMENT

U.S. DEPARTMENT OF ENERGY
Legacy Management

SRNL
SAVANNAH RIVER NATIONAL LABORATORY

washington river protection solutions
an amentum-led company

Los Alamos
NATIONAL LABORATORY

Pacific Northwest
NATIONAL LABORATORY

Funding

- 2019 DOE-MSIPP
- 2021 DOE-MSIPP
- DOE-EM FIU-ARC Cooperative Agreement
- DOE-LM FIU-ARC Cooperative Agreement

Technology Development and Deployment Road Map

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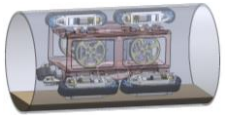
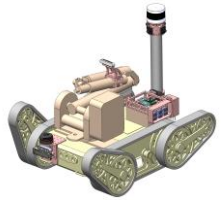
Technology	2020	2021	2022	2023	2024
Hanford Tank Farm	 In-house Deployment	Site Deployment	Site Deployment		
	 Conceptual Design	Evaluation	In-house Deployment	Site Deployment	
	 Conceptual Design	Evaluation	Evaluation	In-house Deployment	Site Deployment
	 Cold Test Facility Deployment	Site Deployment			
H Canyon SRNL	 Conceptual Design	Sensor Integration	Evaluation	In-house Deployment	Site Deployment
WIPP	 Evaluation	In-house Deployment	Site Deployment		
LM Site	 Evaluation	Site Deployment			
	 Evaluation	Site Deployment			

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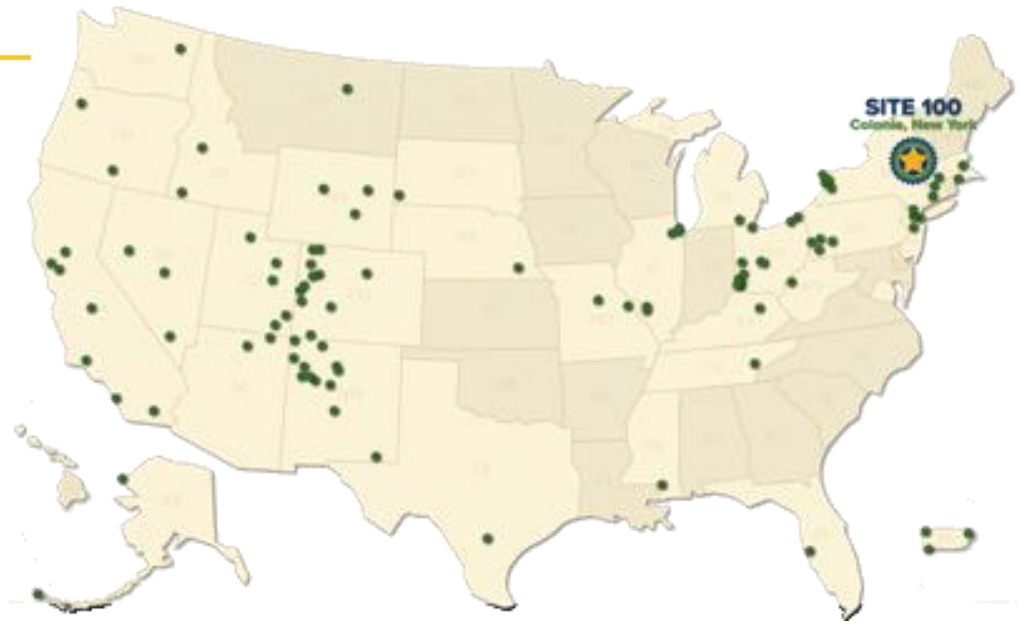
Climate Resiliency and Long-Term Surveillance of Disposal Cells

U.S. DEPARTMENT OF ENERGY

Legacy Management



DOE-LM is responsible for the long-term surveillance and maintenance, property management, land use planning, and community assistance for **101 sites** in the United States and the territory of Puerto Rico.

Objective

FIU current main goal is to evaluate the feasibility of utilizing traditional

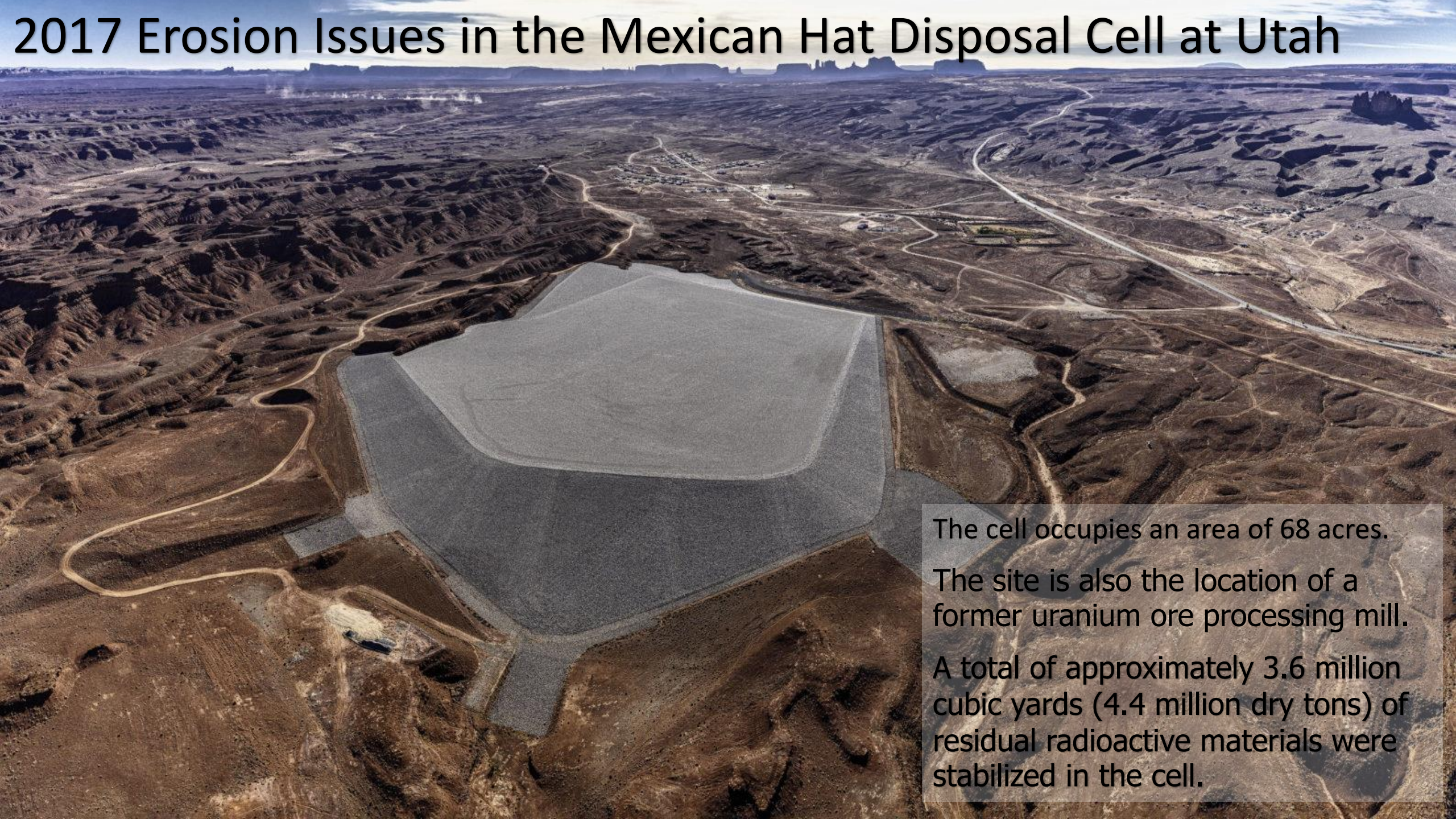
- remote sensing,
- geophysical technologies, and
- state-of-the-art sensory

for cost-effective site characterization and monitoring of existing conditions at the LM's disposal cells.

Relevance

Contribute to Goal 4 of LM's 2020-2025 Strategic Plan: *"Sustainably manage and optimize the use of land and assets, addressing severe weather events."*

2017 Erosion Issues in the Mexican Hat Disposal Cell at Utah



The cell occupies an area of 68 acres.

The site is also the location of a former uranium ore processing mill.

A total of approximately 3.6 million cubic yards (4.4 million dry tons) of residual radioactive materials were stabilized in the cell.

The disposal cell is designed to be effective for at least 200 years

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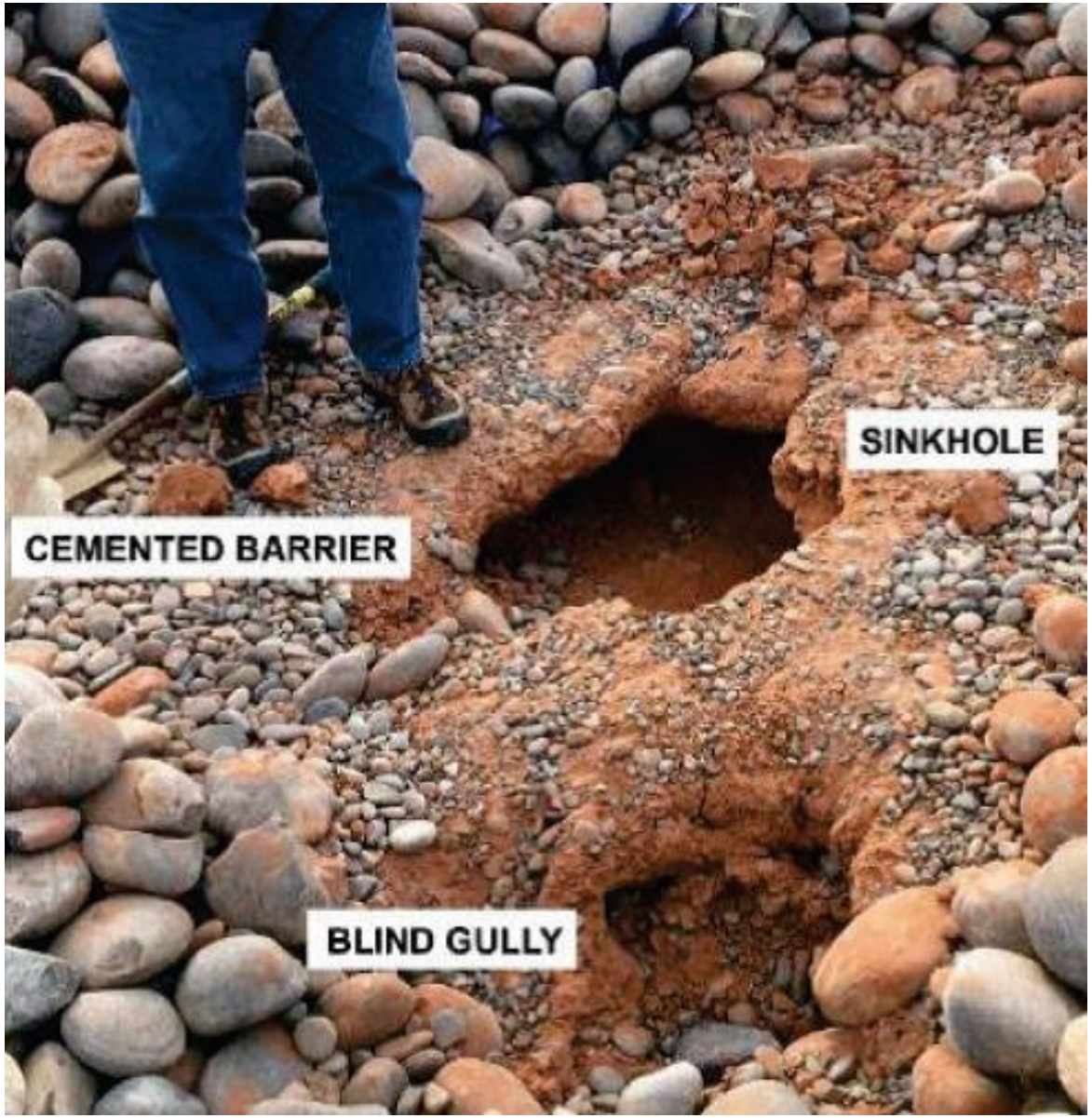
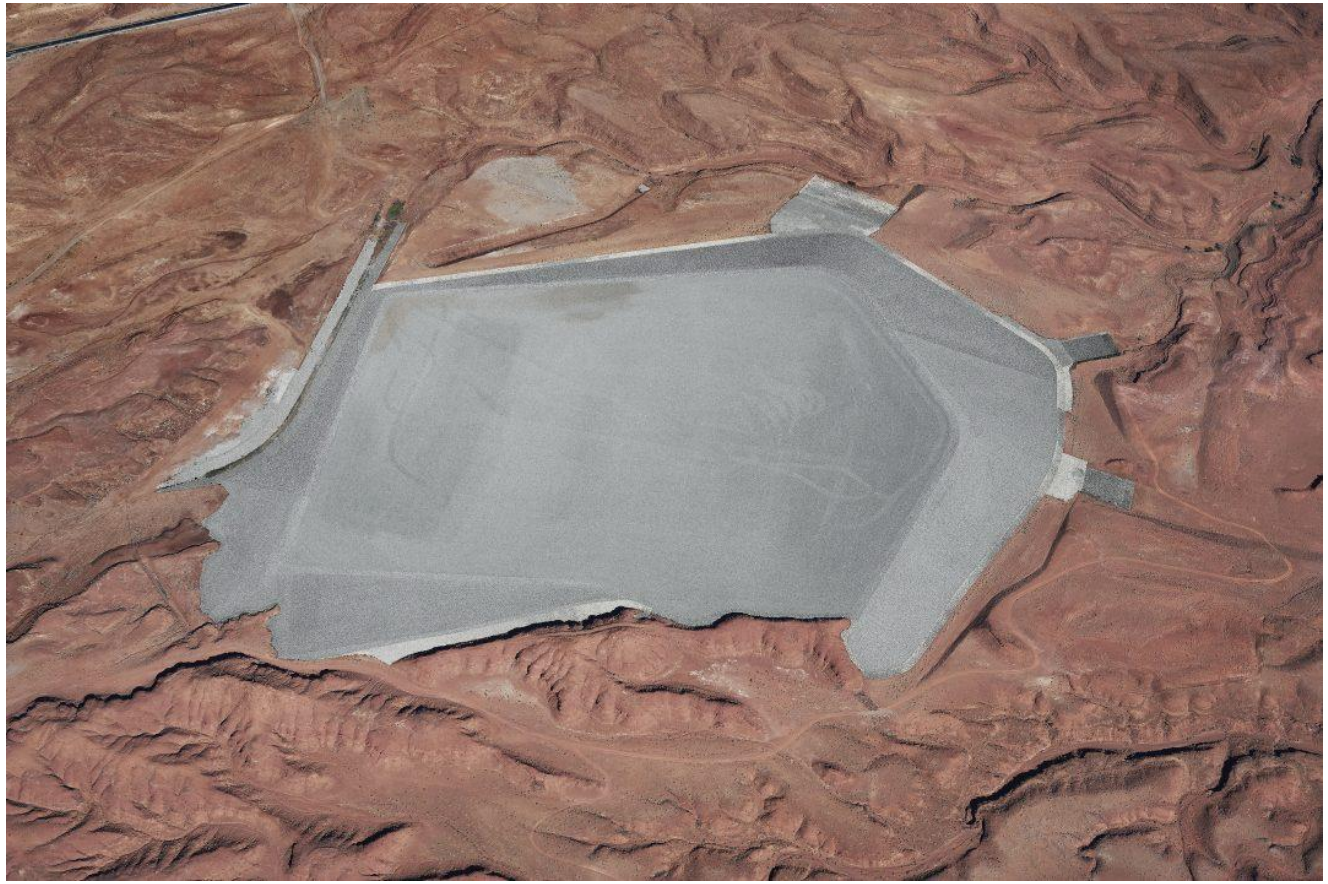
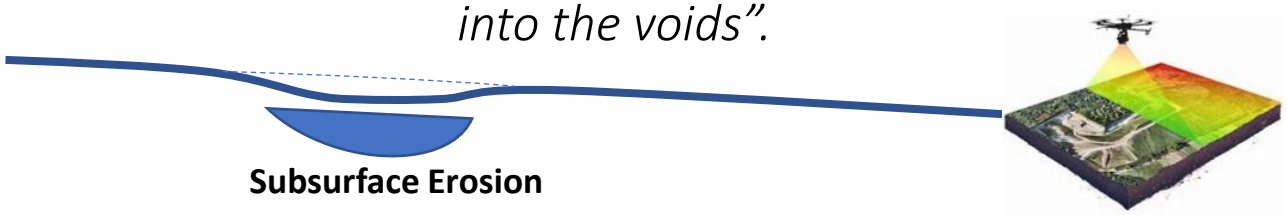


