Efficient Data Collection Practices using the APEX OnePass Sensor with Stencil SLAM and RTK-GNSS Technologies for a Remedial Action

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TPMC-WRT LLC

One-pass dynamic Advanced Geophysical Classification (AGC) survey of the Munitions Response Site (MRS)

- GNSS-denied areas:
  - Kaarta's Stencil 2-16 Simultaneous Localization and Mapping (SLAM) system
- GNSS-accessible areas:
  - RTK-GNSS
- AGC sensor:
  - WRT's APEX

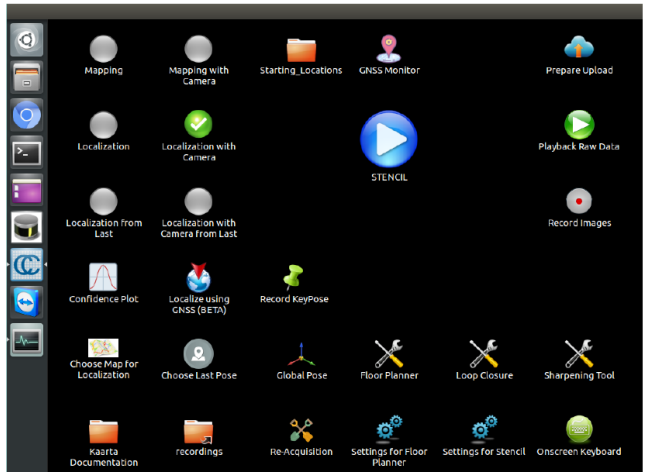
Stencil 2-16 SLAM Positioning System

- Developed and manufactured by Kaarta
- 3D LiDAR, inertial measurement unit (IMU), commercial processor and Kaarta software
- External battery pack
- Stream UTM coordinates/NMEA GNSS data to an external sensor
- Simulates a Robotic Total Station (RTS) or Global Positioning System (GPS)

Tablet connected via Bluetooth to Stencil 2 computer

Top: LiDAR (Velodyne VLP16)

Bottom: Stencil 2 computer, camera, IMU



Kaarta software

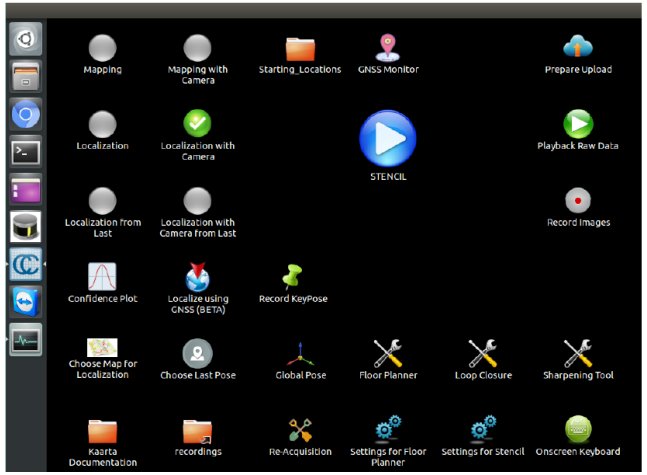
Stencil 2-16 SLAM Positioning System

- 100-meter LiDAR range
- 300,000 points
- Can create dense maps of environment to provide positional accuracies of 5-8 cm
- Areas can be as large as 20 grids of 100 ft x 100 ft

Tablet connected via Bluetooth to Stencil 2 computer

Top: LiDAR (Velodyne VLP16)

Bottom: Stencil 2 computer, camera, IMU



Kaarta software

Stencil Method 3

- Uses survey control points to create geo-referenced map
- Use “Mapping” mode to generate an initial base map
  - Scanning area generates a point cloud in local coordinates
  - SLAM’s local coordinate system is tied to global coordinate system with Ground Control Points (GCPs)
  - Scan area with Stencil, record “Key Pose” on each GCP during scan
  - Use point cloud to generate geo-referenced base map
- Once initial base map is generated, use one of the “Localization” modes to navigate within previously generated base map
  - During scan, Stencil 2 locates itself within base map
  - Localization
  - Localization from last

Stencil 2 Modes

“Mapping” at IVS location

GCP example

APEX

- Advanced Electromagnetic Induction (EMI) sensor designed for dynamic classification of buried UXO.
- Can integrate with SLAM, GNSS, and RTS positioning systems
- IMU for sensor pitch, yaw, and roll
- Ruggedized field acquisition touch screen computer with integrated data acquisition software
- Operated in push-cart/litter mode

