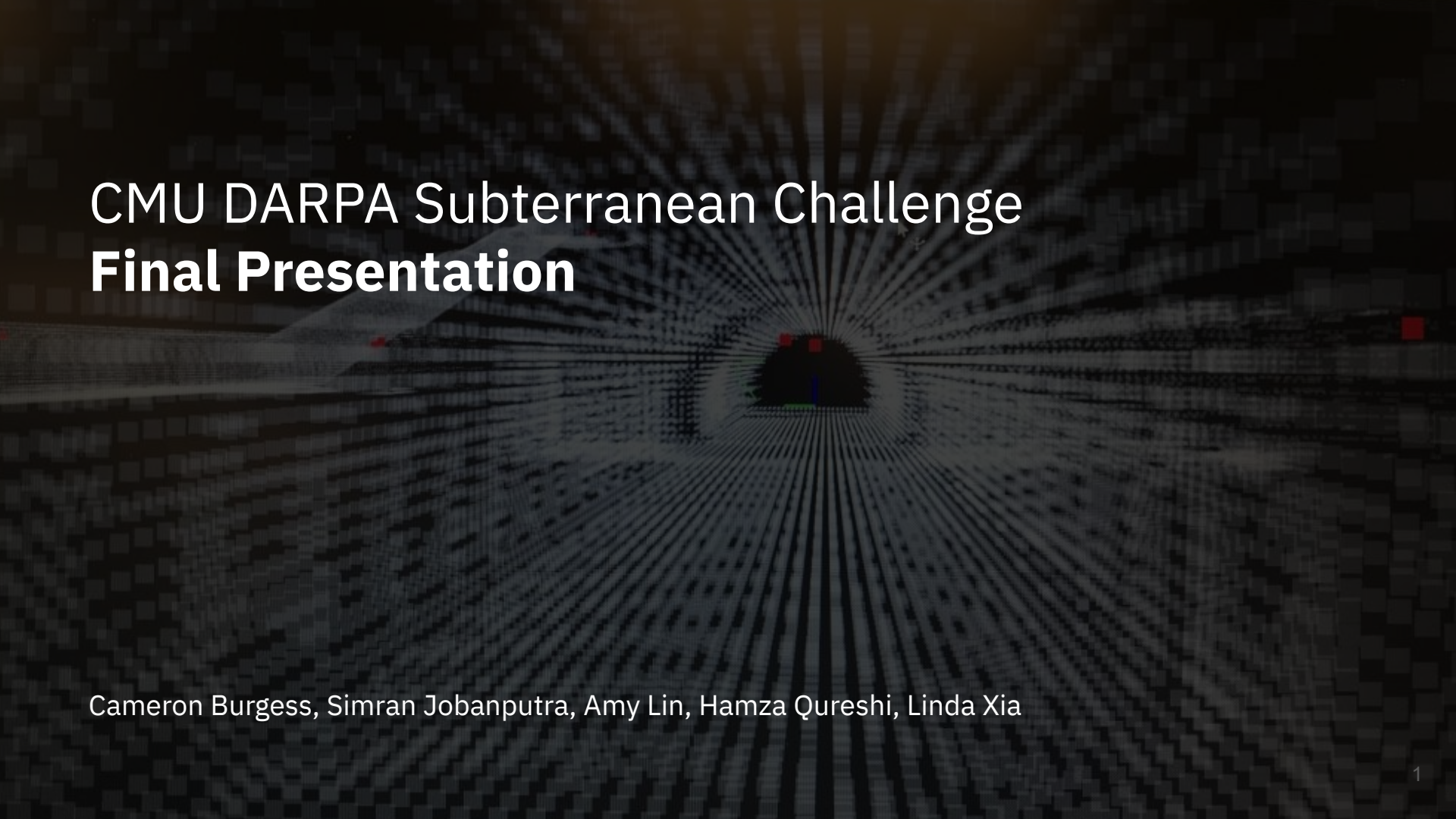


CMU DARPA Subterranean Challenge
Final Presentation

Cameron Burgess, Simran Jobanputra, Amy Lin, Hamza Qureshi, Linda Xia

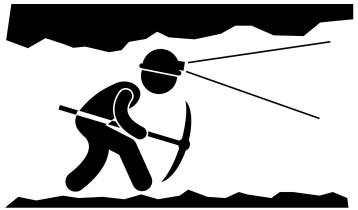
Meet our client

Team Explorer is comprised of 20+ graduate students and full-time faculty members in the **CMU Robotics Institute** and **Oregon State University**'s Robotic Decision Making Lab.

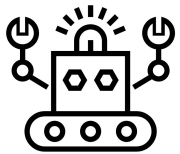
Key terms

Defense Advanced Research Projects Agency (DARPA)

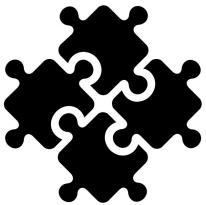
Base Station Operator (BSO)



Subterranean



Rocky



STIX

Communication nodes

DARPA Subterranean Challenge

A multi-year robotics competition that seeks new approaches to **rapidly map, navigate and search** underground environments using semi-autonomous robots.

Application

Support **emergency first responders and combat operators** in complex underground environments.

Competition objective

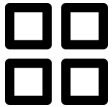
Find all the artifacts that are located in a cave, as quickly and as accurately as possible.

There are **5 artifact categories:**

- 🪛 **Drill**
- 🎒 **Red Backpack**
- 👷 **Survivor**
- **Fire Extinguisher**
- **Cell Phone**

How to win

Accurate location reporting

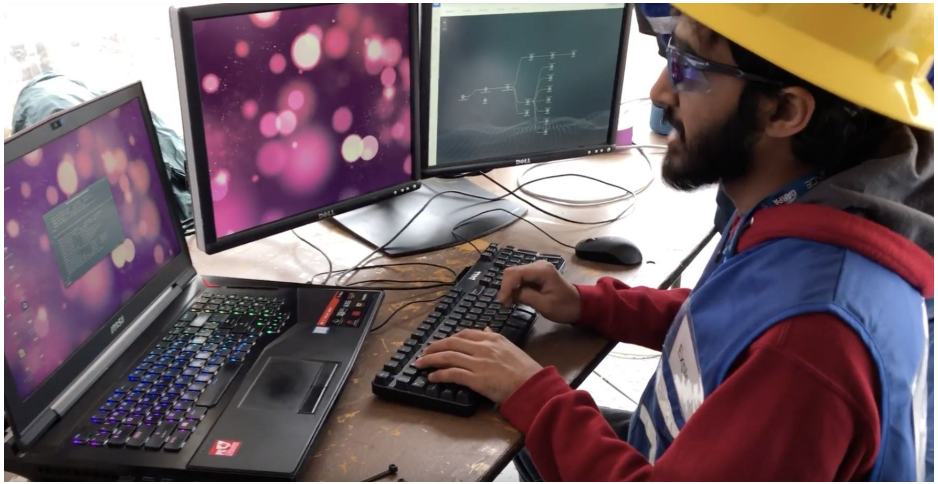


Accurate object category

Faster submissions to DARPA

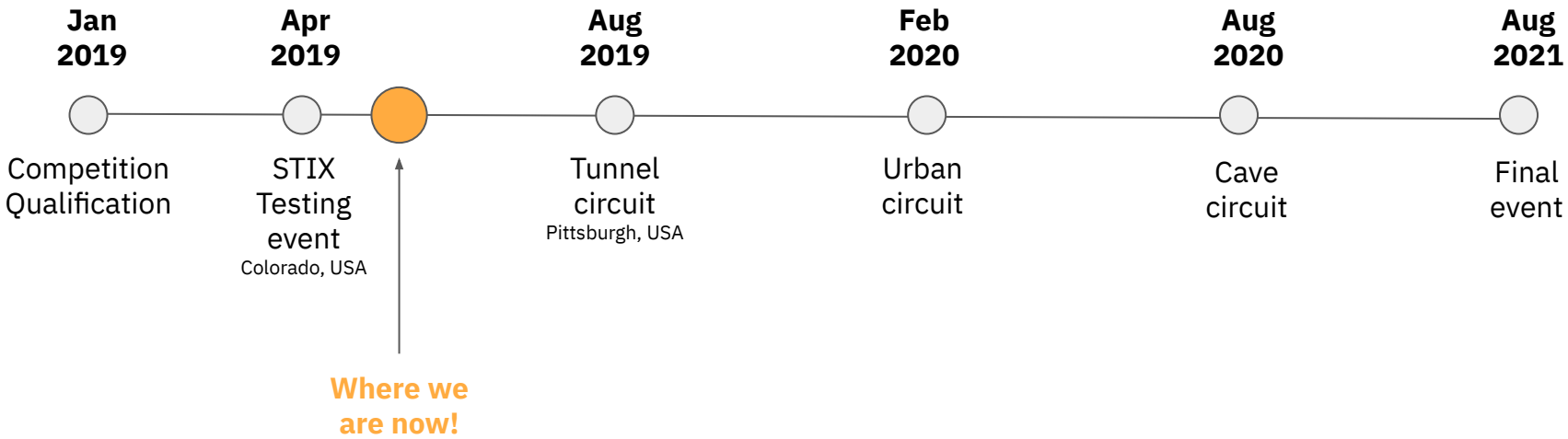
Capstone objective

Design a **base station interface** to increase efficiency and reduce cognitive load for the base station operator as they **monitor multiple air and ground robots.**

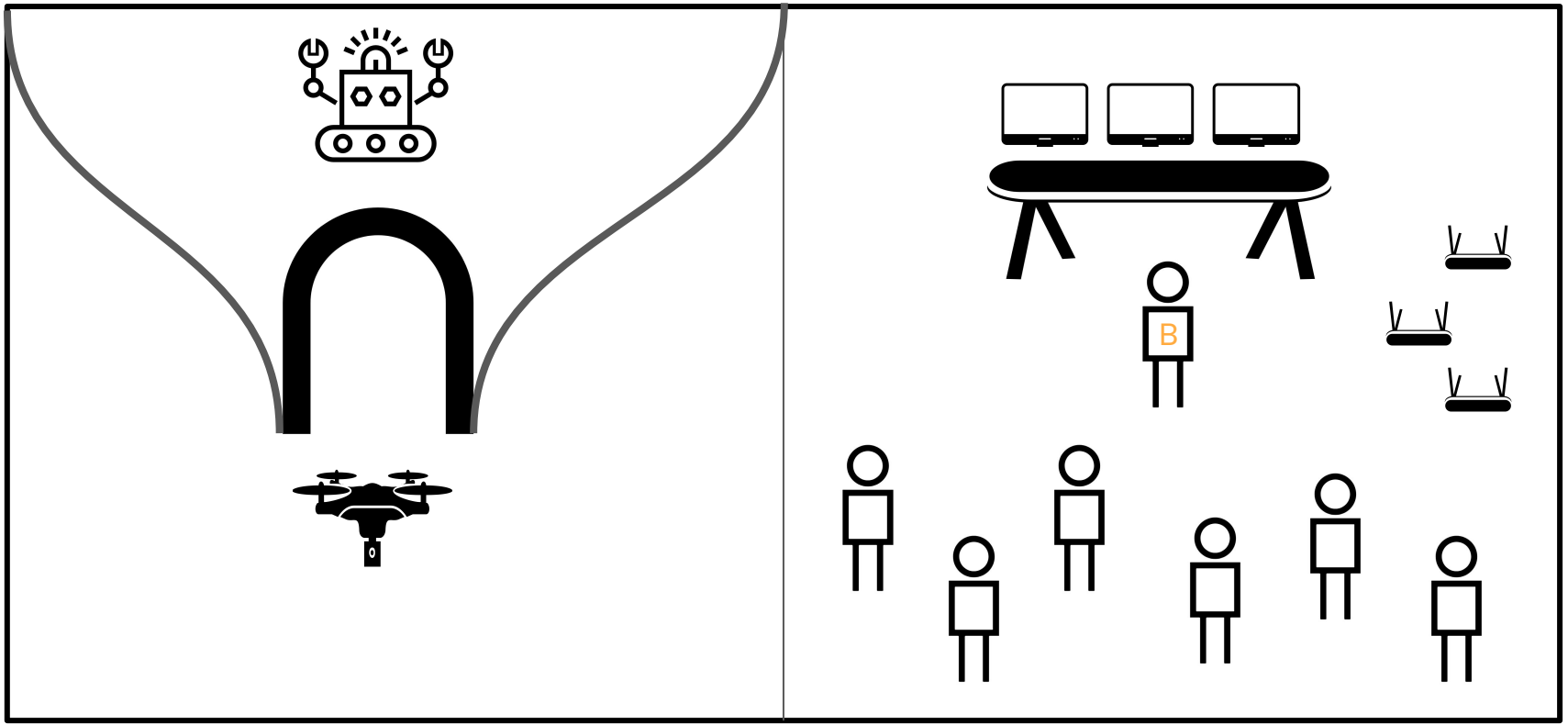


Vasu as the base station operator!