Erosion discovered in 2017



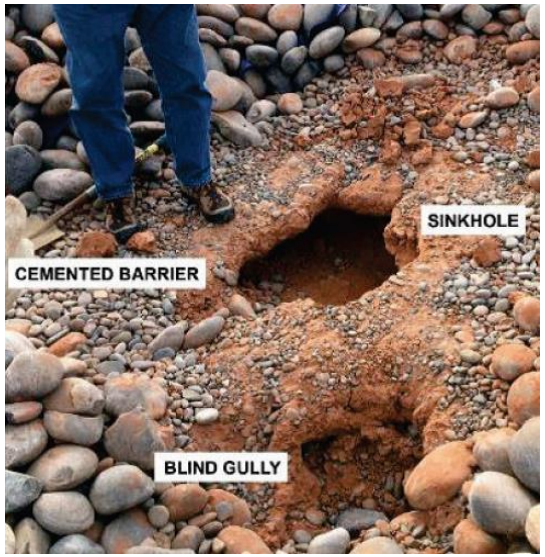
"The erosion only manifested itself on the surface as slight depressions where the rock cover had subsided into the voids".



Subsurface Erosion

Potential Causes

Construction issues including the use of dispersive clays in the interbed layers between the radon barrier and the overlying rock cover.



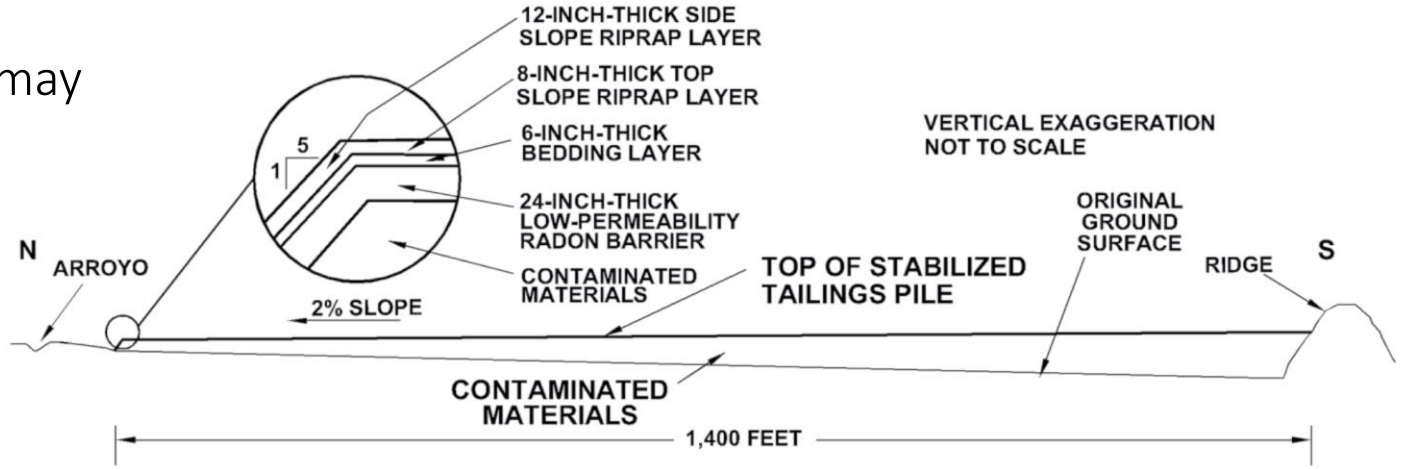
However, LM does suspect climate change is a contributing cause.

"Despite the southwest USA being in a terrible drought, climate change projections that precipitation events will be more intense is showing up in the meteorological record for the site."

During short, intense rainfall events, the rock cover essentially plays little role in slowing runoff.

Rounded cobbles instead of angular rock probably may also, be a factor since water runs off them and into interstices faster than angular rock.

Other LM's sites may have similar features!



Typical cell cross section

Non-evasive Techniques for Evaluating Disposal Cells

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Sensor Fusion
Lidar
3D Cameras
Video
Environmental Data
Photogrammetry
Ground Penetrating Radar

Autonomous Mobile Platforms
Ground and Aerial
Terrain risk-awareness
Informative Path Planning

Weather Trend Analysis
Public available datasets

Digital Twins

Data *"Time Machine"*
Automate change detection over time
Machine Learning
GPU

Immersive Inspections
Virtual Reality
Augmented Reality

Simulation
Hydrological modeling
Geomechanical modeling

"Investigate the extent and depth of such erosion features without having to pull back a lot of material since ***if the radon barrier has been eroded there is a risk of radiological exposure."***

Aerial Platforms

Aerial Lidar and Photogrammetry Mapping

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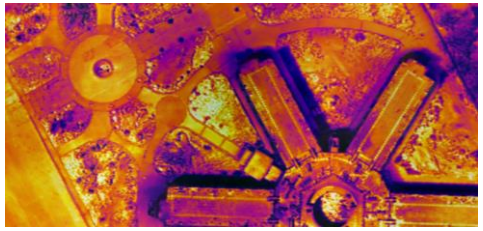
Delivery Platform + Sensory + Applications

Onsite UAV surveys?

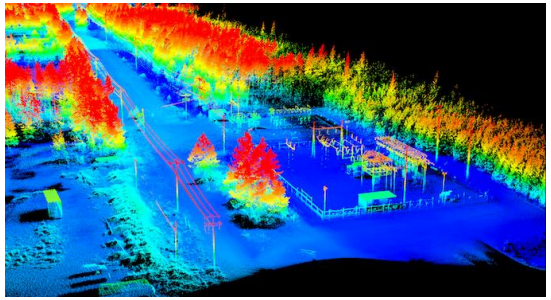
- Centimeter-level precision
- Cost-effective
- Meaningful data at your disposal
- Broad custom-built sensory
- See beneath the surface
- Automated data collection
- Machine Learning historical change
- Data-driven decision-making