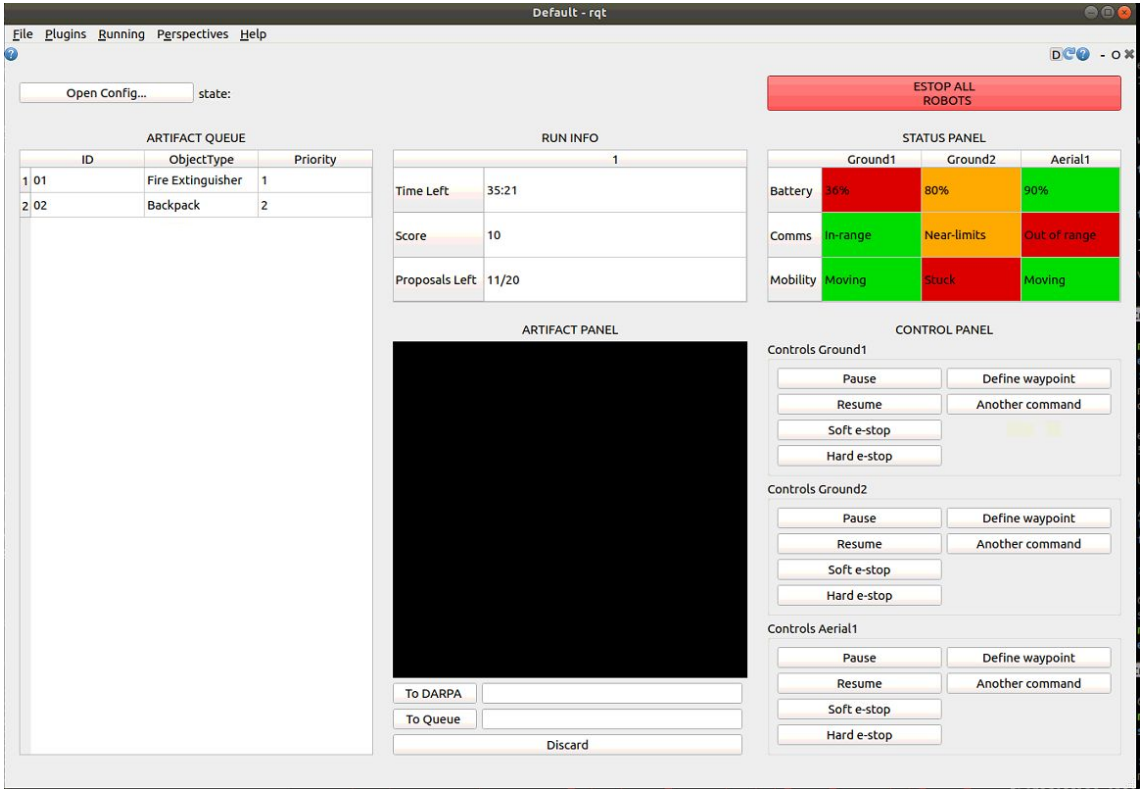
Team Explorer timeline



Base station setup

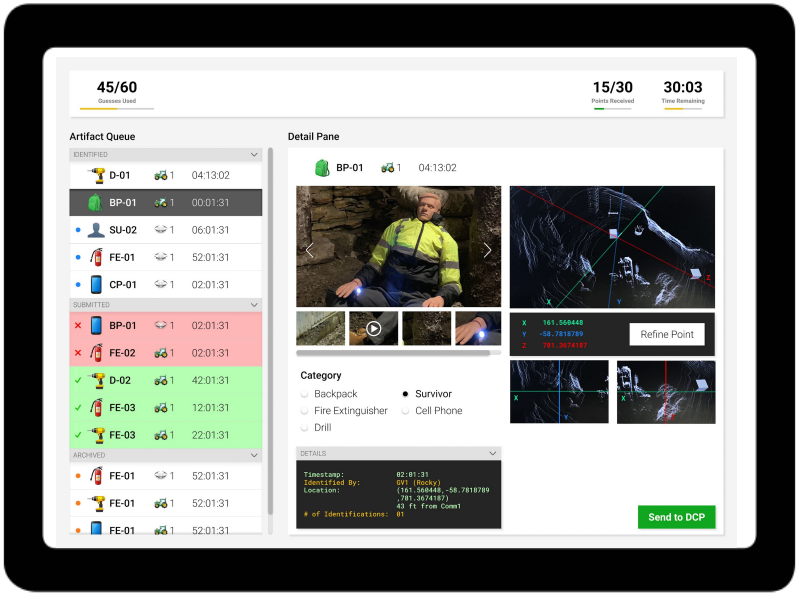


Initial client GUI

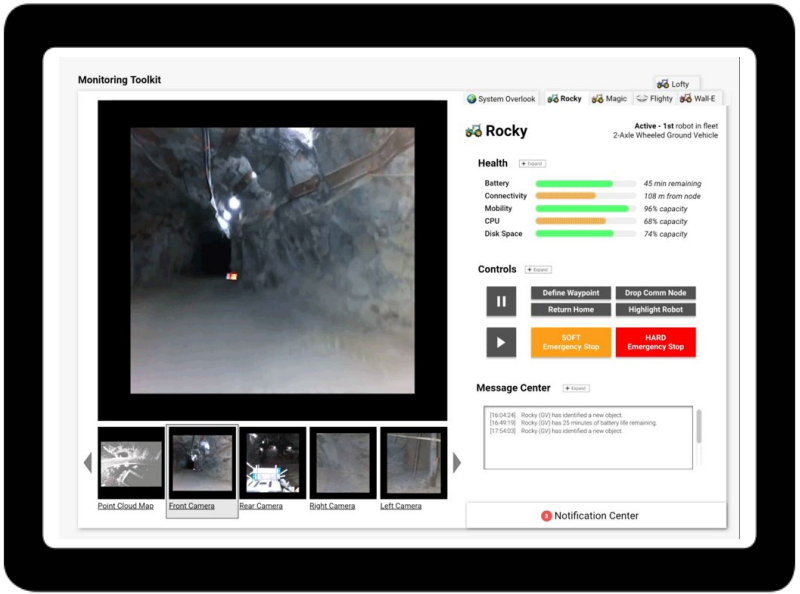


- **Walkthrough + Demo**

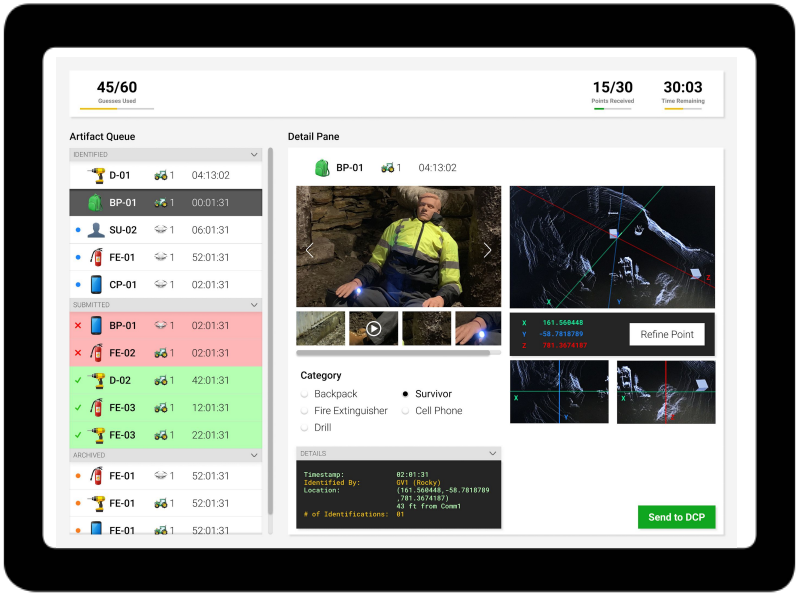
Action/Detection



Monitoring



Action/Detection



45/60
Guesses Used

15/30
Points Received

30:03
Time Remaining

Artifact Queue

IDENTIFIED

	D-01	1	04:13:02
	SU-03	1	00:01:31
•	SU-02	1	06:01:31
•	FE-01	1	52:01:31
•	CP-01	1	02:01:31

SUBMITTED

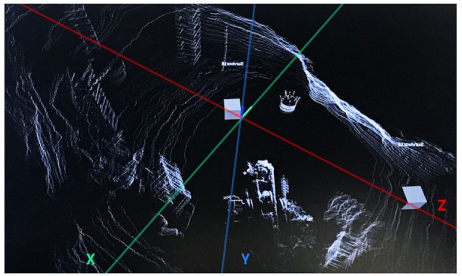
✕	BP-01	1	02:01:31
✕	FE-02	1	02:01:31
✓	D-02	1	42:01:31
✓	FE-03	1	12:01:31
✓	FE-03	1	22:01:31

ARCHIVED

•	FE-01	1	52:01:31
•	FE-01	1	52:01:31
•	FE-01	1	52:01:31

Detail Pane

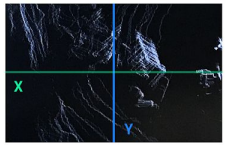
SU-03 1 04:13:02

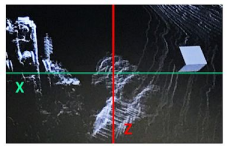





X 161.560448
Y -58.7818789
Z 781.3674187

Refine Point





Category

- ○ Backpack
- ○ Fire Extinguisher
- ○ Drill
- ● Survivor
- ○ Cell Phone

DETAILS

```
Timestamp:                02:01:31
Identified By:            GV1 (Rocky)
Location:                 (161.560448,-58.7818789
                          ,781.3674187)
                          43 ft from Comm1
# of Identifications:     01
```