Multispectral

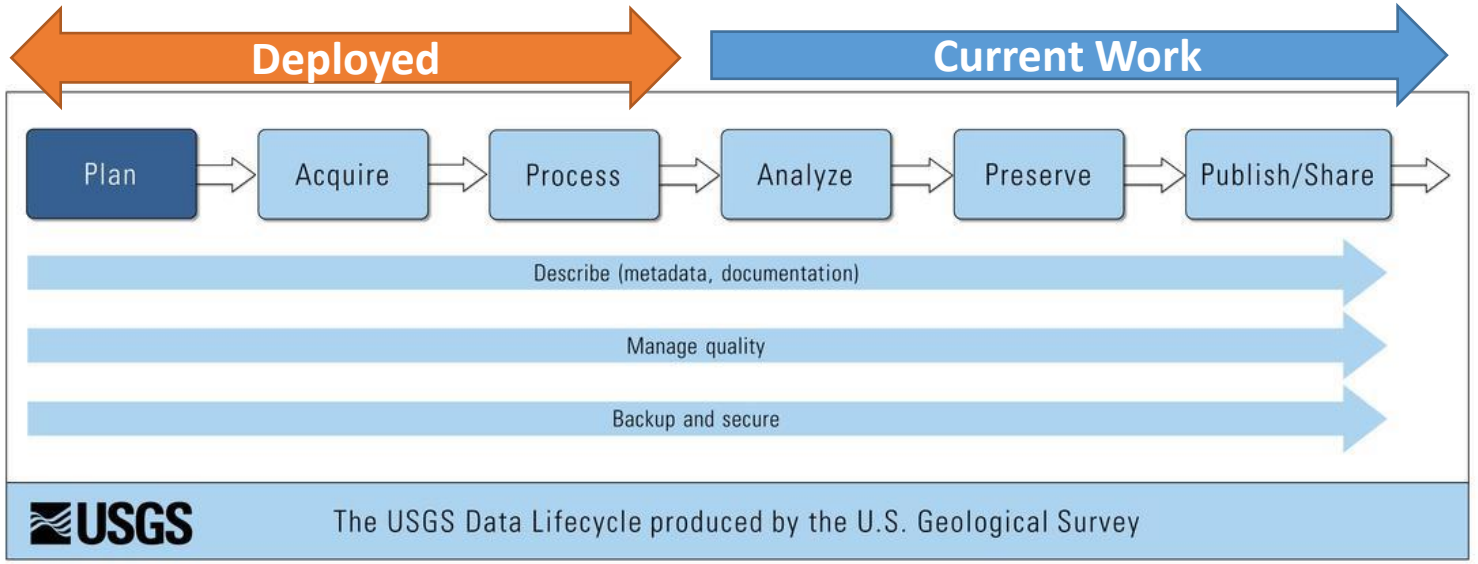


Thermal

RGB



LiDAR



In-house Lidar System

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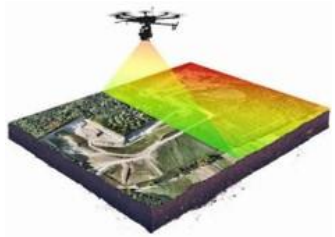
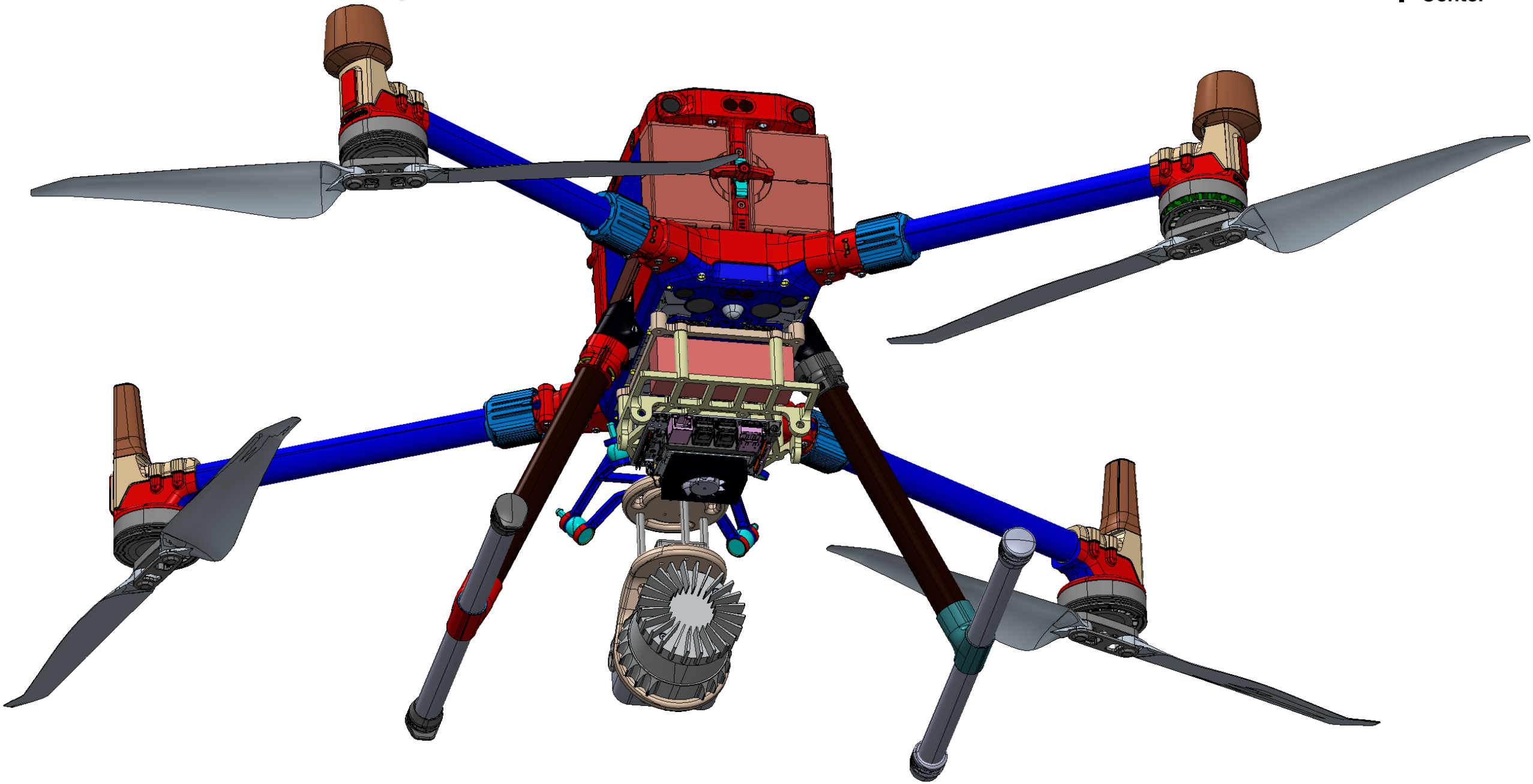


In-house Lidar System

FIU | Applied Research Center



In-house Lidar System

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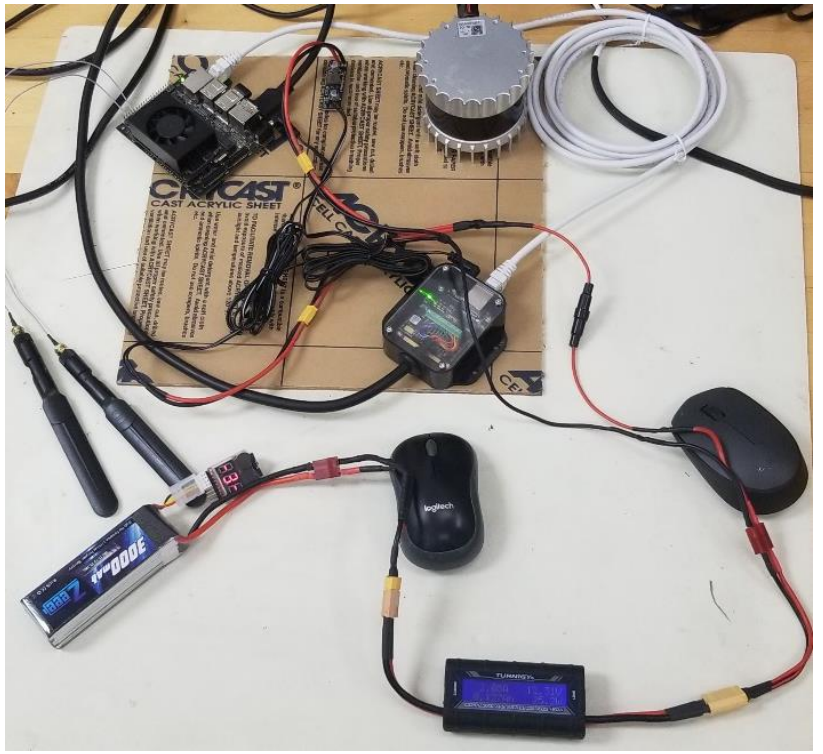
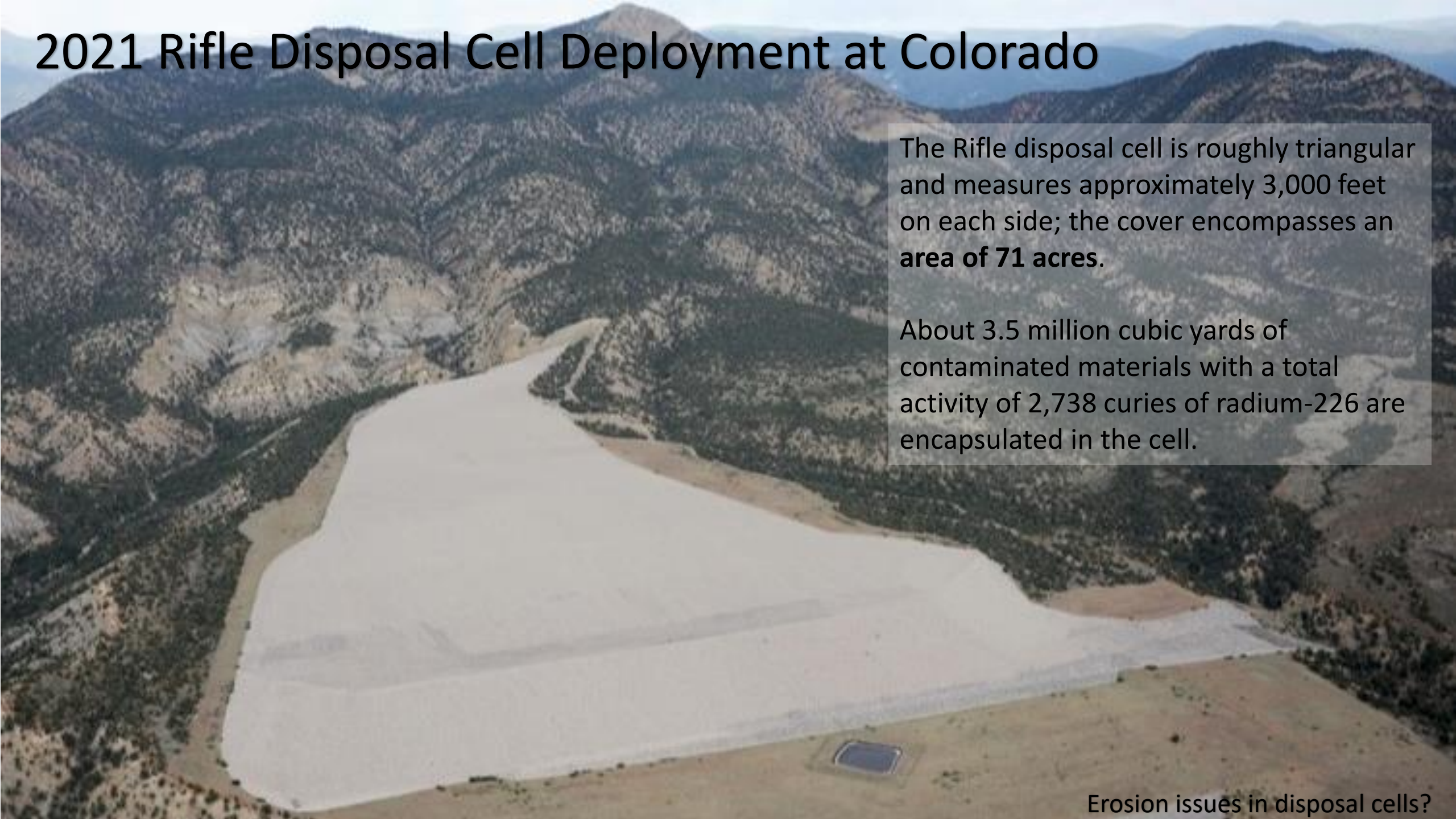


2021 Rifle Disposal Cell Deployment at Colorado



The Rifle disposal cell is roughly triangular and measures approximately 3,000 feet on each side; the cover encompasses an **area of 71 acres**.

About 3.5 million cubic yards of contaminated materials with a total activity of 2,738 curies of radium-226 are encapsulated in the cell.

Erosion issues in disposal cells?

Deployment Preparation

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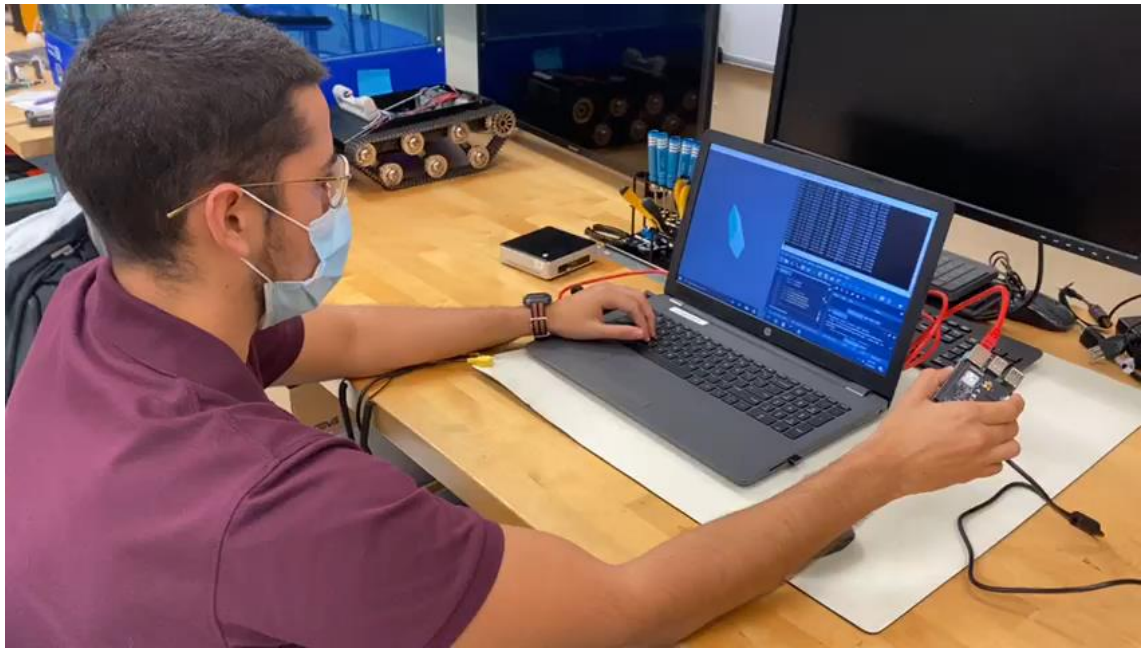

- Aviation safety plan submition
- Obtain pilot license
- Perform safety briefings
- Flight mission Inspections
- Conduct pre/pos flight checklist
- Act as Remote Pilot in Command
- Delegate and instruct flight crew

2021 Rifle Disposal Cell Deployment

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2021 Rifle Disposal Cell Deployment

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Rifle’s Digital Twin

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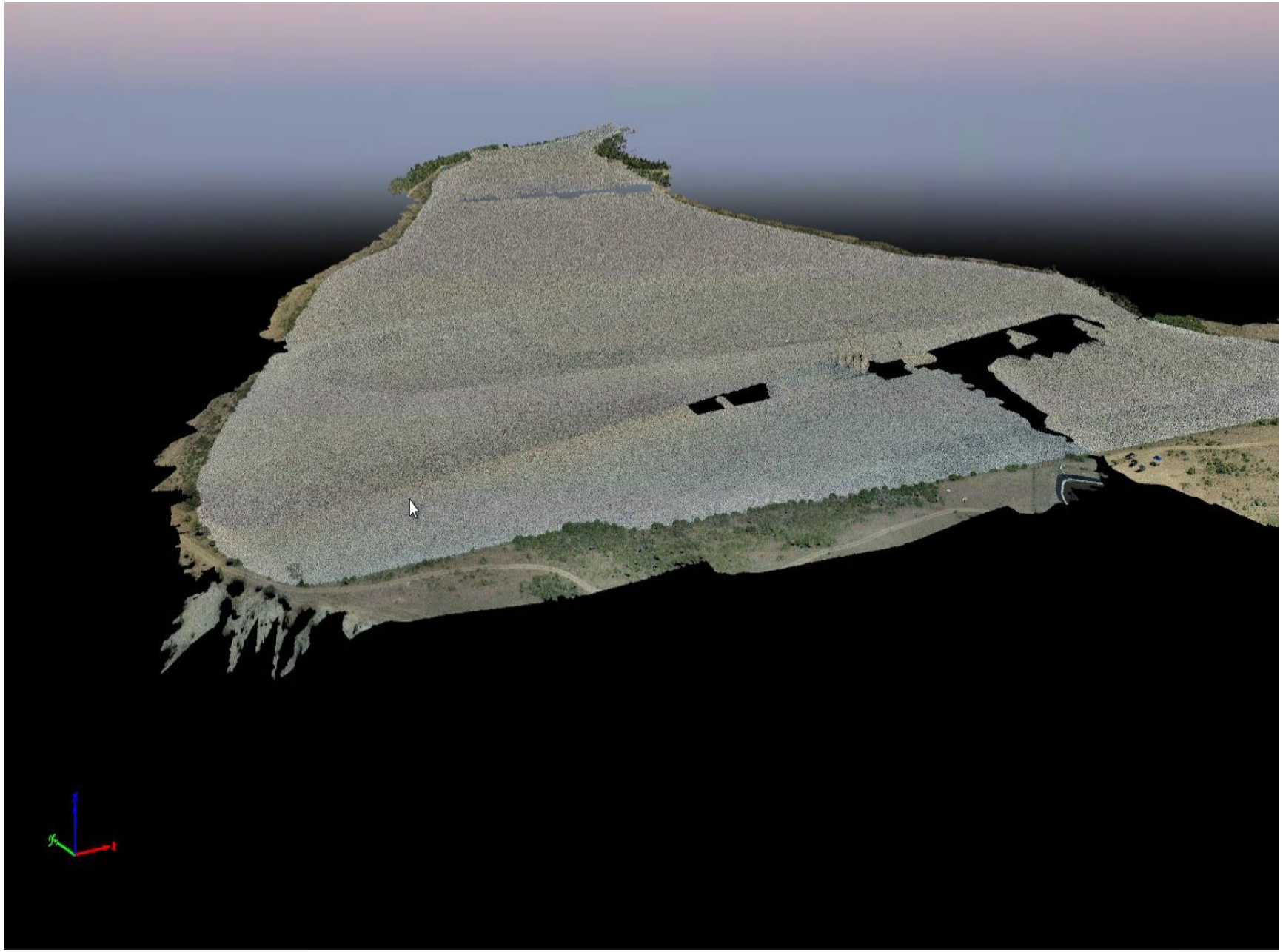