Send to DCP

- **Scenario: An artifact is detected!**

Artifact Queue

IDENTIFIED

	D-01	1	04:13:02
	SU-03	1	00:01:31
•	SU-02	1	06:01:31
•	FE-01	1	52:01:31
•	CP-01	1	02:01:31

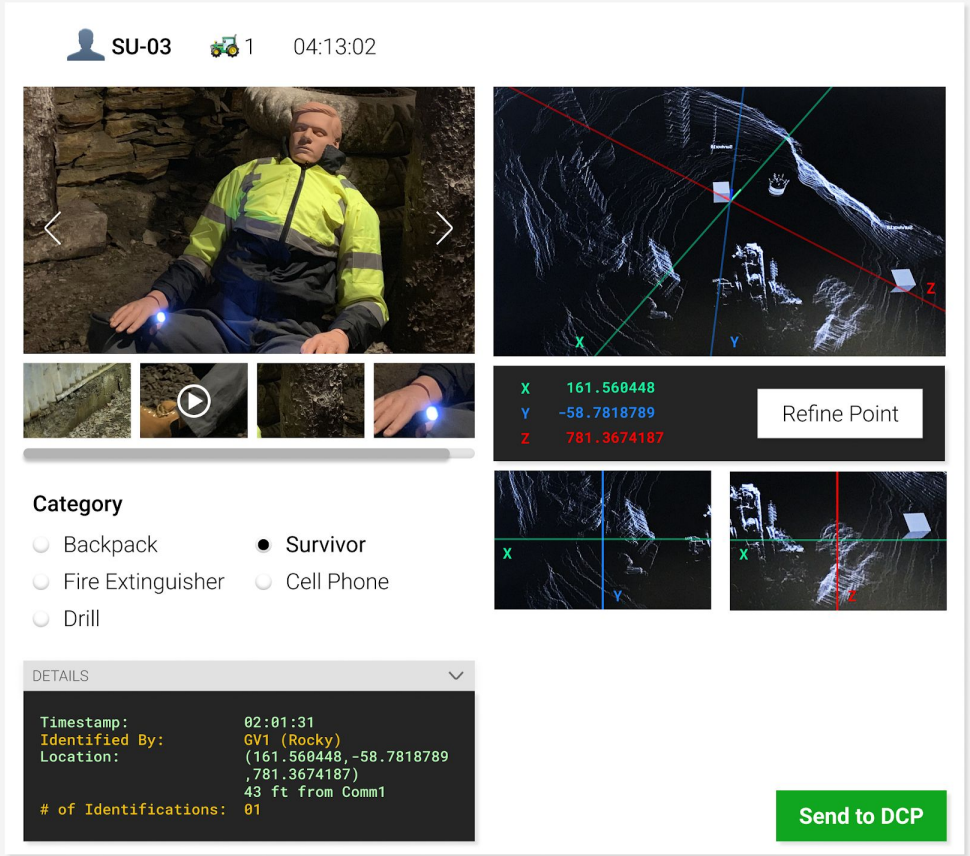
SUBMITTED

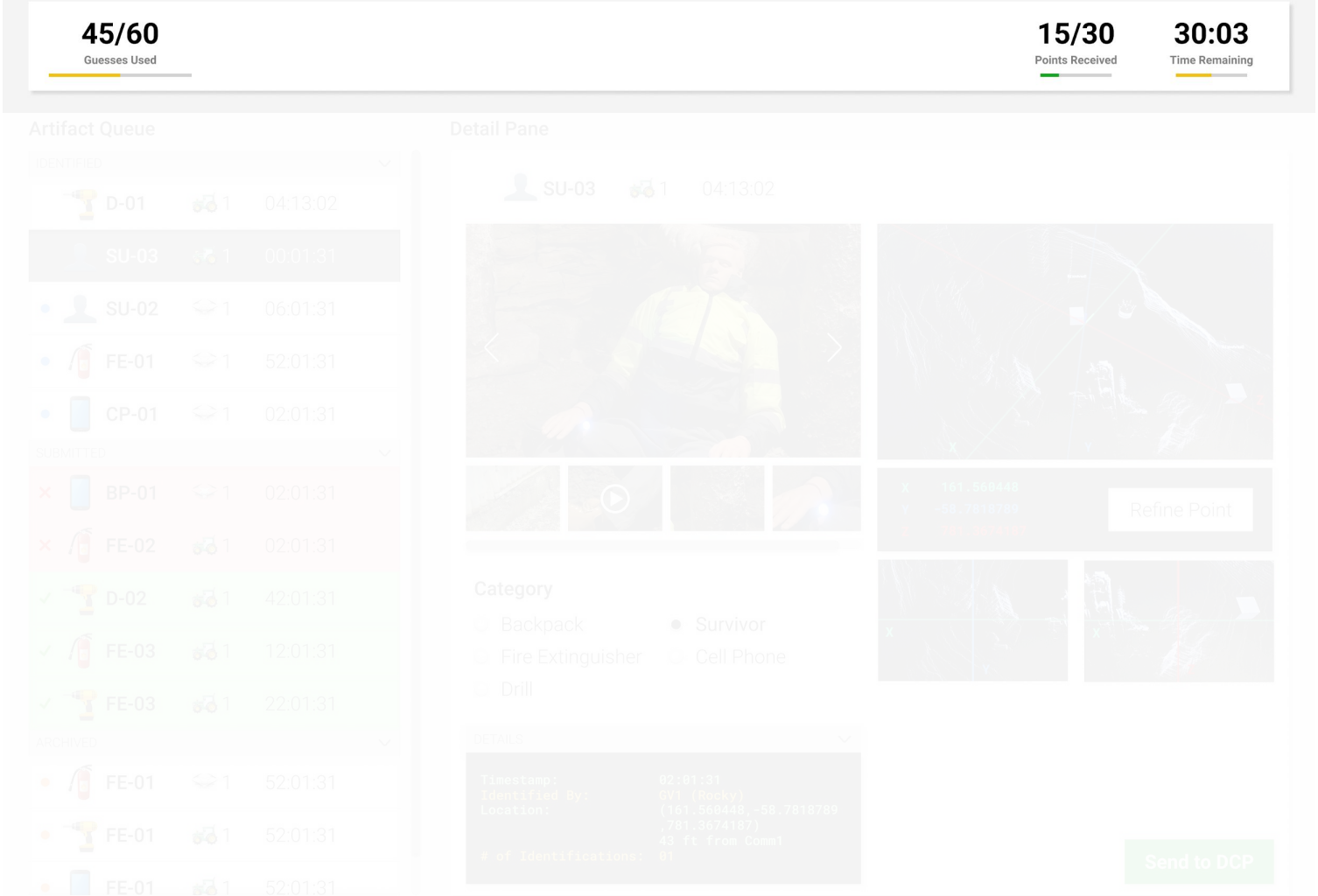
✕	BP-01	1	02:01:31
✕	FE-02	1	02:01:31
✓	D-02	1	42:01:31
✓	FE-03	1	12:01:31
✓	FE-03	1	22:01:31

ARCHIVED

•	FE-01	1	52:01:31
•	FE-01	1	52:01:31
•	FE-01	1	52:01:31

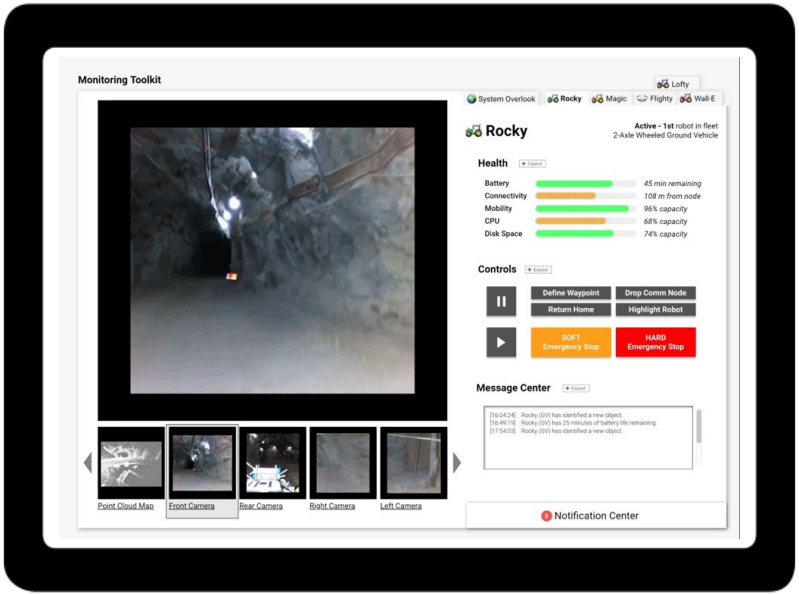
Detail Pane


SU-03
1
04:13:02
X 161.560448
Y -58.7818789
Z 781.3674187
Refine Point
Category
Backpack
Survivor
Fire Extinguisher
Cell Phone
Drill
DETAILS
Timestamp: 02:01:31
Identified By: GV1 (Rocky)
Location: (161.560448,-58.7818789 ,781.3674187)
43 ft from Comm1
# of Identifications: 01
Send to DCP

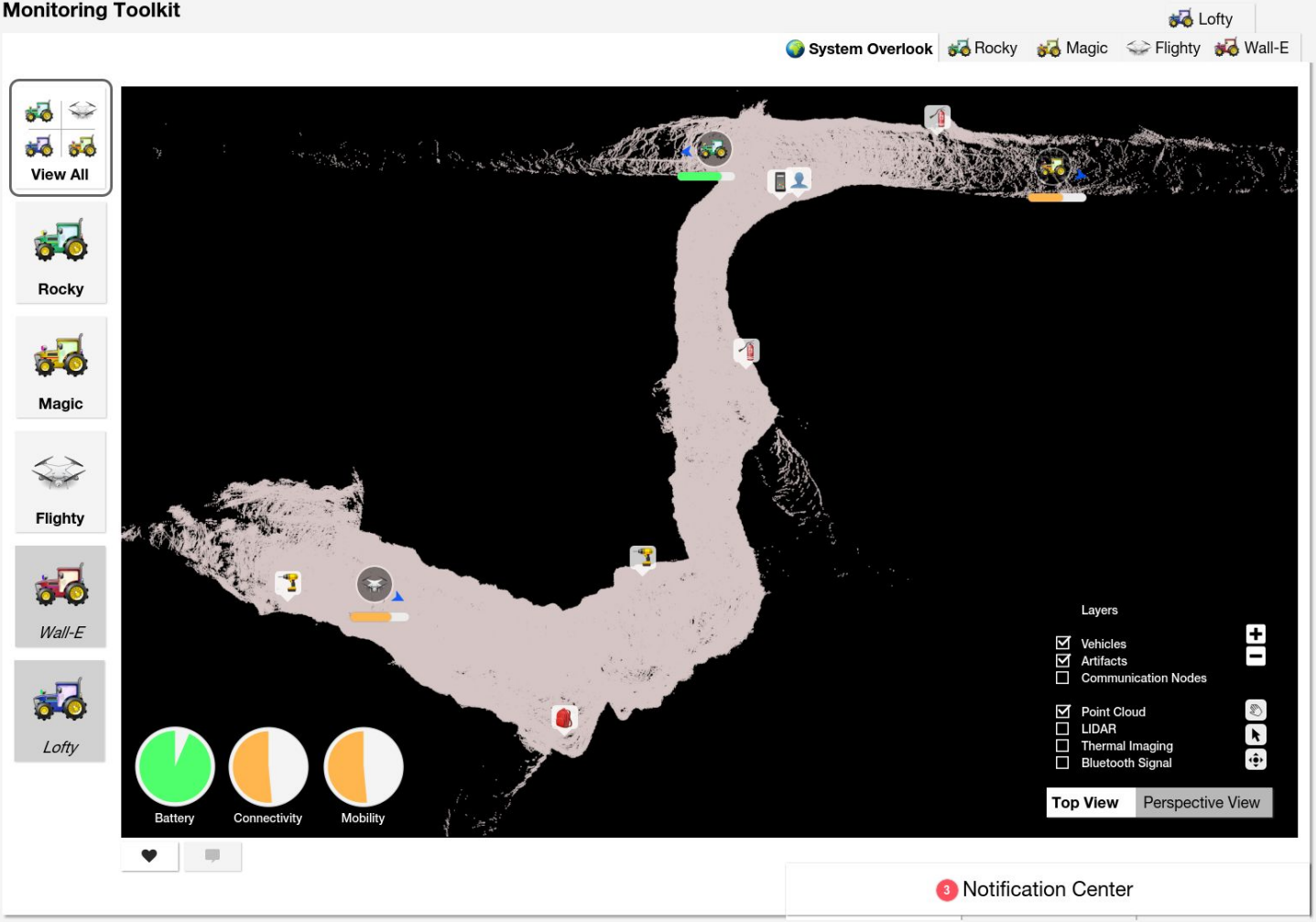

45/60
Guesses Used
15/30
Points Received
30:03
Time Remaining
Artifact Queue
Detail Pane
IDENTIFIED
D-01 1 04:13:02
SU-03 1 00:01:31
SU-02 1 06:01:31
FE-01 1 52:01:31
CP-01 1 02:01:31
SUBMITTED
BP-01 1 02:01:31
FE-02 1 02:01:31
D-02 1 42:01:31
FE-03 1 12:01:31
FE-03 1 22:01:31
ARCHIVED
FE-01 1 52:01:31
FE-01 1 52:01:31
FE-01 1 52:01:31
SU-03 1 04:13:02
Refine Point
Category
Backpack
Survivor
Fire Extinguisher
Cell Phone
Drill
DETAILS
Timestamp: 02:01:31
Identified By: CV1 (Rocky)
Location: (161.560448,-58.7818789
,781.3674187)
43 ft from Comm1
# of Identifications: 01
Send to DCP

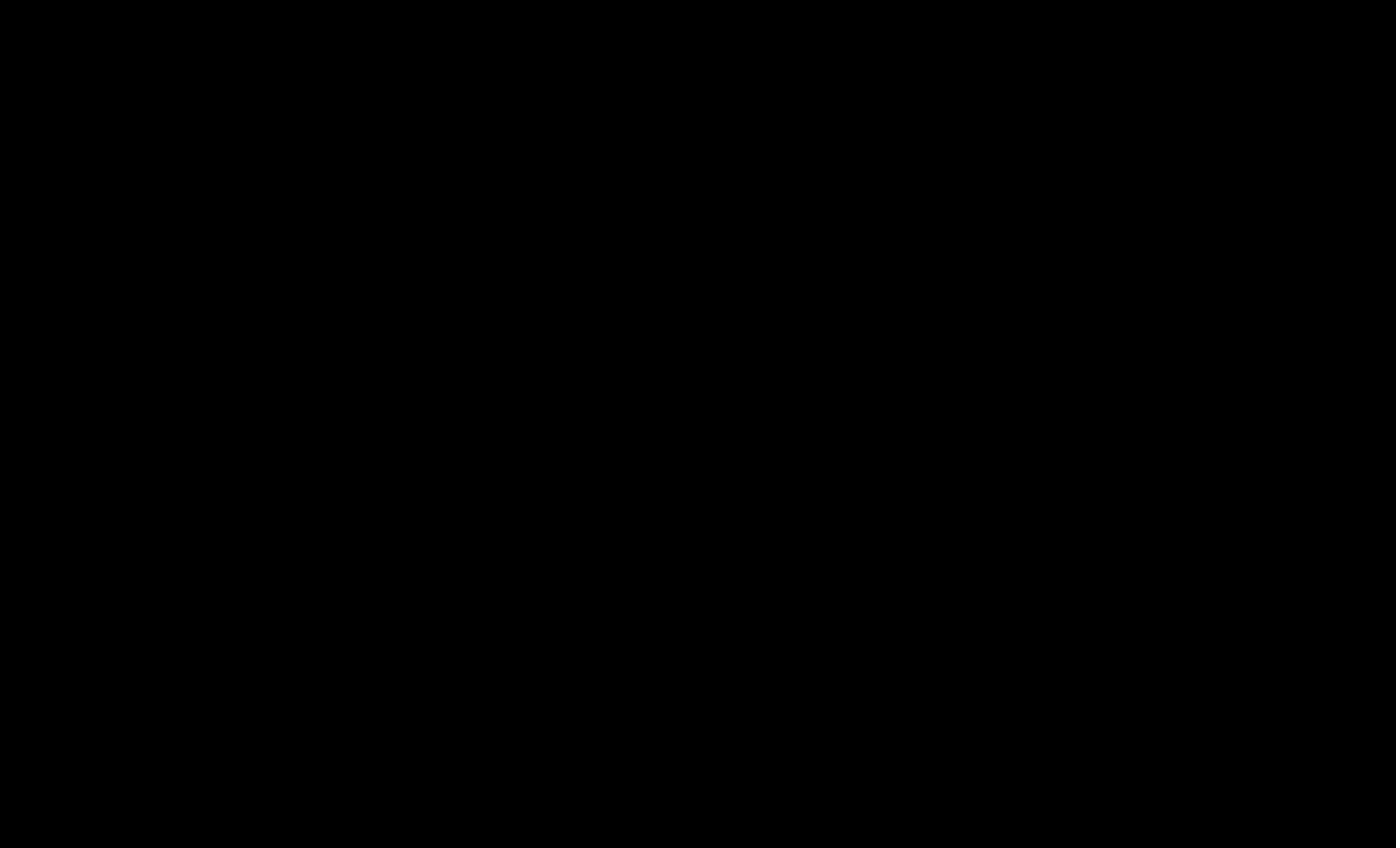
Monitoring

45/60
15/30
30:03
Artifact Queue
Detail Pane
Refine Point
Send to DCP

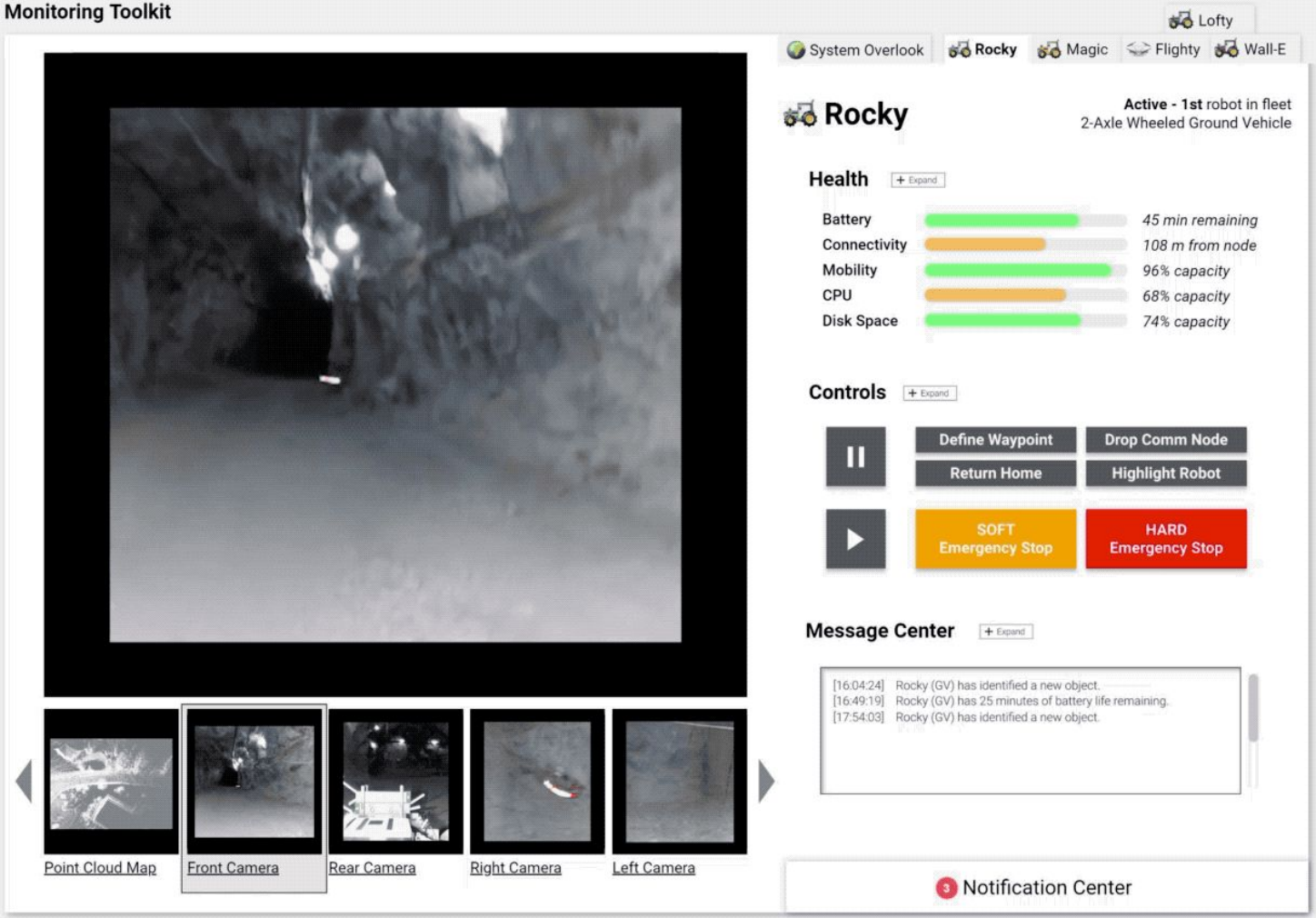

Monitoring Toolkit
Lofty
System Overlook
Rocky
Magic
Flighty
Wall-E
Rocky
Active - 1st robot in fleet
2-Axle Wheeled Ground Vehicle
Health
Battery
45 min remaining
Connectivity
108 m from node
Mobility
96% capacity
CPU
68% capacity
Disk Space
74% capacity
Controls
Define Waypoint
Drop Comm Node
Return Home
Highlight Robot
SOFT Emergency Stop
HARD Emergency Stop
Message Center
Point Cloud Map
Front Camera
Rear Camera
Right Camera
Left Camera
Notification Center