Rifle's Digital Twin and Elevation Model

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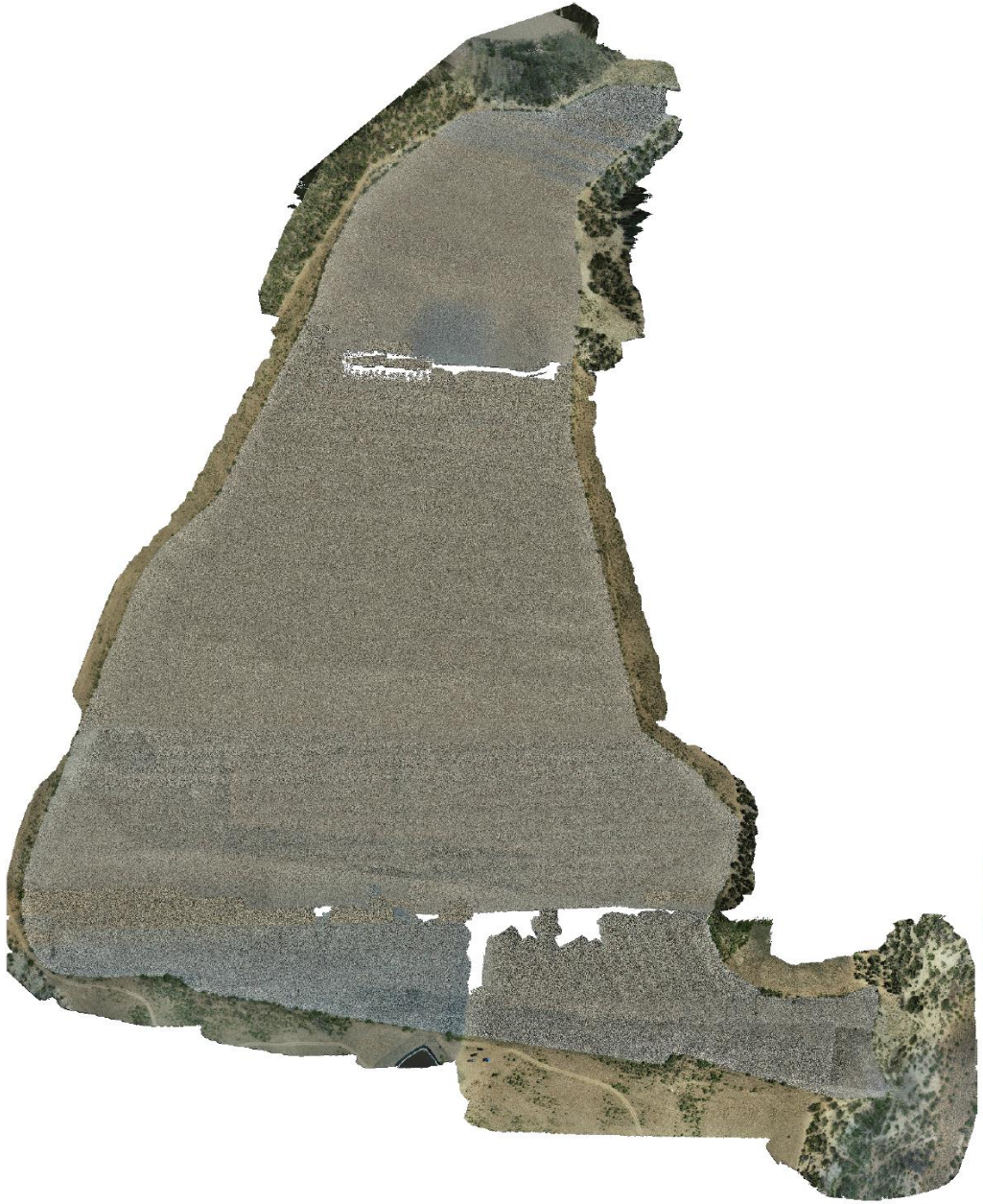
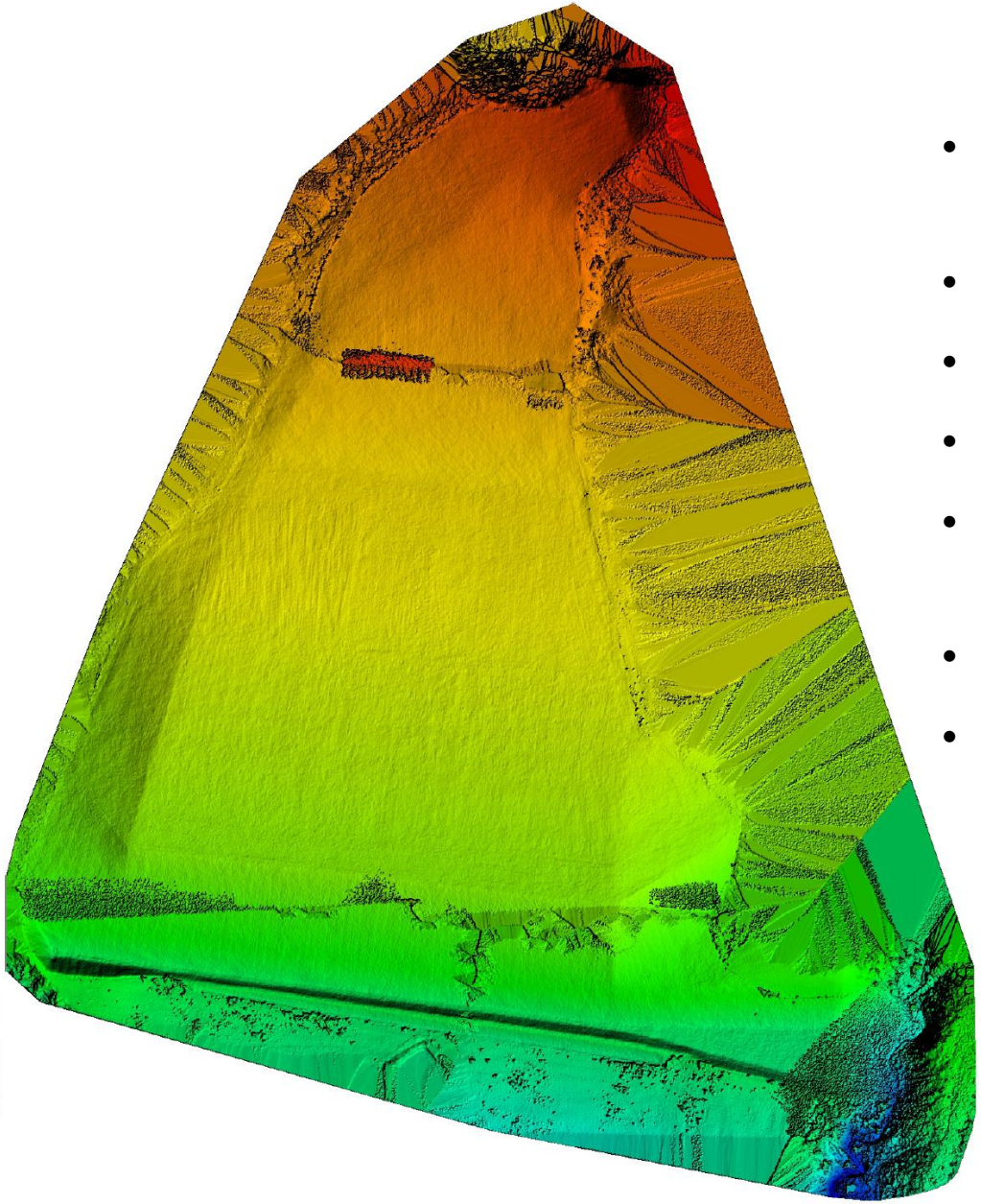
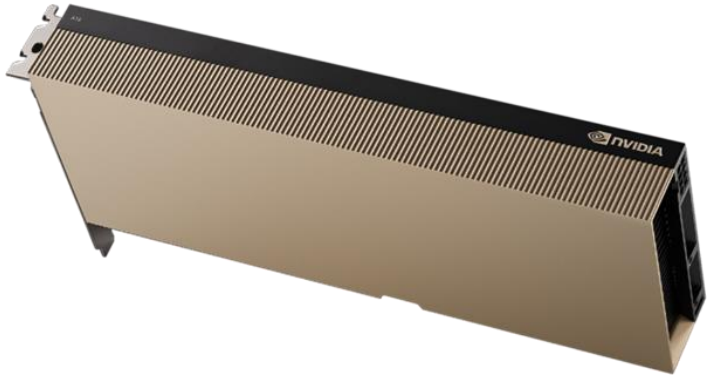




- 5,266 high-resolution aerial images
- One week survey
- Crew of four
- High liabilities
- Restrictive FAA regulations
- Weather constrains
- Extreme heat

Erosion analysis using potholes detection and Machine Learning

Graphical Process Unit (GPU)



“Data is Cheap,
Information is Expensive”

Data is raw and unorganized

↓

Information has meaning and context

NVIDIA A100 TENSOR CORE GPU SPECIFICATIONS (SXM4 AND PCIE FORM FACTORS)

	A100 80GB PCIe	A100 80GB SXM
FP64	9.7 TFLOPS	
FP64 Tensor Core	19.5 TFLOPS	
FP32	19.5 TFLOPS	
Tensor Float 32 (TF32)	156 TFLOPS | 312 TFLOPS*	
BFLOAT16 Tensor Core	312 TFLOPS | 624 TFLOPS*	
FP16 Tensor Core	312 TFLOPS | 624 TFLOPS*	
INT8 Tensor Core	624 TOPS | 1248 TOPS*	
GPU Memory	80GB HBM2e	80GB HBM2e
GPU Memory Bandwidth	1,935GB/s	2,039GB/s
Max Thermal Design Power (TDP)	300W	400W***
Multi-Instance GPU	Up to 7 MIGs @ 10GB	Up to 7 MIGs @ 10GB
Form Factor	PCIe dual-slot air cooled or single-slot liquid cooled	SXM
Interconnect	NVIDIA® NVLink® Bridge for 2 GPUs: 600GB/s ** PCIe Gen4: 64GB/s	NVLink: 600GB/s PCIe Gen4: 64GB/s
Server Options	Partner and NVIDIA-Certified Systems™ with 1-8 GPUs	NVIDIA HGX™ A100-Partner and NVIDIA-Certified Systems with 4,8, or 16 GPUs NVIDIA DGX™ A100 with 8 GPUs