Monitoring Toolkit



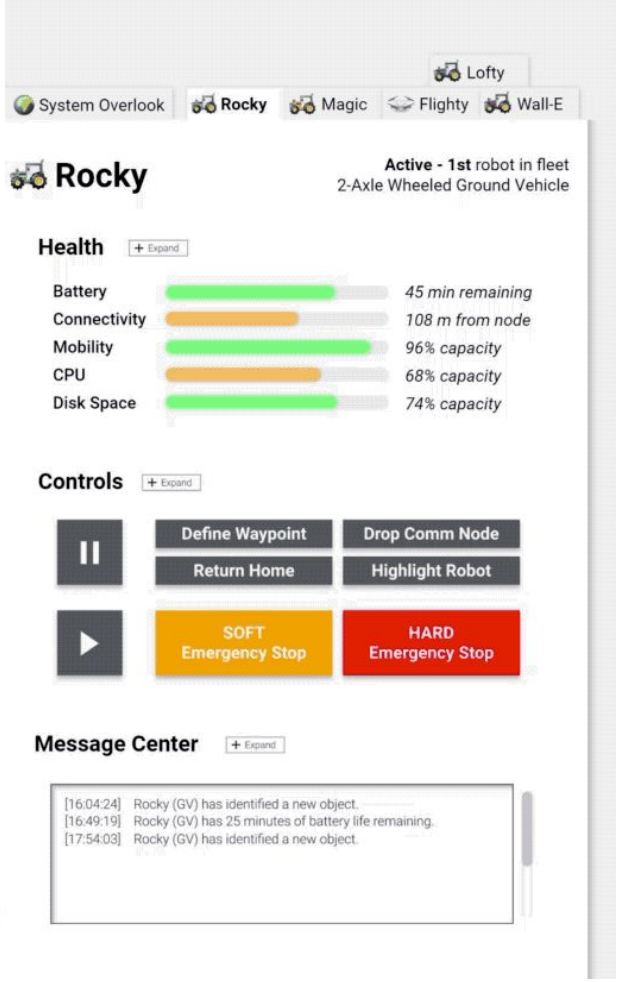


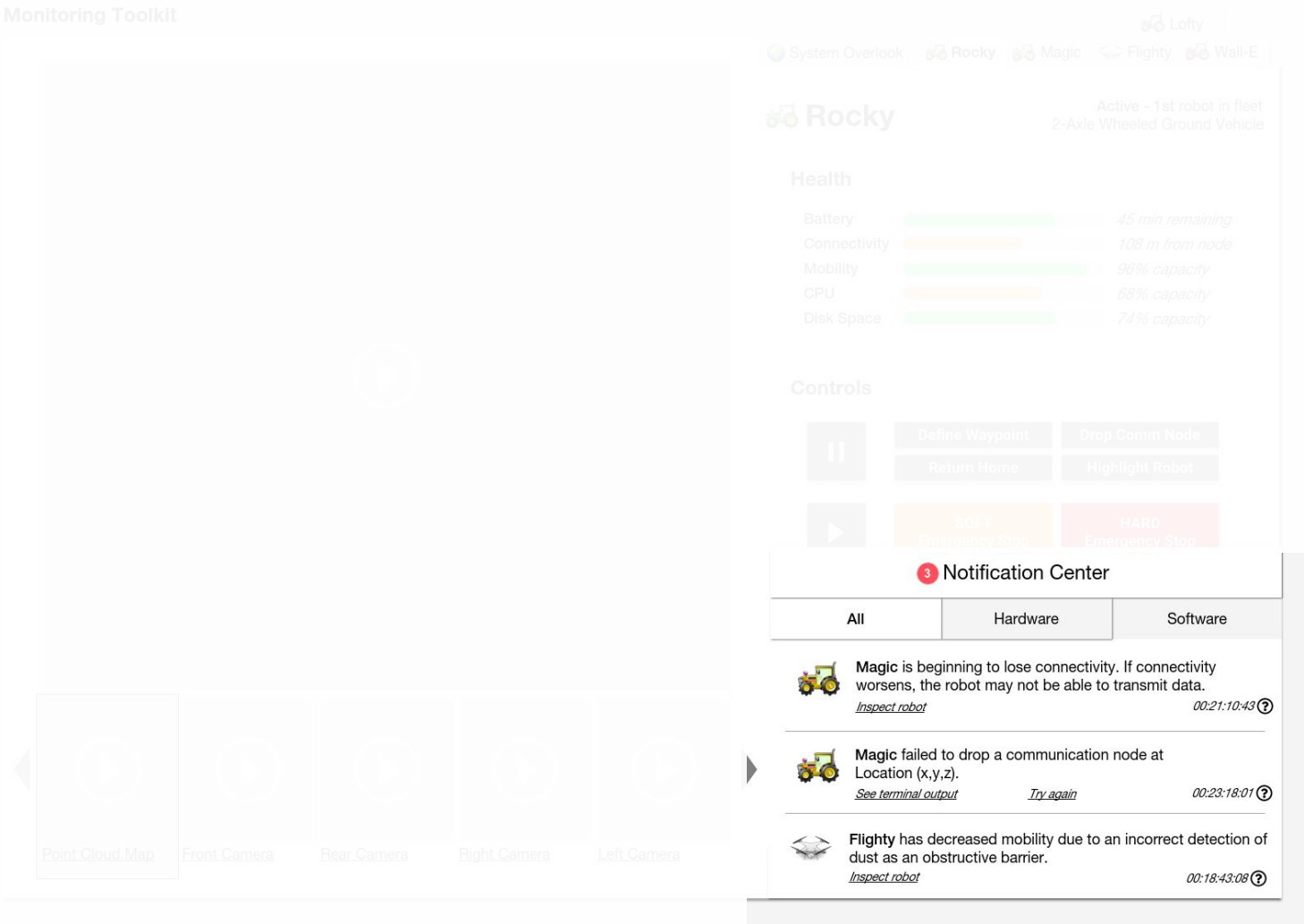
Monitoring Toolkit

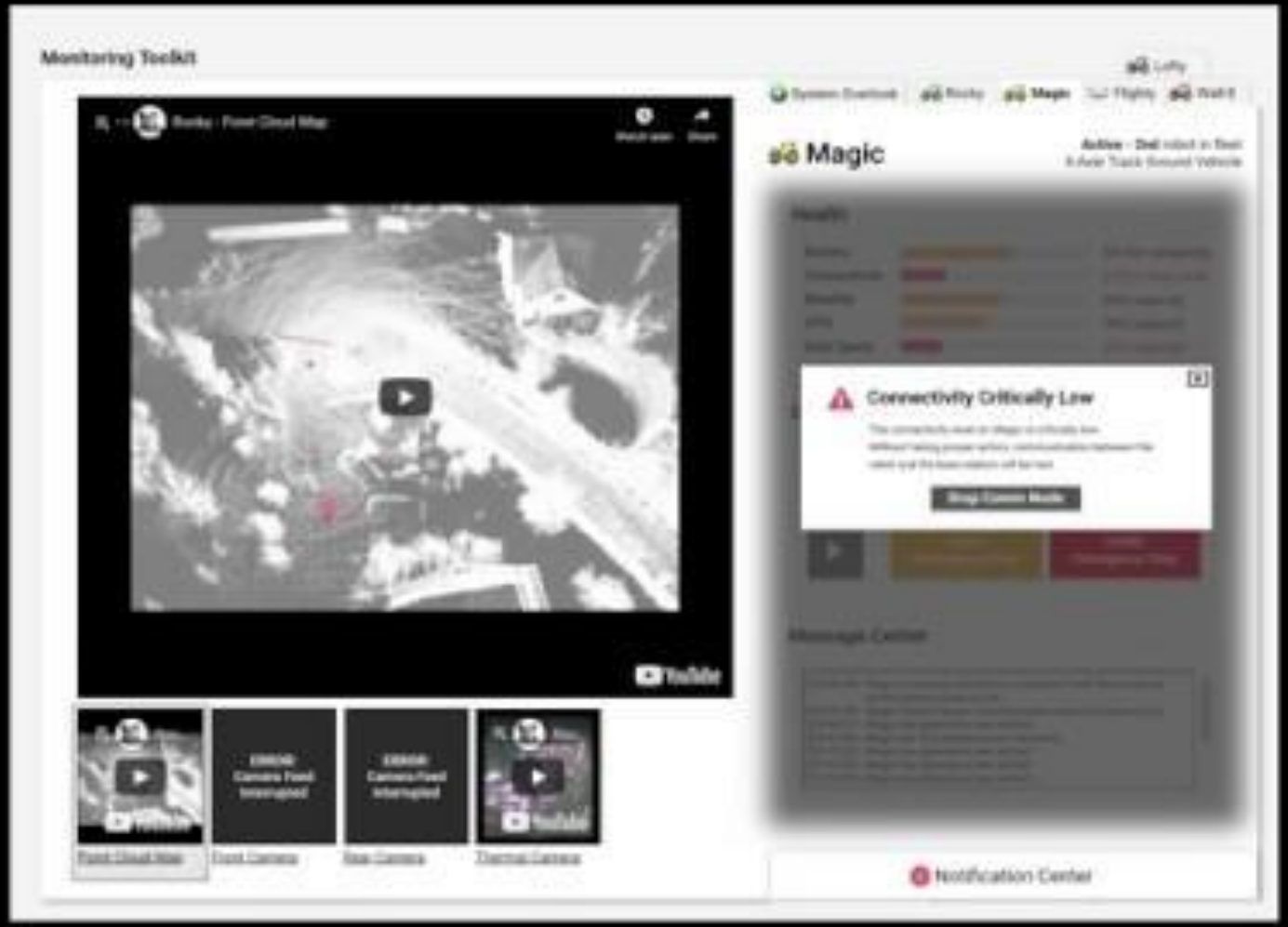


Monitoring Toolkit

Point Cloud Map | Front Camera | Rear Camera | Right Camera | Left Camera


Lofty
System Overlook
Rocky
Magic
Flighty
Wall-E
Rocky
Active - 1st robot in fleet
2-Axle Wheeled Ground Vehicle
Health
Expand
Battery
45 min remaining
Connectivity
108 m from node
Mobility
96% capacity
CPU
68% capacity
Disk Space
74% capacity
Controls
Expand
Define Waypoint
Drop Comm Node
Return Home
Highlight Robot
SOFT Emergency Stop
HARD Emergency Stop
Message Center
Expand
[16:04:24] Rocky (GV) has identified a new object.
[16:49:19] Rocky (GV) has 25 minutes of battery life remaining.
[17:54:03] Rocky (GV) has identified a new object.


Monitoring Toolkit
Lofty
System Overlook
Rocky
Magic
Flighty
Wall-E
Rocky
Active - 1st robot in fleet
2-Axle Wheeled Ground Vehicle
Health
Battery
45 min remaining
Connectivity
108 m from node
Mobility
96% capacity
CPU
68% capacity
Disk Space
74% capacity
Controls
Define Waypoint
Drop Comm Node
Return Home
Highlight Robot
SOFT Emergency Stop
HARD Emergency Stop
Point Cloud Map
Front Camera
Rear Camera
Right Camera
Left Camera
3 Notification Center
All
Hardware
Software
Magic is beginning to lose connectivity. If connectivity worsens, the robot may not be able to transmit data.
Inspect robot
00:21:10:43
Magic failed to drop a communication node at Location (x,y,z).
See terminal output
Try again
00:23:18:01
Flighty has decreased mobility due to an incorrect detection of dust as an obstructive barrier.
Inspect robot
00:18:43:08


Monitoring Toolkit
Magic
Connectivity Critically Low
Notification Center

Research & Prototyping

Lab research

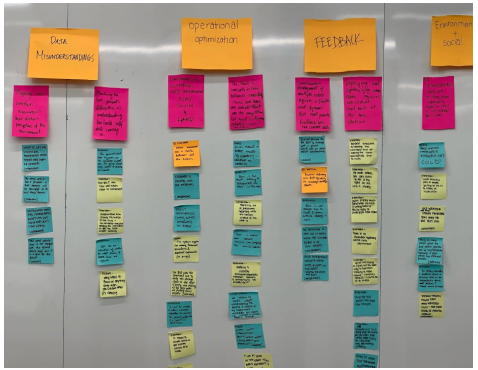
System walkthroughs

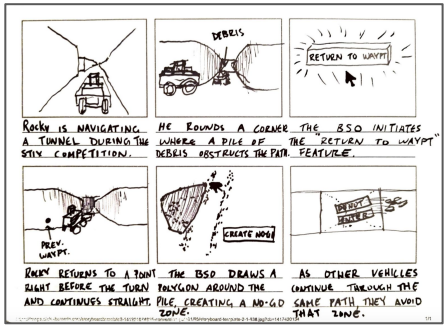
Literature review

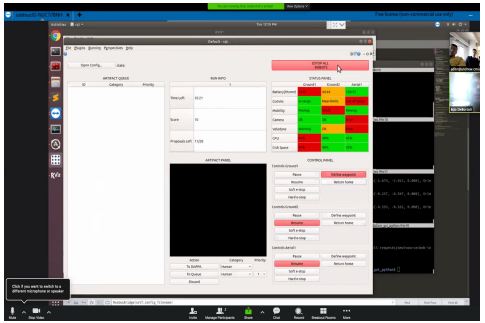
Storyboarding

Dynamic prototyping

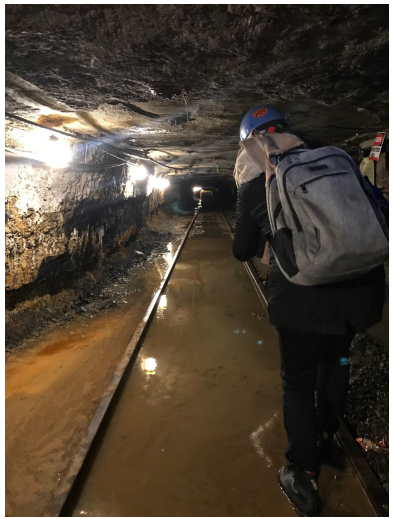
Affinity diagramming







Field research



Mine observational studies

Expert shadowing

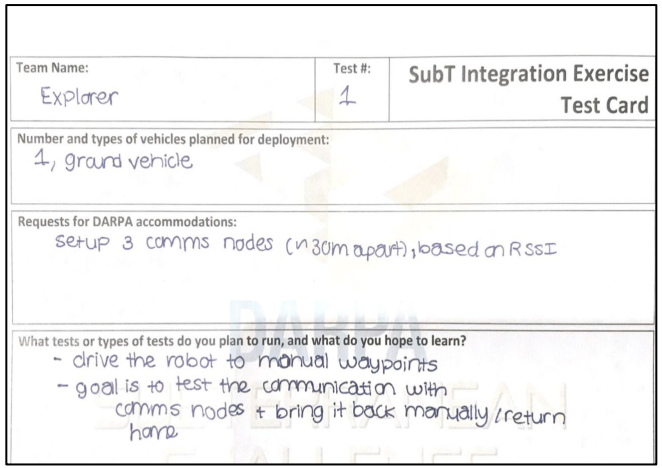
Retrospective interviews

Field research: Testing in Colorado

Field interview methods

- Coming up with initial questions
- Observing test runs
- Revamping questions based on failures/issues during runs
- Learning new terminology and writing up any new questions
- Interview Vasu!

Field Test Cards

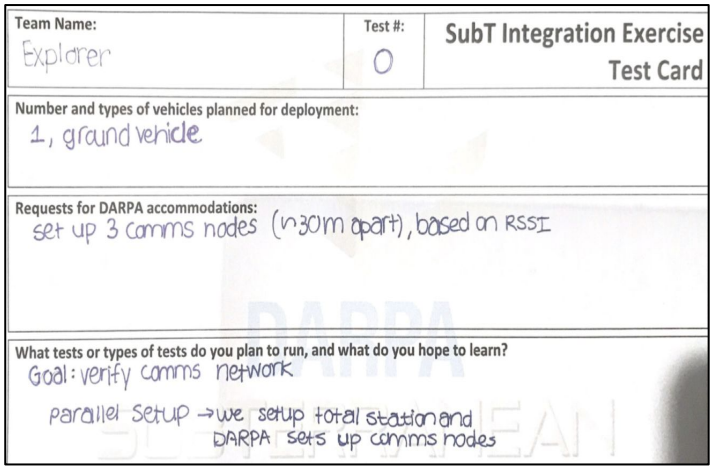


Team Name: Explorer | Test #: 1 | SubT Integration Exercise Test Card

Number and types of vehicles planned for deployment:
1, ground vehicle

Requests for DARPA accommodations:
setup 3 comms nodes (~30m apart), based on RSSI

What tests or types of tests do you plan to run, and what do you hope to learn?
- drive the robot to manual waypoints
- goal is to test the communication with comms nodes + bring it back manually / return home



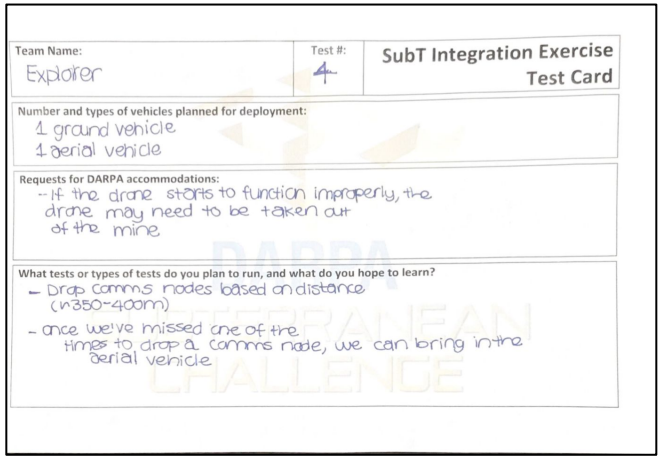
Team Name: Explorer | Test #: 0 | SubT Integration Exercise Test Card

Number and types of vehicles planned for deployment:
1, ground vehicle

Requests for DARPA accommodations:
set up 3 comms nodes (~30m apart), based on RSSI