Object Detection Using Machine Learning

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On-Board in Real-time

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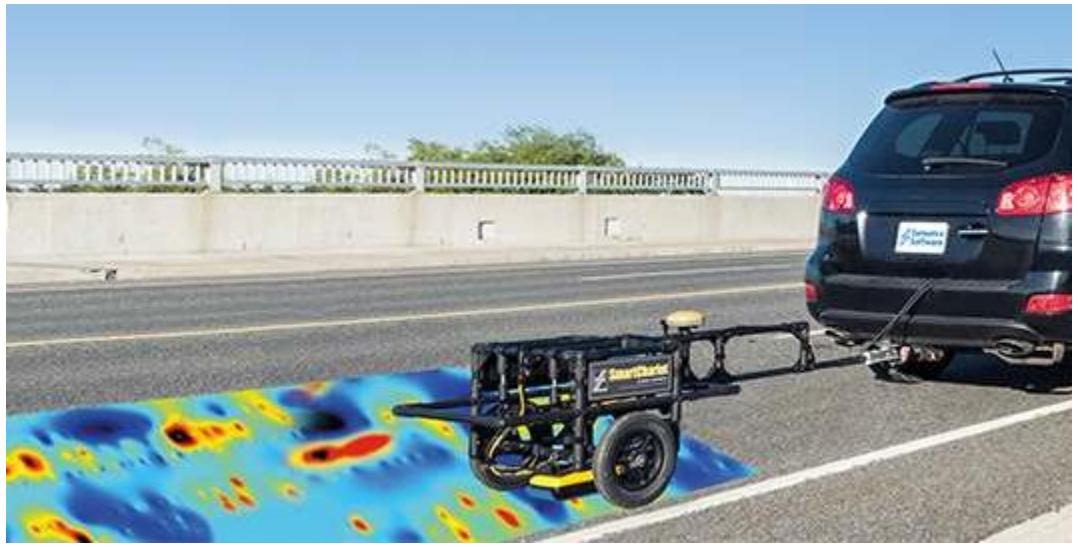
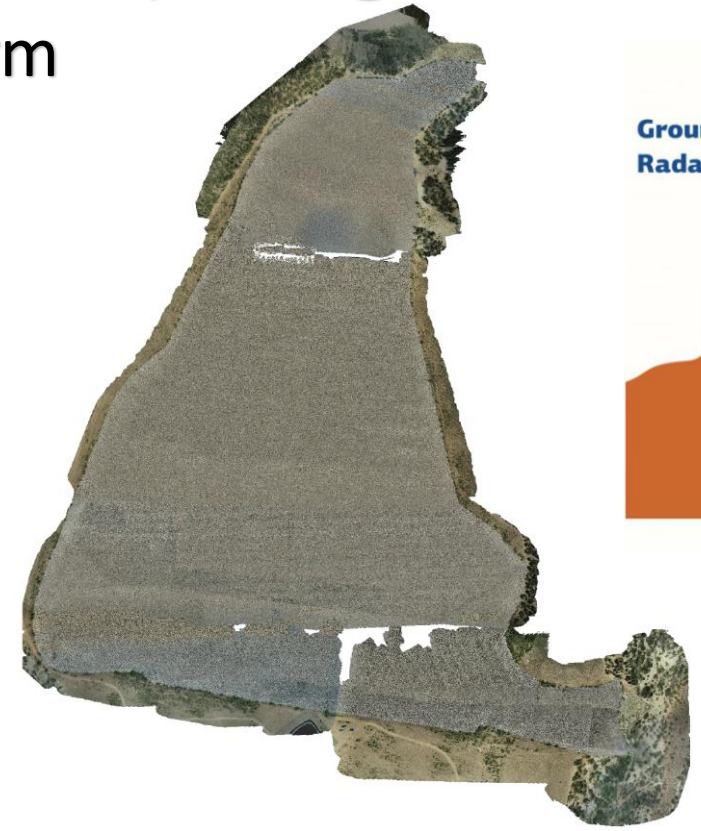
Autonomous Ground Platforms

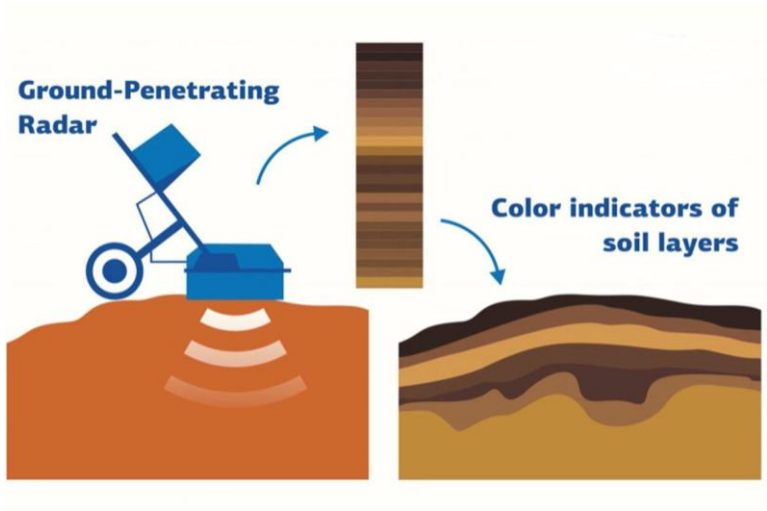
Ground Penetrating Radar (GPR) Integration

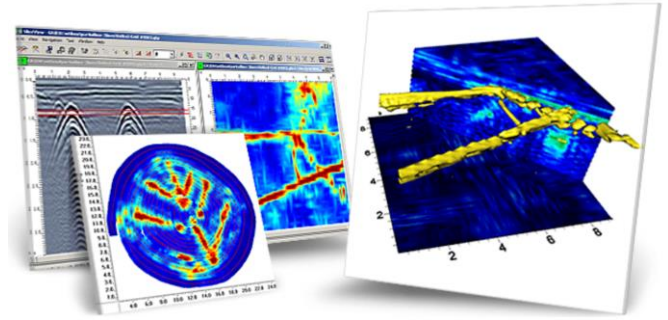
into an Autonomous Ground Platform

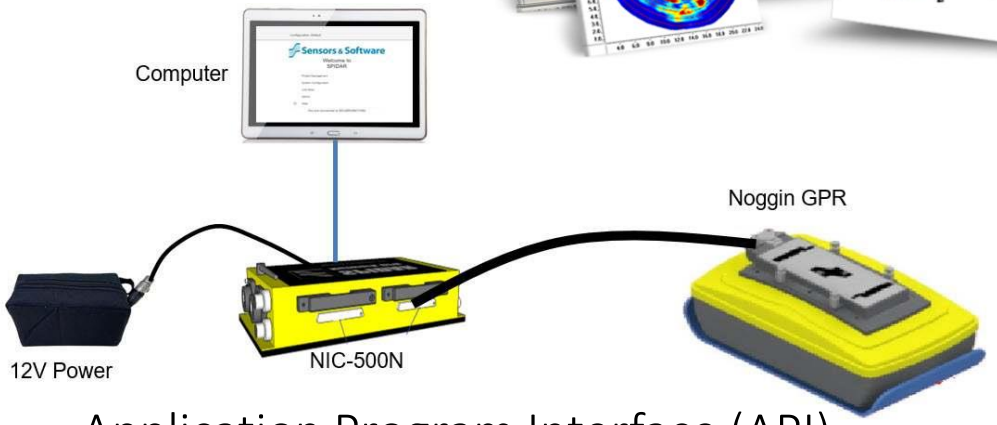
SENSORS & SOFTWARE
from RADIODETECTION











Application Program Interface (API)

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Why Autonomous Systems?

1. Reduce unnecessary radiation exposure
   Remote system

2. Provide quality data → **AI and big data!**
   Global reference frame
   Timestamp

3. Build dynamic models → **Understanding, prediction and decision-making!**
   Frequent periodic missions
   Evolution in time

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Why Unsupervised Autonomous Systems?

IBM Pollyanna Principle

"machines should work; people should think."

- e.g. machines should do all the hard work, freeing people to think
- e.g. most of the world's **major problems result** from:
  - **machines that fail to work, and**
  - **people who fail to think.**

In-house Ground Platform

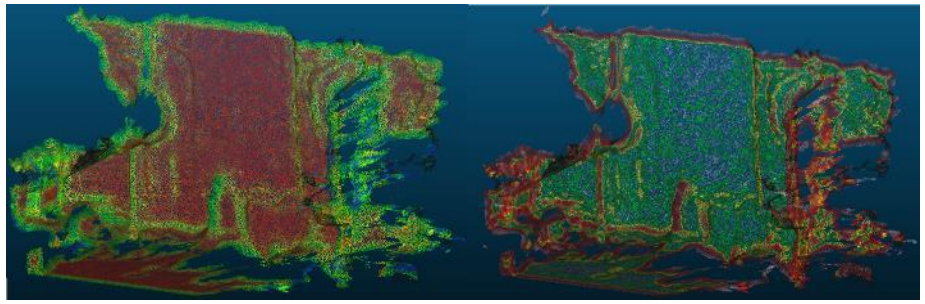
- Data fusion
  GPR
  Lidar
  3D Cameras
  IMUs
- Fully Autonomous
- Terrain risk-awareness
- Roughed
- All-terrain
- Driving effort feedback
- High payload
- Weatherproof
- Solar powered

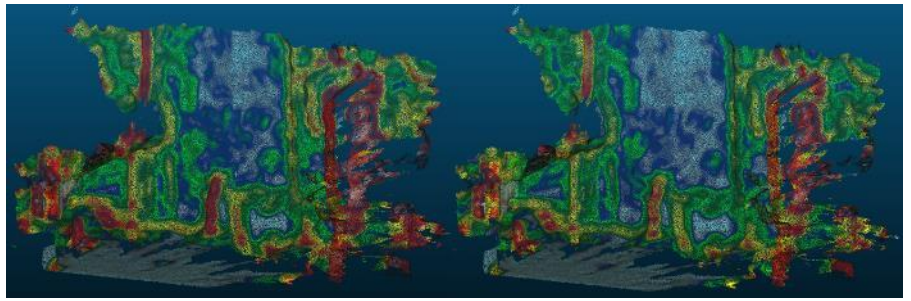
Sensor Uncertainty Quantification

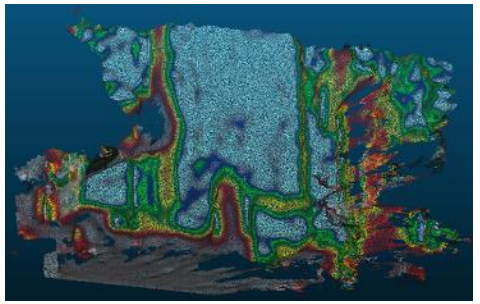
3D imagers interact with environments, surfaces, materials, angles, and locations?

*"For visualization is okay; however, for baseline measurement requires **Information-driven planning and control**!"*