What tests or types of tests do you plan to run, and what do you hope to learn?
Goal: verify comms network

parallel setup → we setup total station and DARPA sets up comms nodes

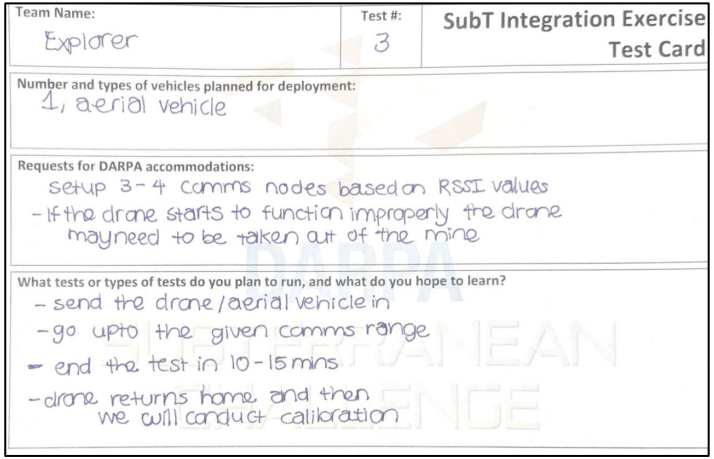


Team Name: Explorer | Test #: 4 | SubT Integration Exercise Test Card

Number and types of vehicles planned for deployment:
1 ground vehicle
1 aerial vehicle

Requests for DARPA accommodations:
- If the drone starts to function improperly, the drone may need to be taken out of the mine

What tests or types of tests do you plan to run, and what do you hope to learn?
- Drop comms nodes based on distance (~350-400m)
- once we've missed one of the times to drop a comms node, we can bring in the aerial vehicle



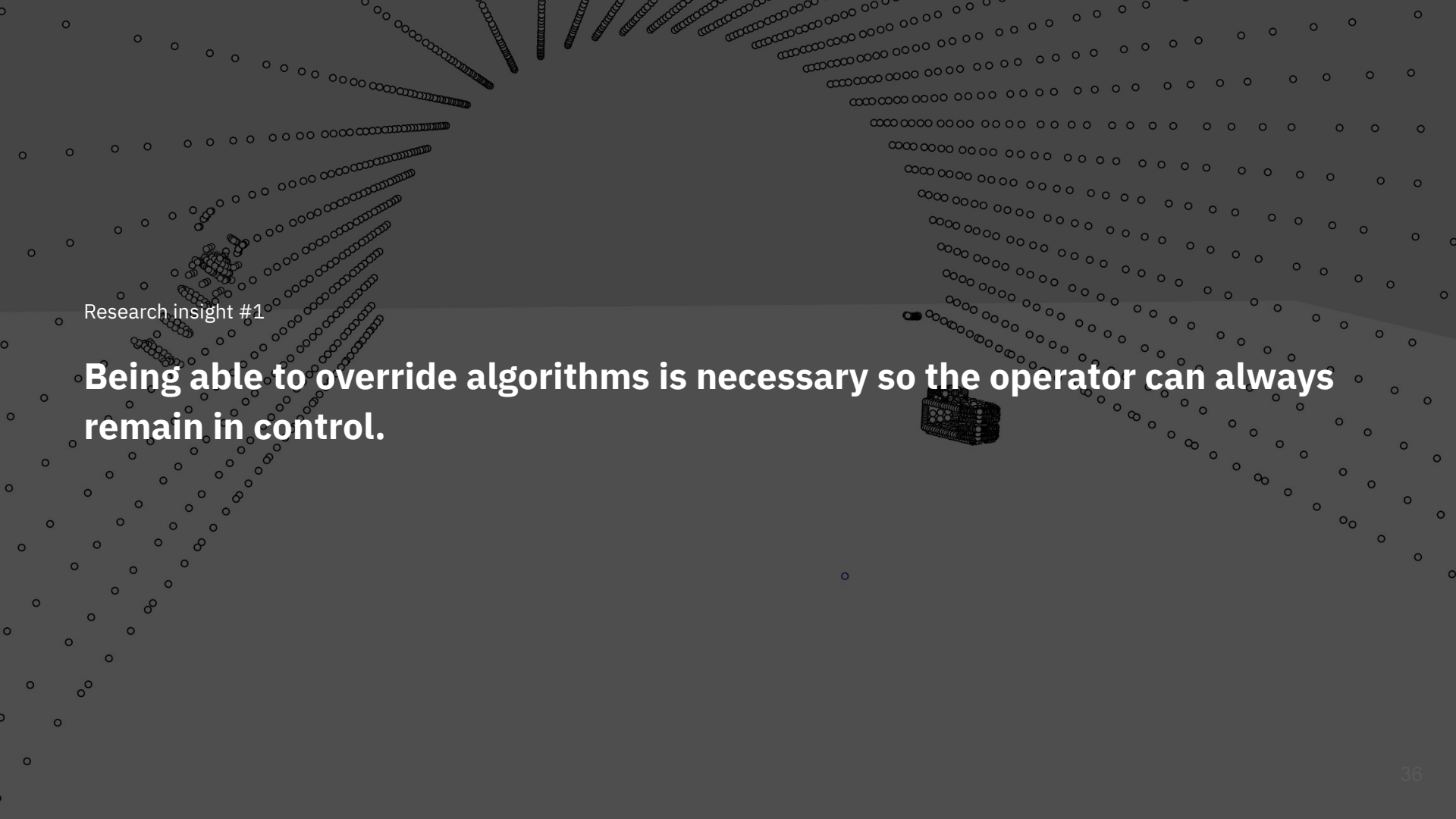
Team Name: Explorer | Test #: 3 | SubT Integration Exercise Test Card

Number and types of vehicles planned for deployment:
1, aerial vehicle

Requests for DARPA accommodations:
setup 3-4 comms nodes based on RSSI values
- If the drone starts to function improperly the drone may need to be taken out of the mine

What tests or types of tests do you plan to run, and what do you hope to learn?
- send the drone / aerial vehicle in
- go upto the given comms range
- end the test in 10-15 mins
- drone returns home and then we will conduct calibration

Research insights



Research insight #1

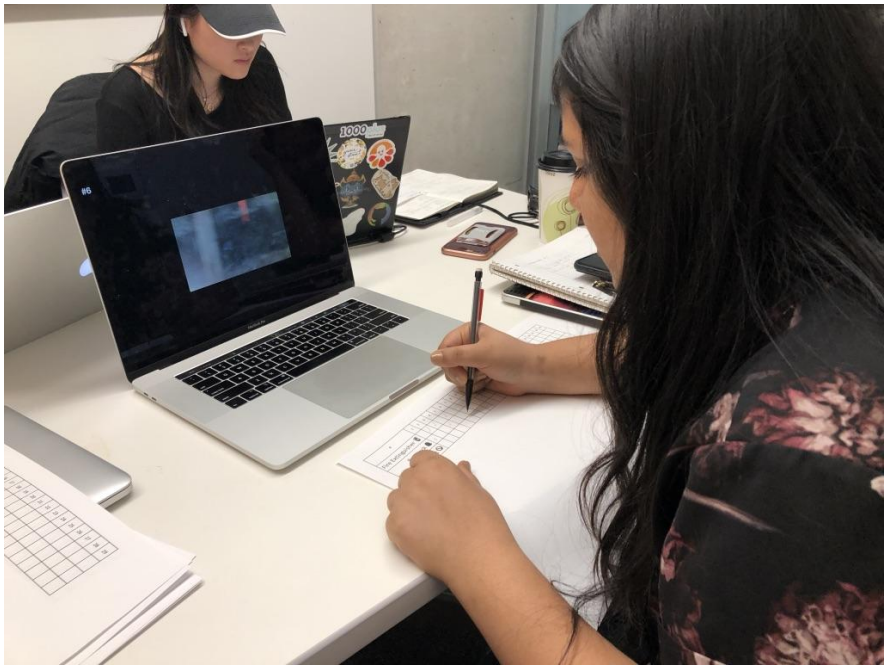
Being able to override algorithms is necessary so the operator can always remain in control.

Dynamic prototype: Manual Image recognition test

We tested people's **ability to recognize objects under time pressure**.

- Avg. Score of 27/29 correct recognitions

This makes us confident operators can be a reliable fallback when autonomous detection fails.



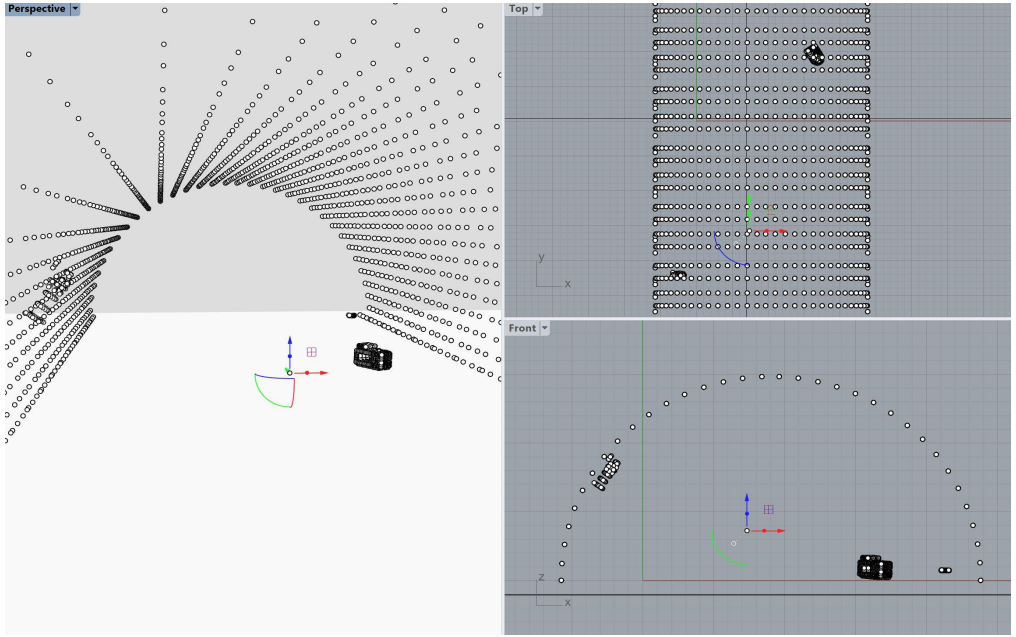
Dynamic prototype: location refinement

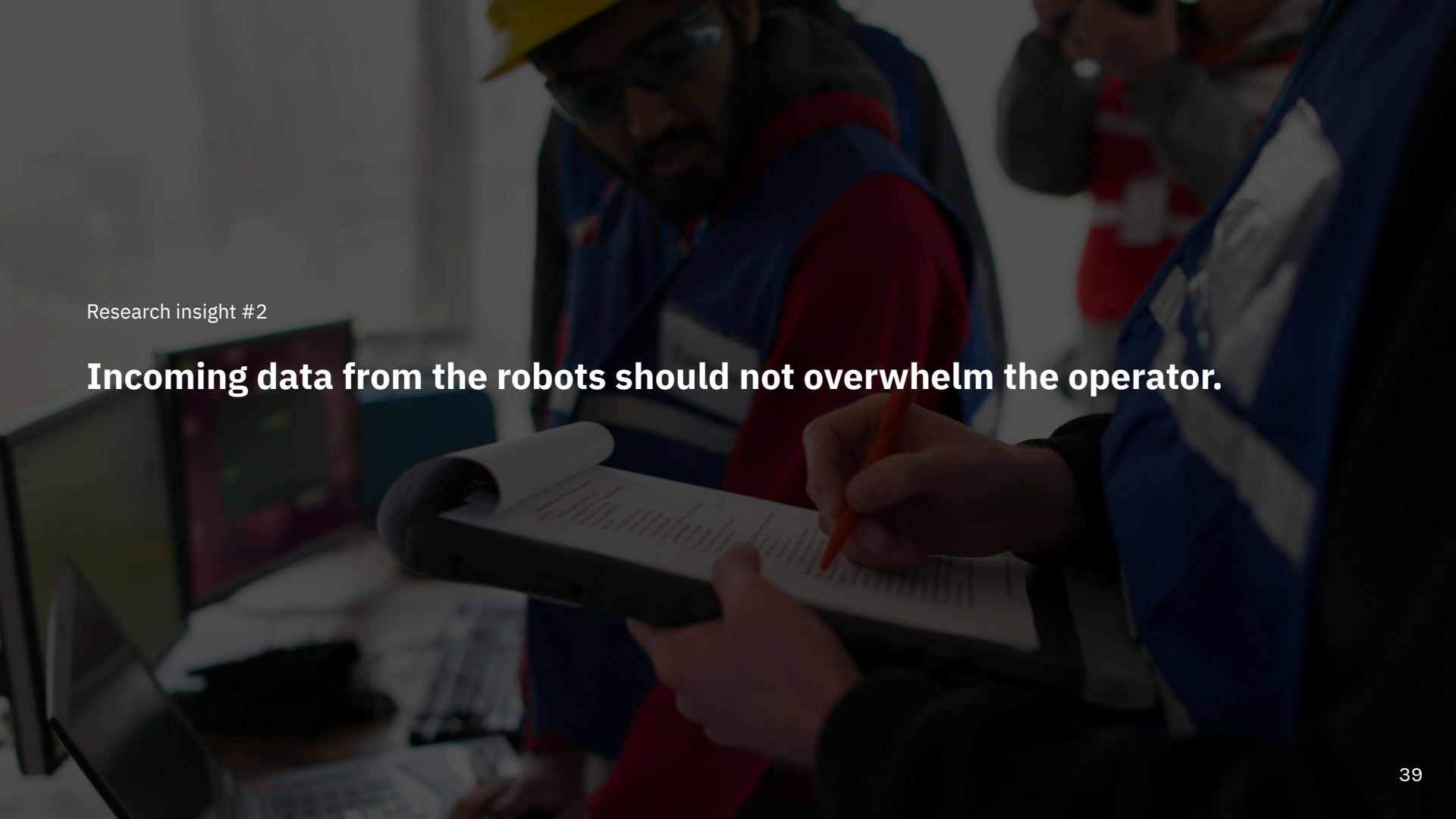
What?