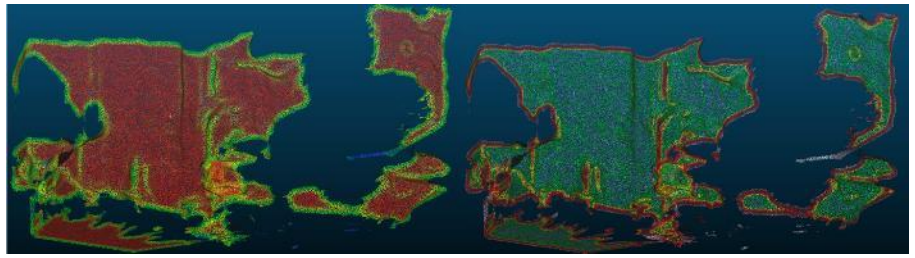
Intel Realsense 3D D415 Camera

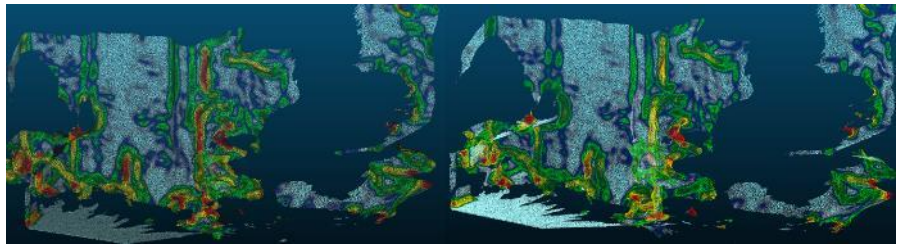


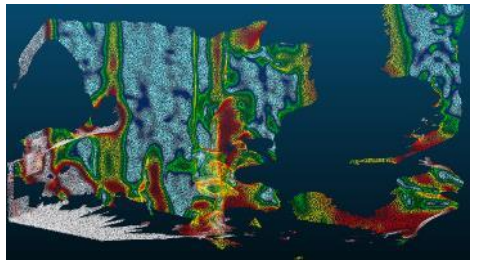




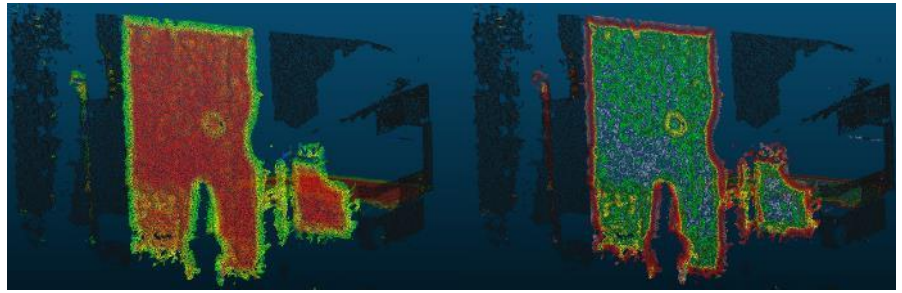
Intel Realsense 3D D455 Camera

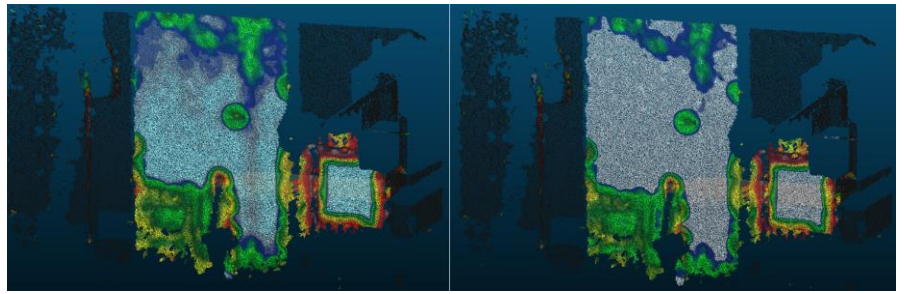


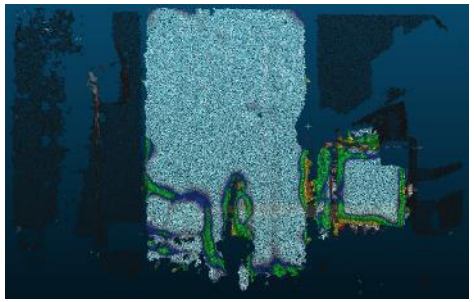




Intel Realsense L515 Solid-State Lidar



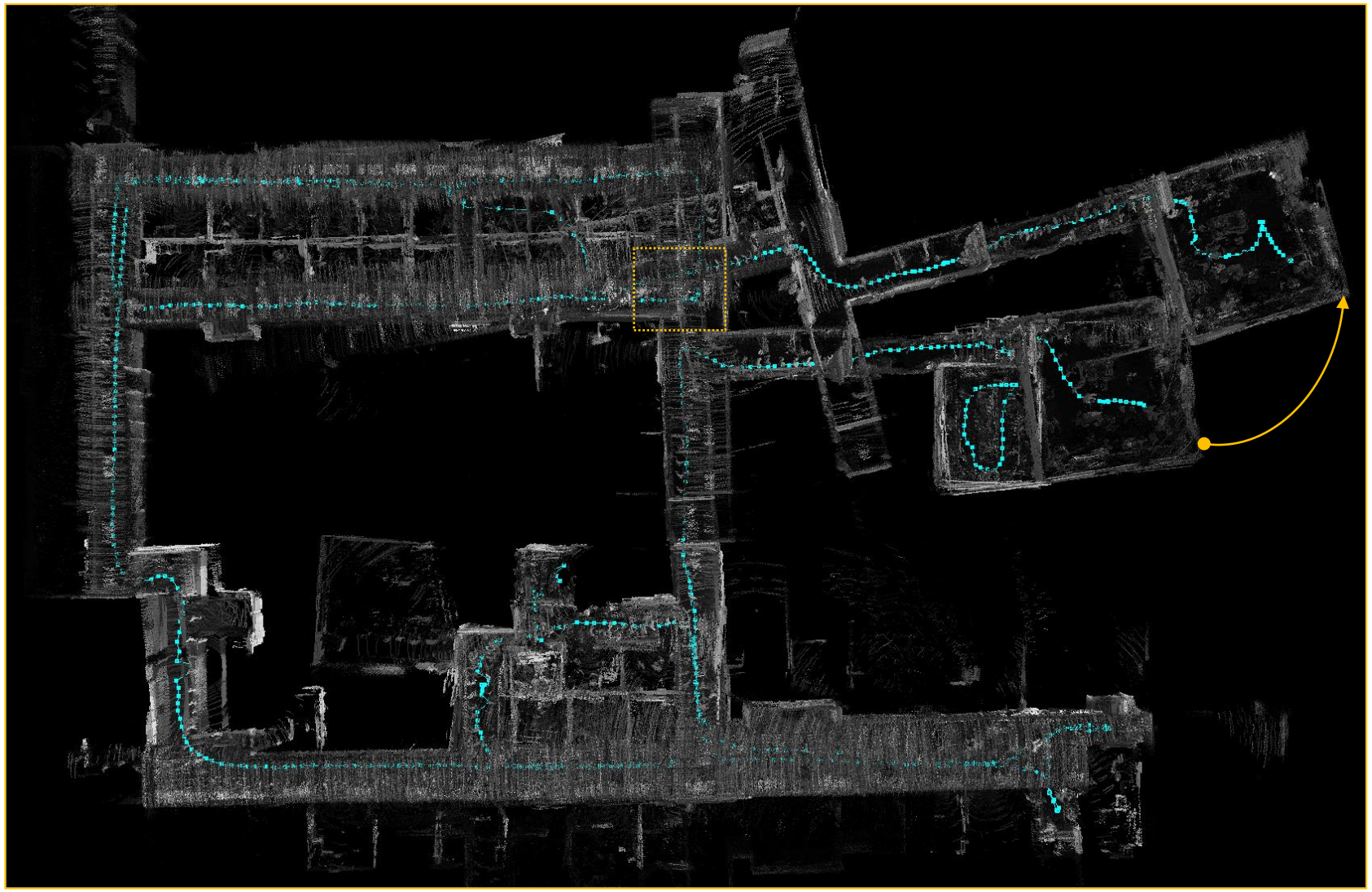


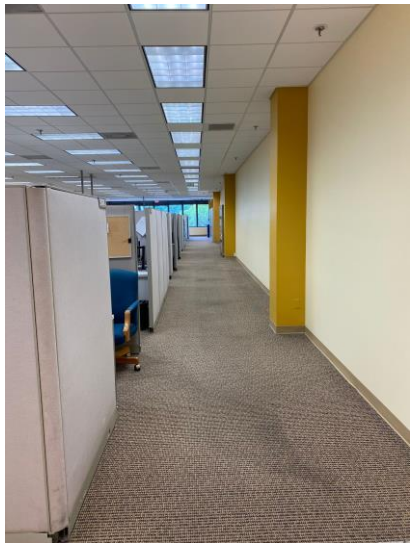


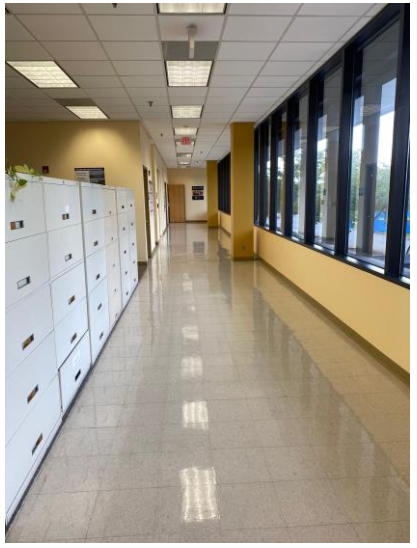
Metrics **Planarity** **Linearity** **Surface Variation** **Sphericity** **Verticality**

Information-driven planning and control

"The sensing system act as an agent using perception of the environment to make decisions about actions to take."







In-house Testing Areas

"Teaching our framework to be smart and robust"

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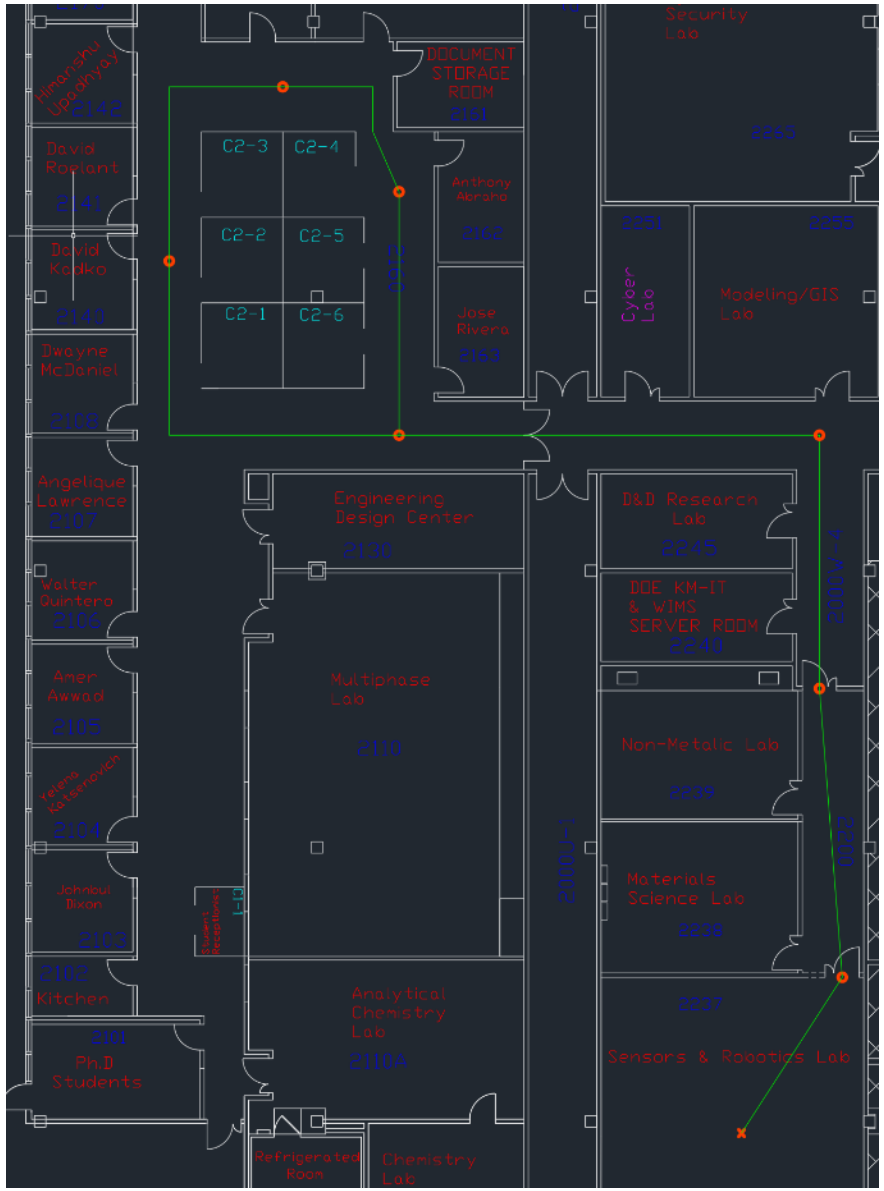
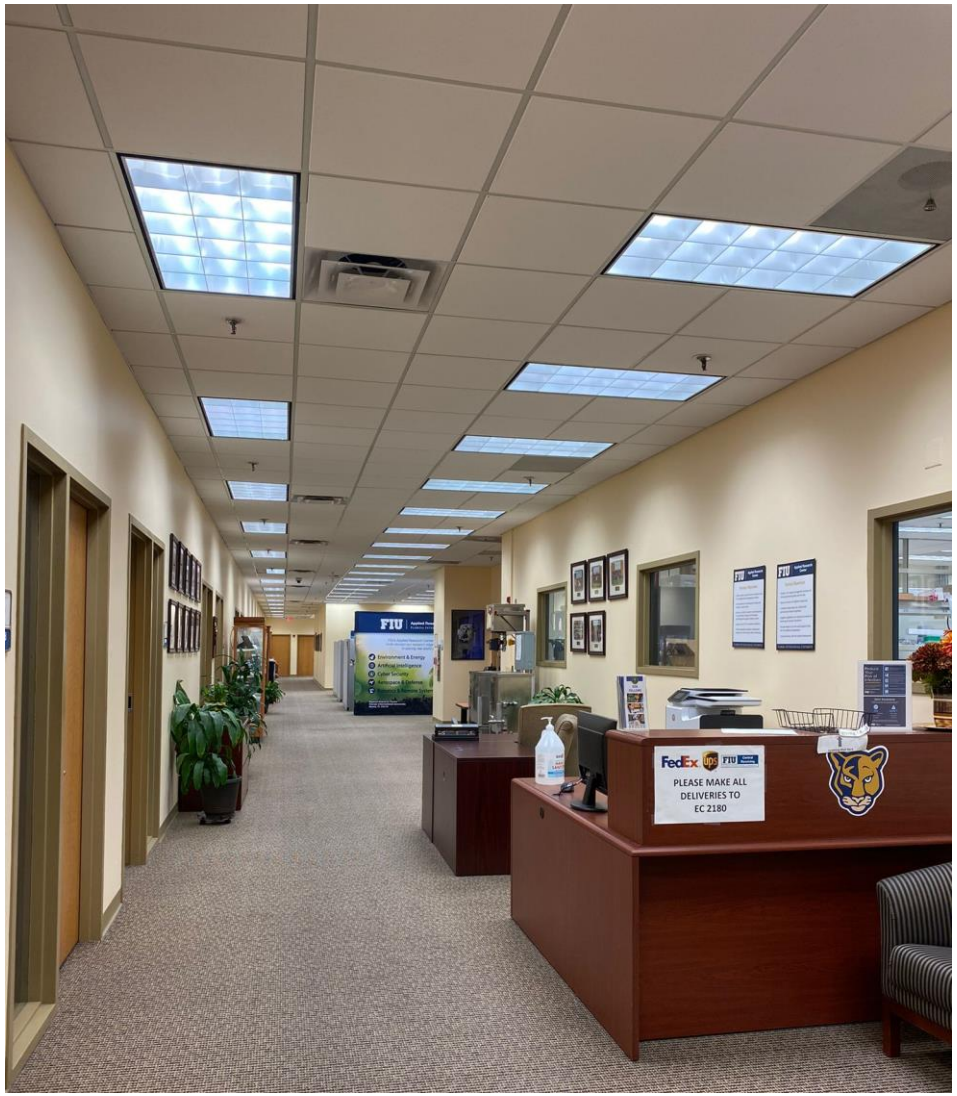