Refining the XYZ-point location of artifacts detected by the robots

Why?

Existing method can cause inaccuracies and delays

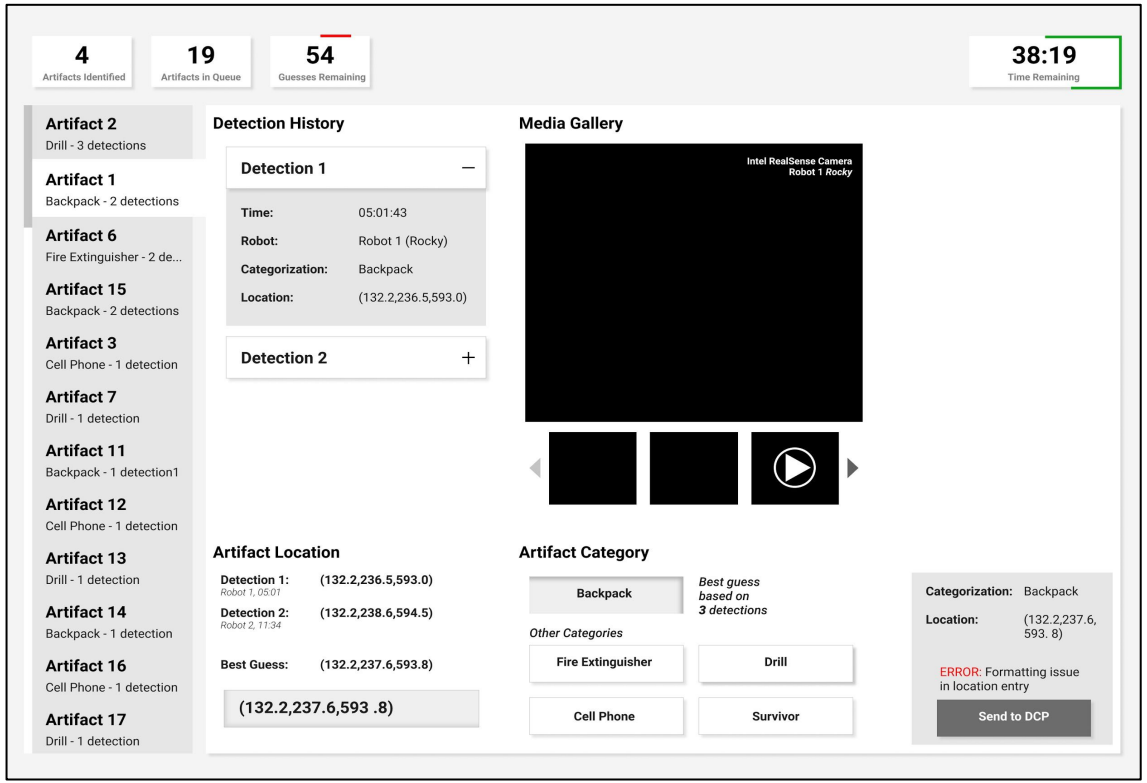




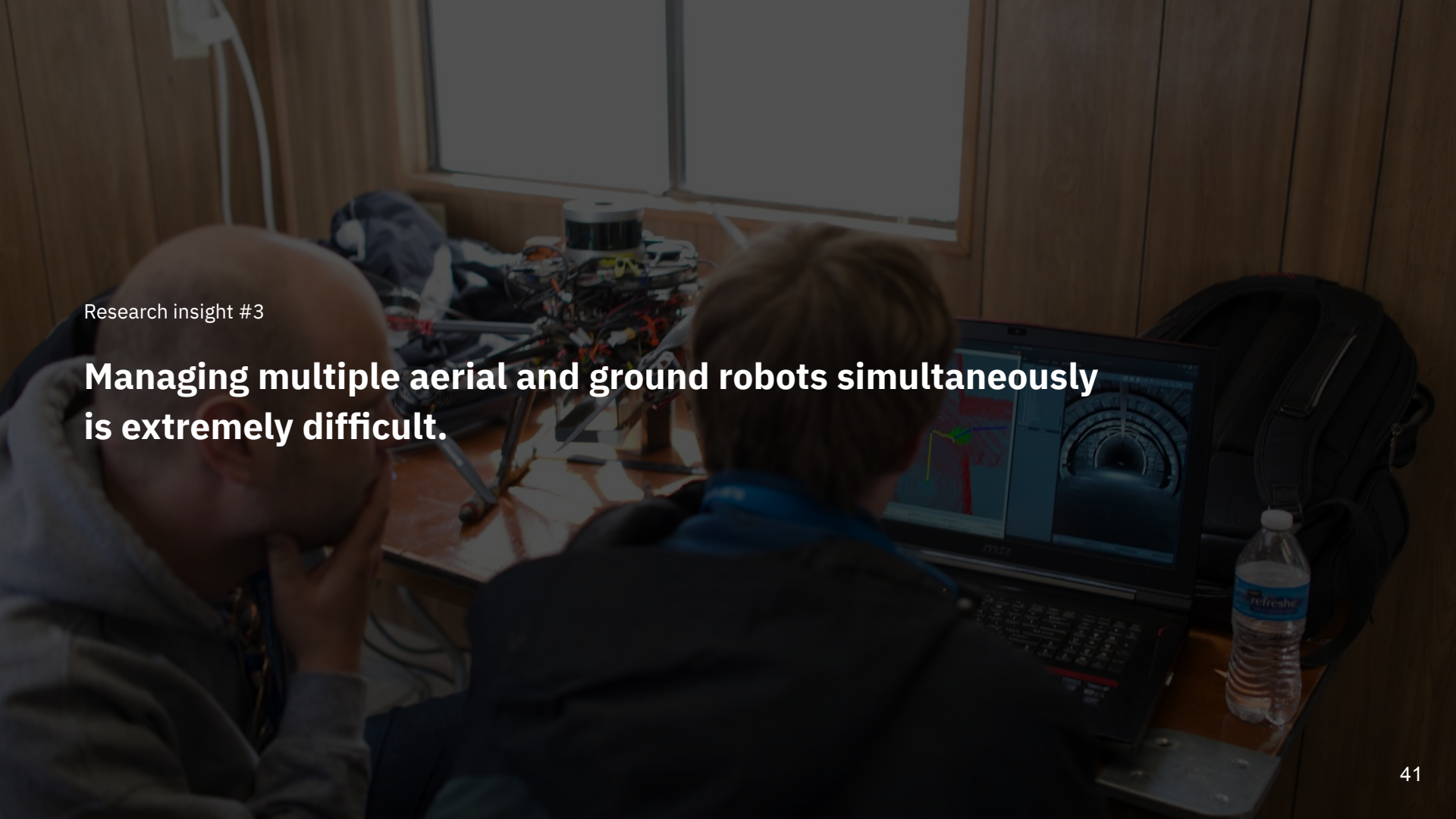
Research insight #2

Incoming data from the robots should not overwhelm the operator.

Low-fi prototype: Artifact queue



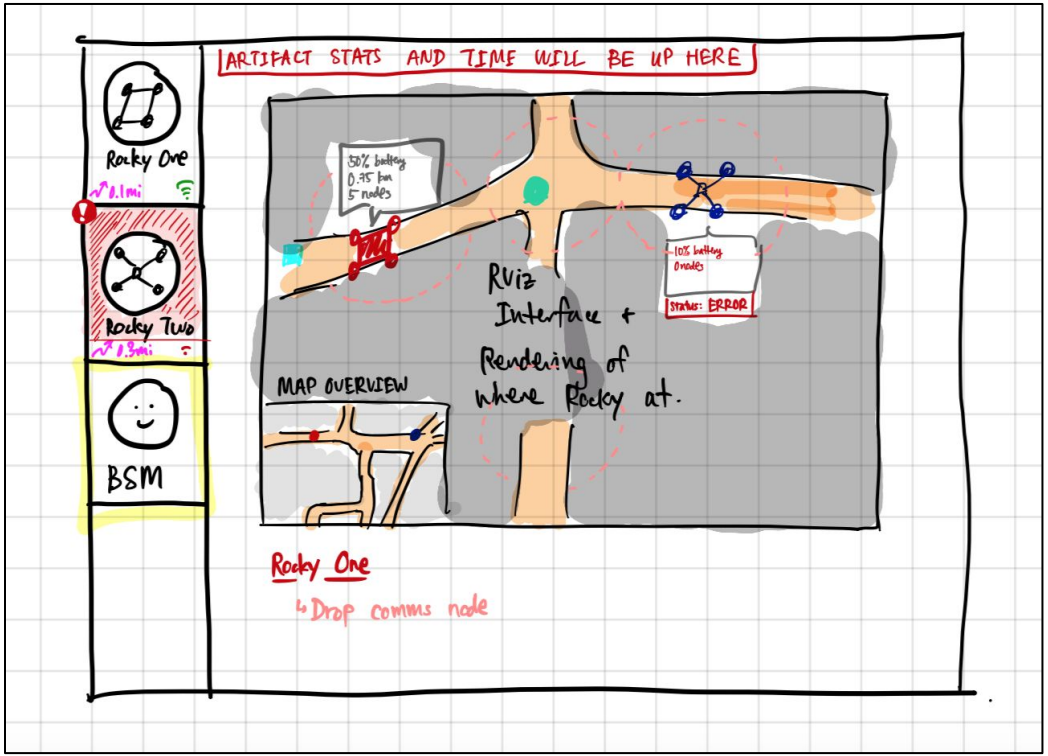
The artifact queue allows the base station manager to be able to **prioritize detections,** make changes, and optimize a **strategy for sending to DARPA.**



Research insight #3

Managing multiple aerial and ground robots simultaneously is extremely difficult.

Low-fi prototype: Scalability

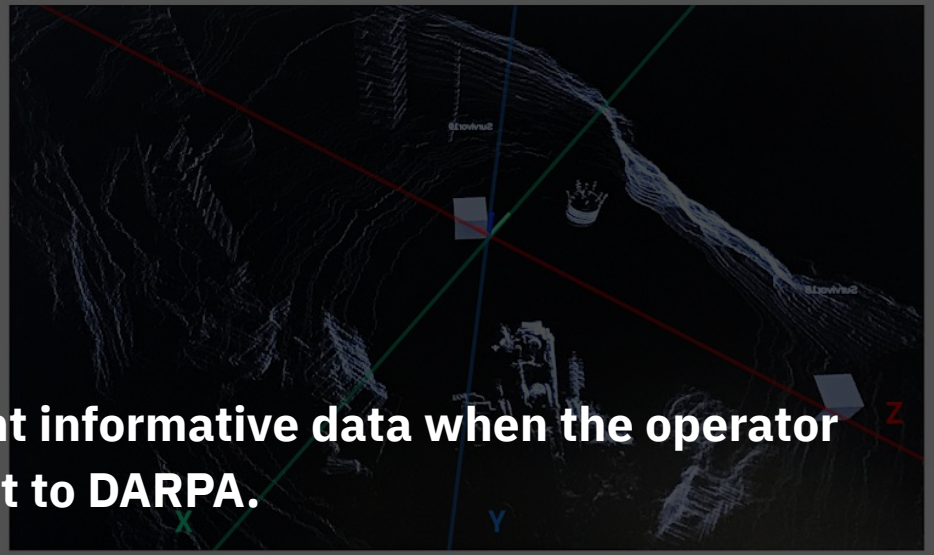


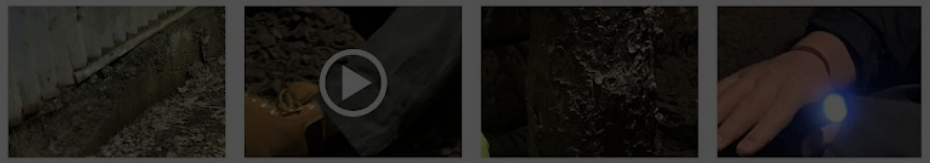
Features a **tabbed sidebar** that shows a preview of all deployed robots

Design insights

Design insight #1

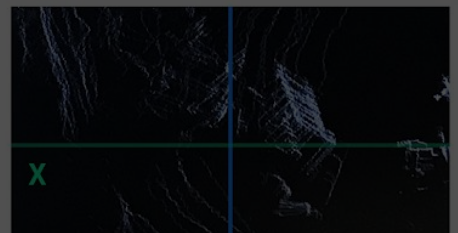
Our interface should efficiently present informative data when the operator is refining artifact detections to submit to DARPA.