FIU-ARC main floor

Engineering Center Parking Lot

On-board Terrain Risk-awareness

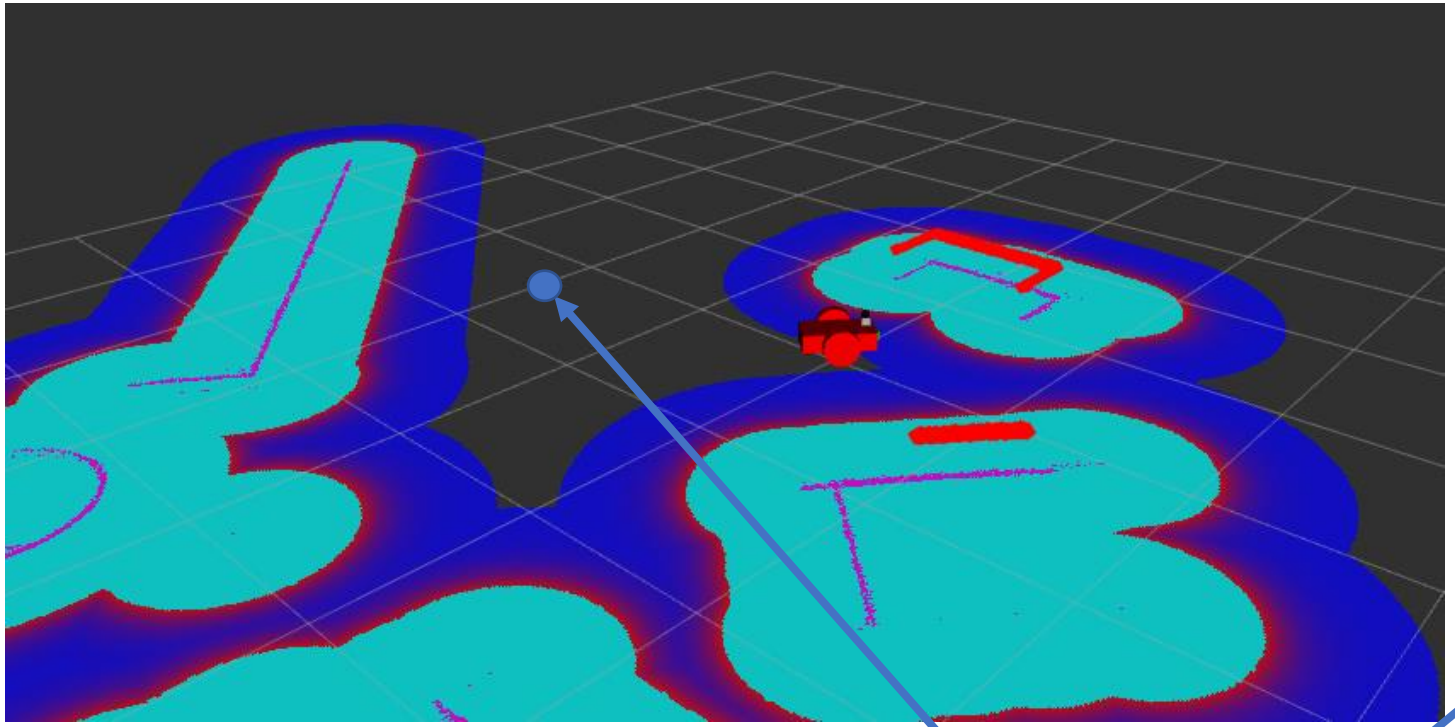


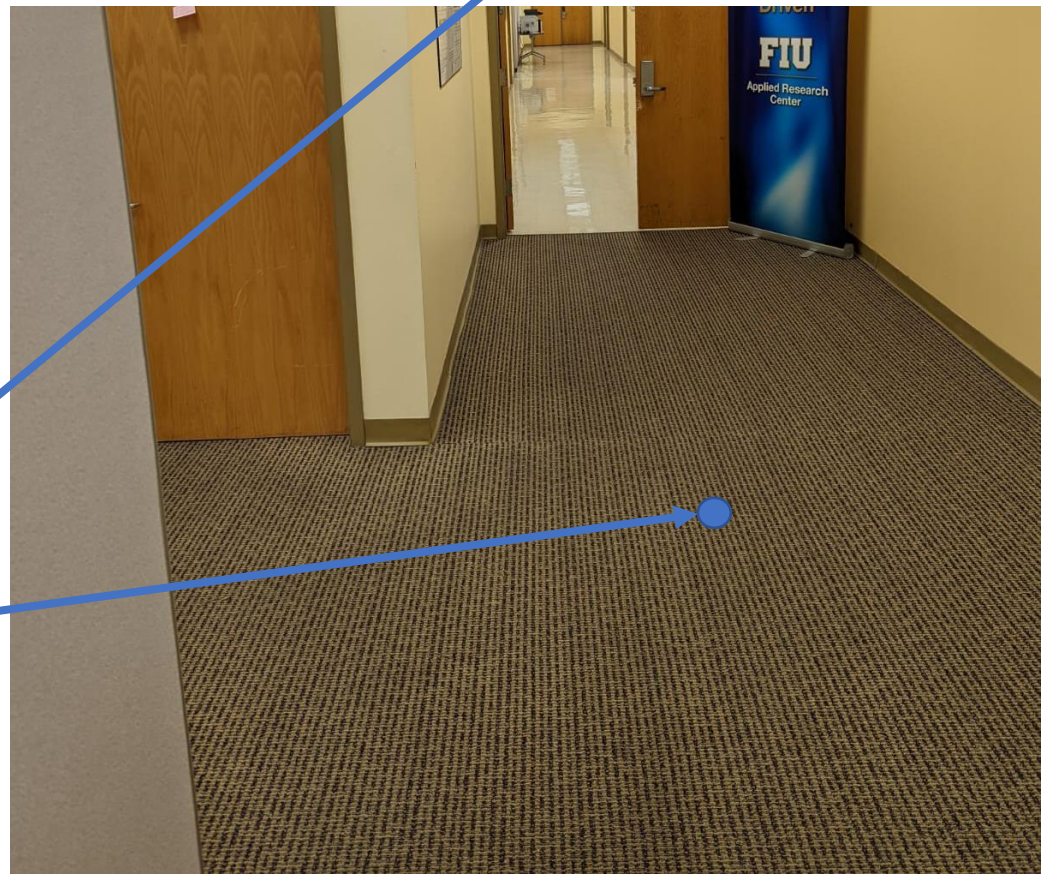
Video → Terrain types and Object classification

Point Cloud → Terrain elevations and geometric obstacles

On-board Terrain Risk-awareness

Gray occupancy matrix instead of binary

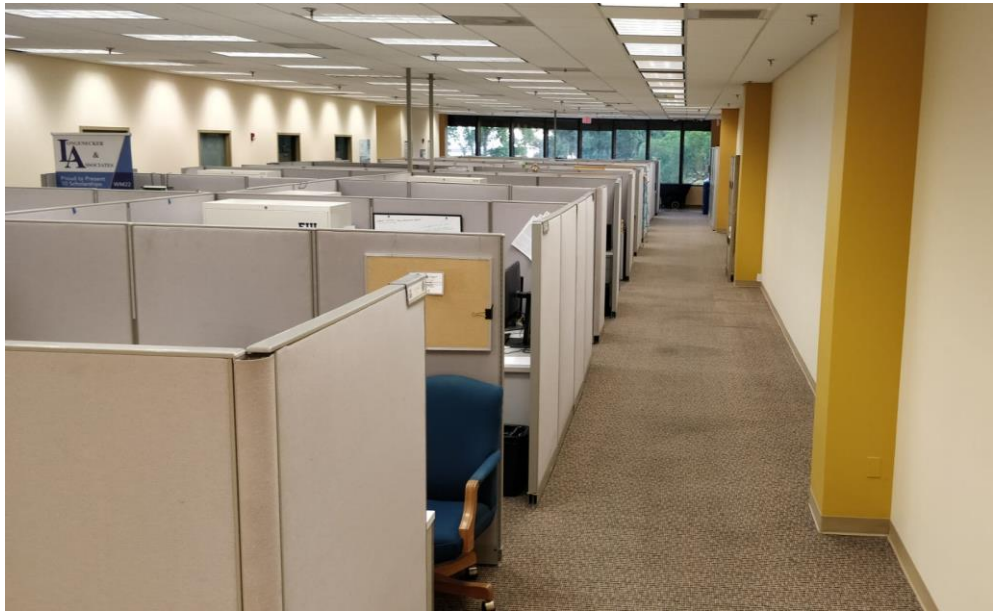


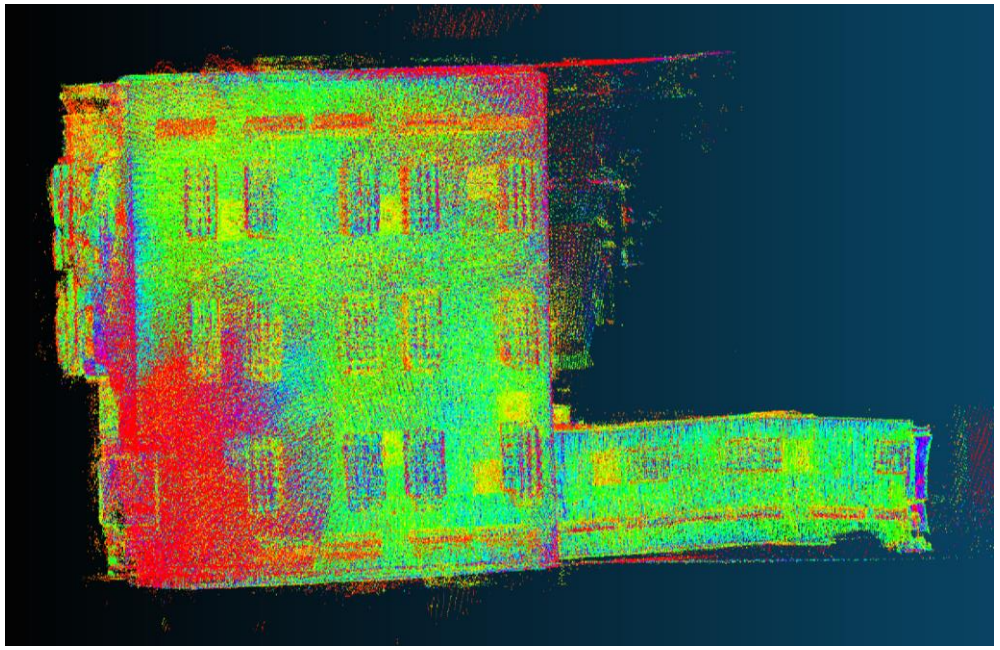


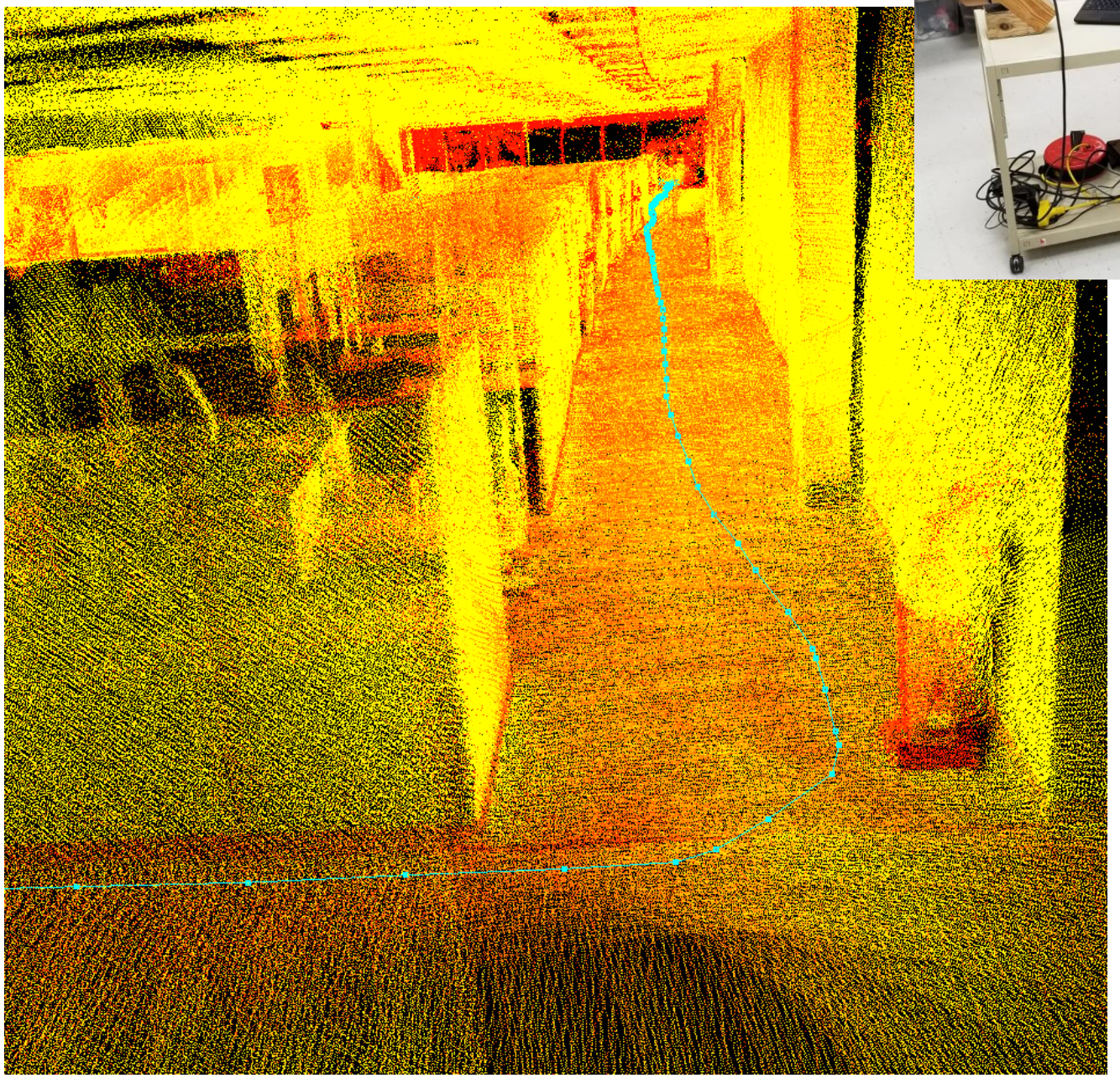
No obstacle!

Is safe?

Digital Twin Reconstruction Over Time



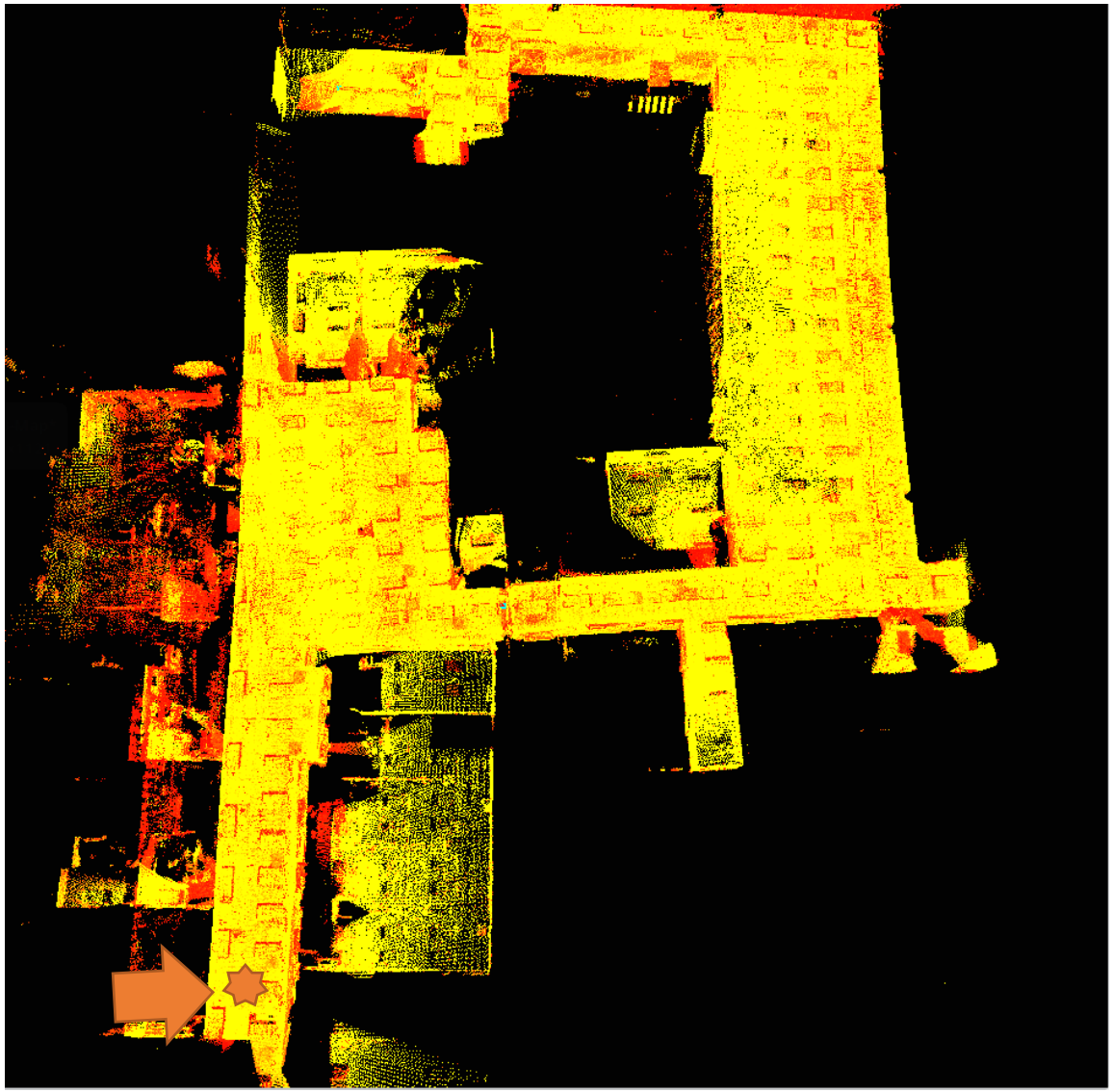




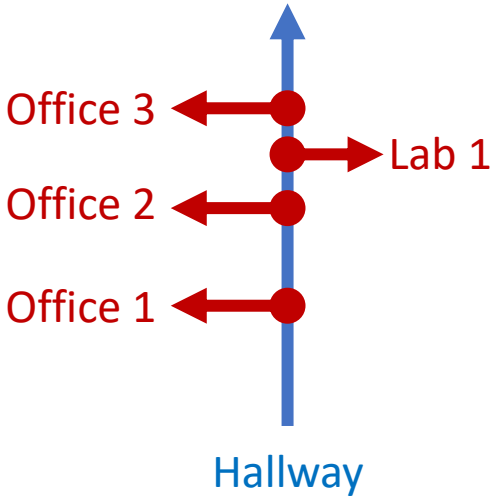
Surveillance Maps and Events

- Object Detection
- Hallways, doors, offices, windows, furniture, etc
- Landmark labeling based on unsupervised learning

Objects → **Facility Layout**
Terrain Landmarks



Semantic hierarchical Maps



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Immersive Inspections Using Digital Twins

Virtual Reality (VR)

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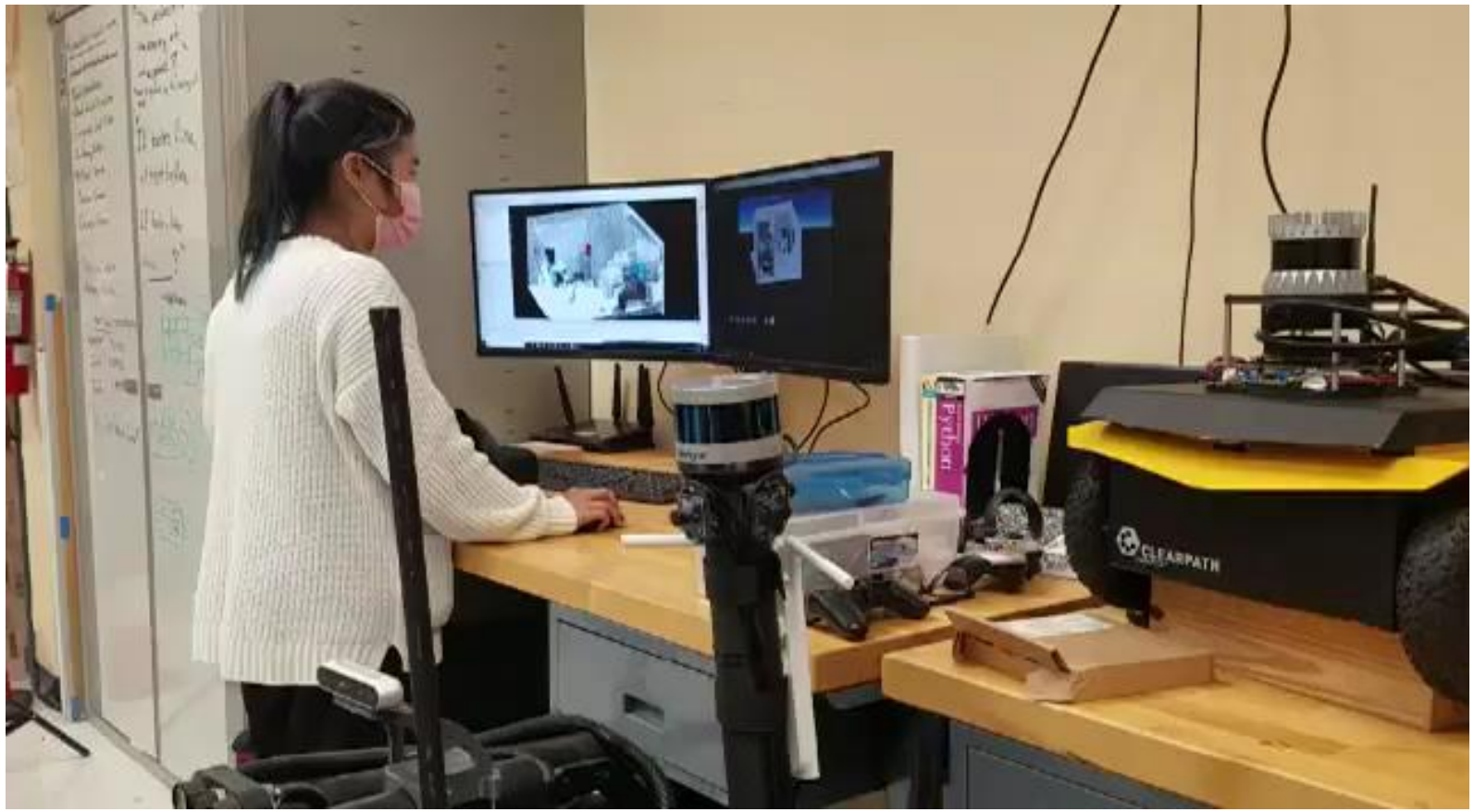
"Off-site immersive inspection using captured digital twins"

Inspectors interact with the data dynamically!



Augmented Reality (AR)

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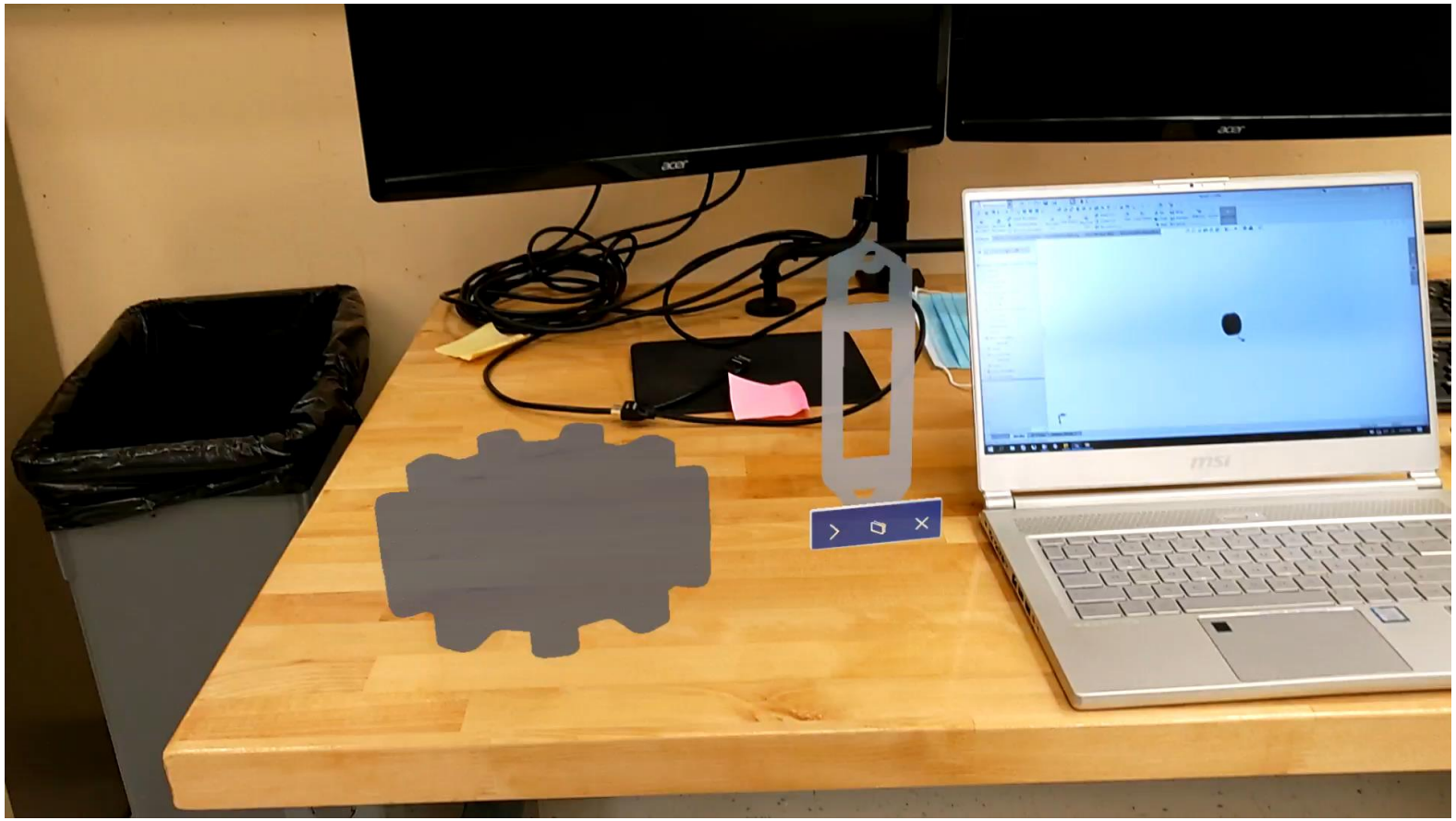
"On-site inspection using superimpose data analytics"

Inspectors interact with the environment during site walkthroughs!



Final Thoughts

Conclusion

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- Digital twin technologies are useful tools for decision-making because it permits taking many spatial data and trends into account
- Consequently, managers can make more optimal and safer decisions based on updated, abundant, and reliable information