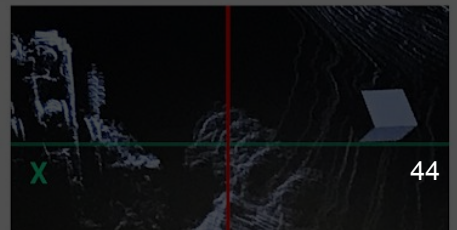


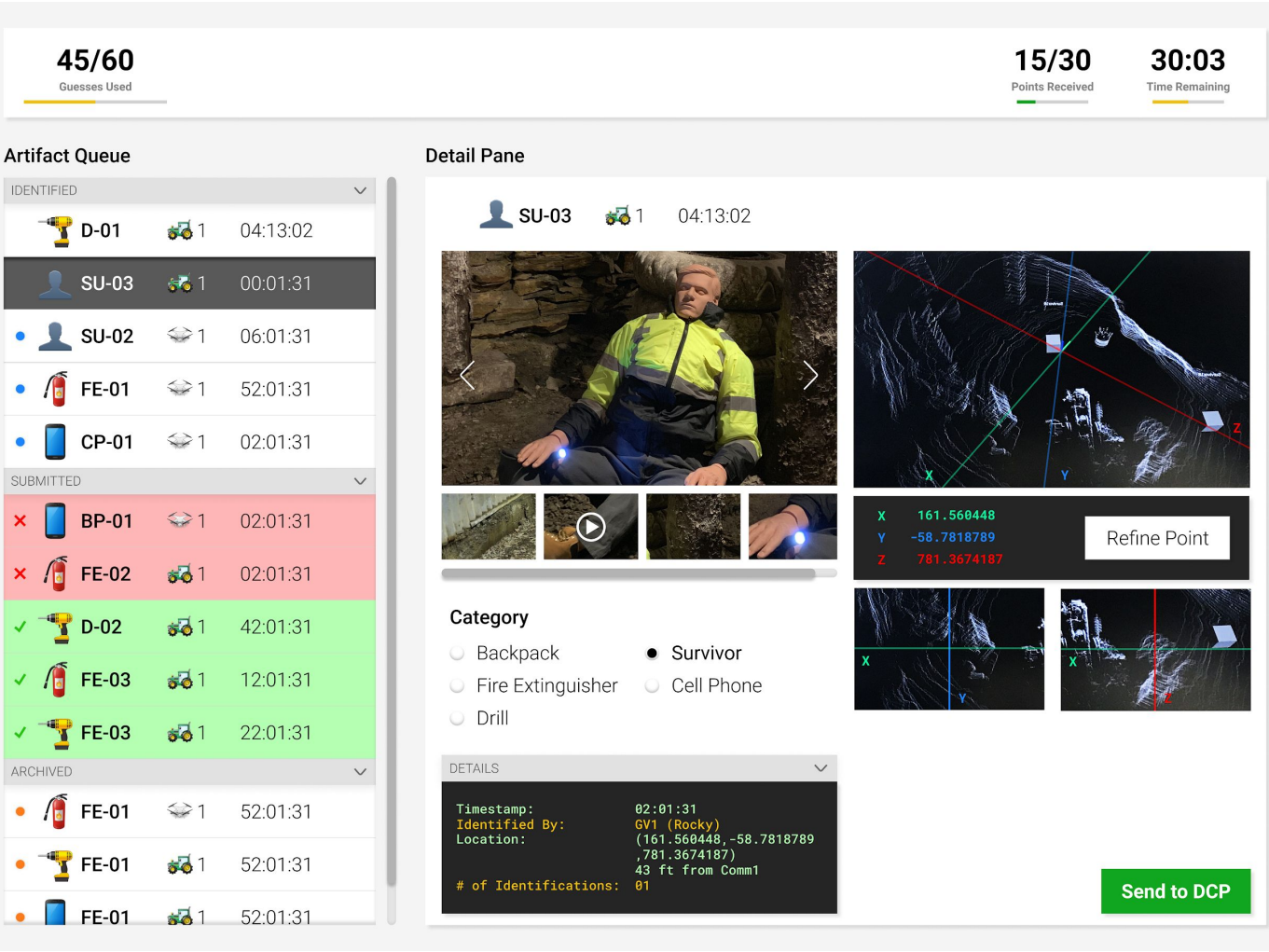


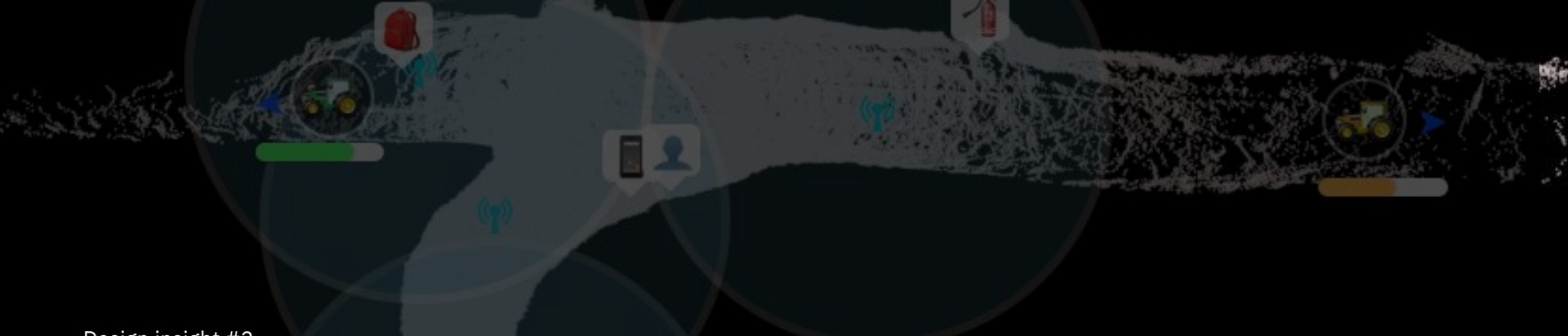
Category

- Backpack
- Survivor






45/60
Guesses Used
15/30
Points Received
30:03
Time Remaining
Artifact Queue
IDENTIFIED
D-01 1 04:13:02
SU-03 1 00:01:31
SU-02 1 06:01:31
FE-01 1 52:01:31
CP-01 1 02:01:31
SUBMITTED
BP-01 1 02:01:31
FE-02 1 02:01:31
D-02 1 42:01:31
FE-03 1 12:01:31
FE-03 1 22:01:31
ARCHIVED
FE-01 1 52:01:31
FE-01 1 52:01:31
FE-01 1 52:01:31
Detail Pane
SU-03 1 04:13:02
X 161.560448
Y -58.7818789
Z 781.3674187
Refine Point
Category
Backpack
Survivor
Fire Extinguisher
Cell Phone
Drill
DETAILS
Timestamp: 02:01:31
Identified By: GV1 (Rocky)
Location: (161.560448,-58.7818789 ,781.3674187)
43 ft from Comm1
# of Identifications: 01
Send to DCP



Design insight #2

Our interface should allow the operator to focus on tasks from one vehicle at a time, while still dynamically monitoring the entire system.

Monitoring Toolkit

Monitoring Toolkit

Conclusion

Despite some small feature updates, the team was **impressed** by GUI prototypes and can foresee them being **instrumental to their success** in the future competition.

Handoffs

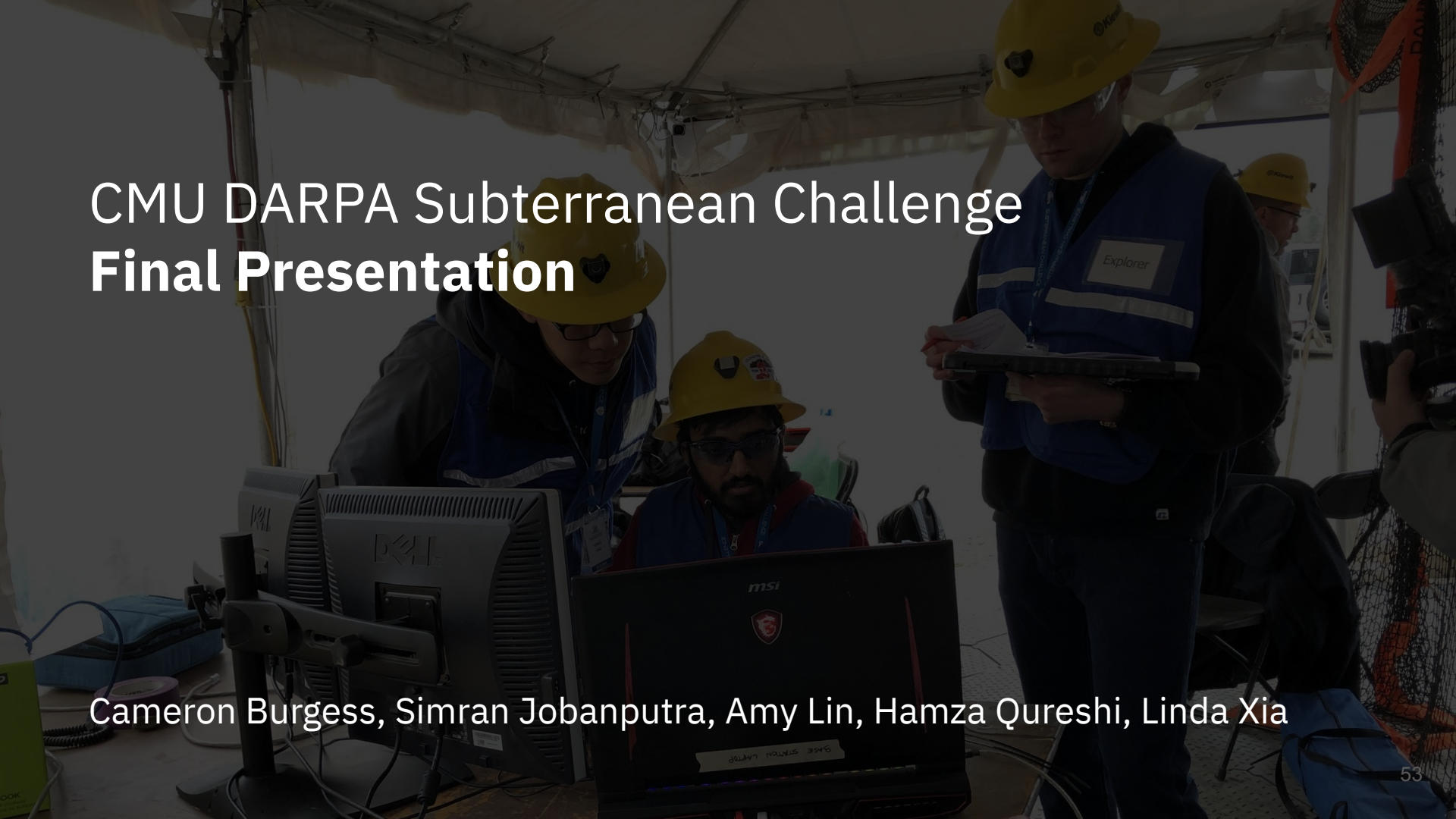
- **Design documentation** and recommendations that will guide them throughout future states of the competition

- Detailed **breakdown of the components** of the Action and Monitoring screens

- A **report of our insights** from our observations of the test runs in Colorado

Future Vision

- Using the GUI we designed, the team is able to **successfully manage a full fleet of robots** through the rest of the competition.
- As new challenges arise throughout the course of the competition, the team is able to the **use design principles** we've introduced to solve them.



CMU DARPA Subterranean Challenge
Final Presentation

Cameron Burgess, Simran Jobanputra, Amy Lin, Hamza Qureshi, Linda Xia