Navigating APEX in MRS

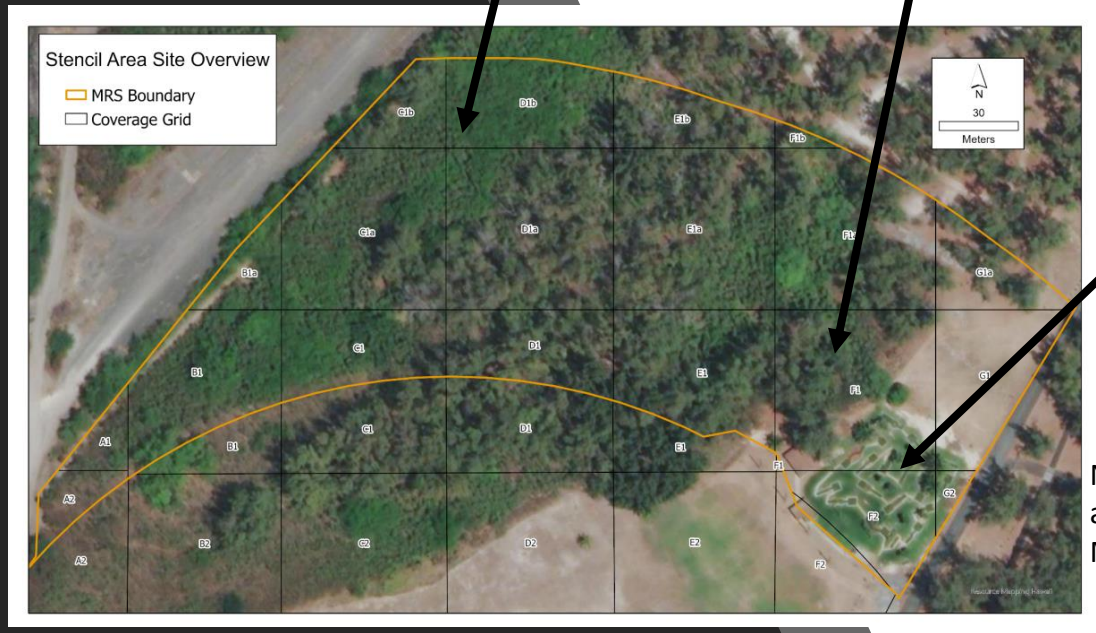
APEX with SLAM

Munitions Response Site

- Remedial Action
- One-pass dynamic AGC survey
- 16.4 acres total
- 4.4 acres GNSS-denied
- Majority of grids in north area were partially GNSS-denied

GNSS-accessible area

GNSS-denied area



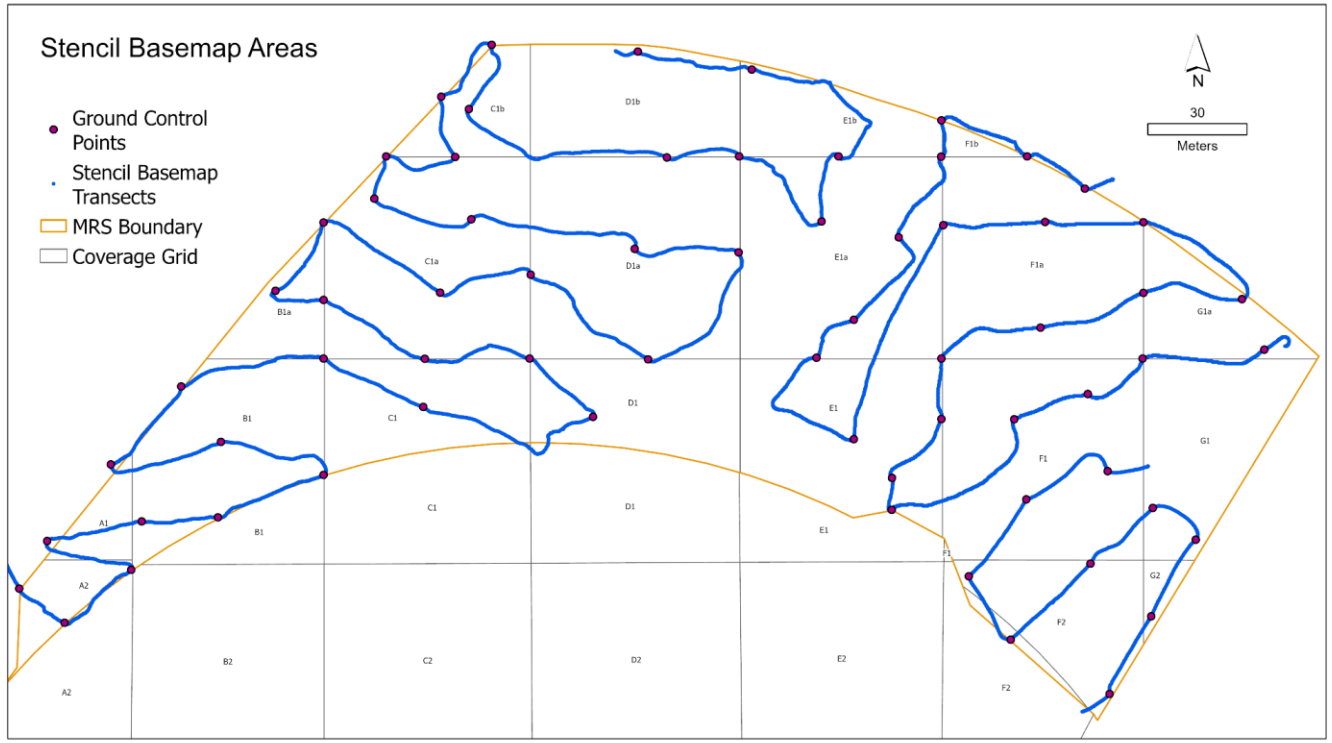
North area of MRS

Mini-golf area

Planning for SLAM

Site Preparation:

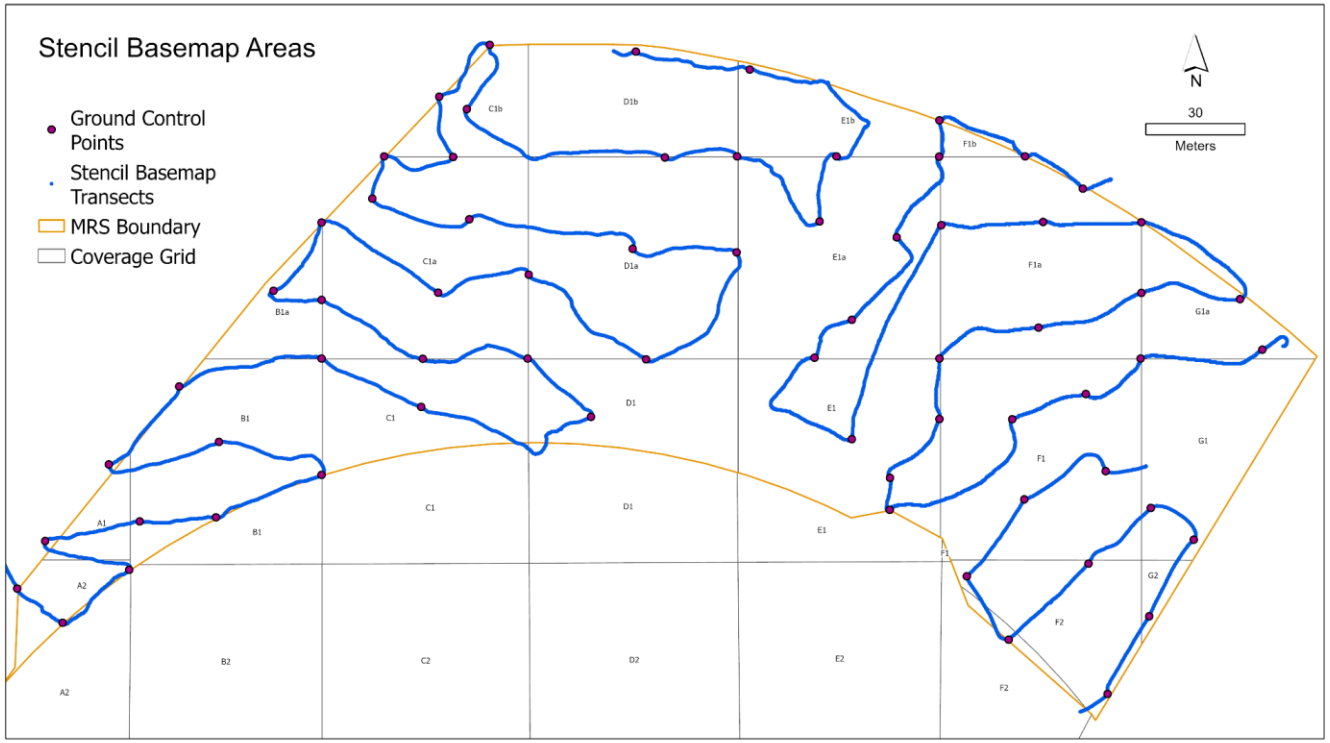
- Determine GNSS-denied areas
- Plan Ground Control Points (GCPs) for aligning point cloud and trajectories to external survey data
  - Planned location of GCPs to be in area with satellite coverage
  - 100 ft apart
- GSI performed vegetation removal
- Install GCPs

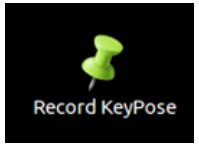


Planning for SLAM

Plan a trajectory to each GCP, navigate to and record local Stencil position with “Key Pose”

- No overlapping paths
- No sharp turns
- Start ~50ft from first GCP
- Don’t close trajectory loop
- No variable objects (vegetation, people, truck, etc) in area while generating base map
- Can set a ‘blind radius’ distance to ignore a set diameter around the Lidar (to remove the operator and sensor)





Initial Base map of GNSS-denied area

Created the Base Point Cloud with Stencil 2 mapping feature

- Stencil determines how it needed to move to match up successive laser scans from a 3D lidar
- Can create a 3-D registered point cloud while moving Can create a position estimate of where it is in that point cloud

Generated the reference map that was used for localization

- Georeferenced using Kaarta's proprietary loop closure method
- Accuracy of map checked with Kaarta UXO QC tool

4 point clouds created:

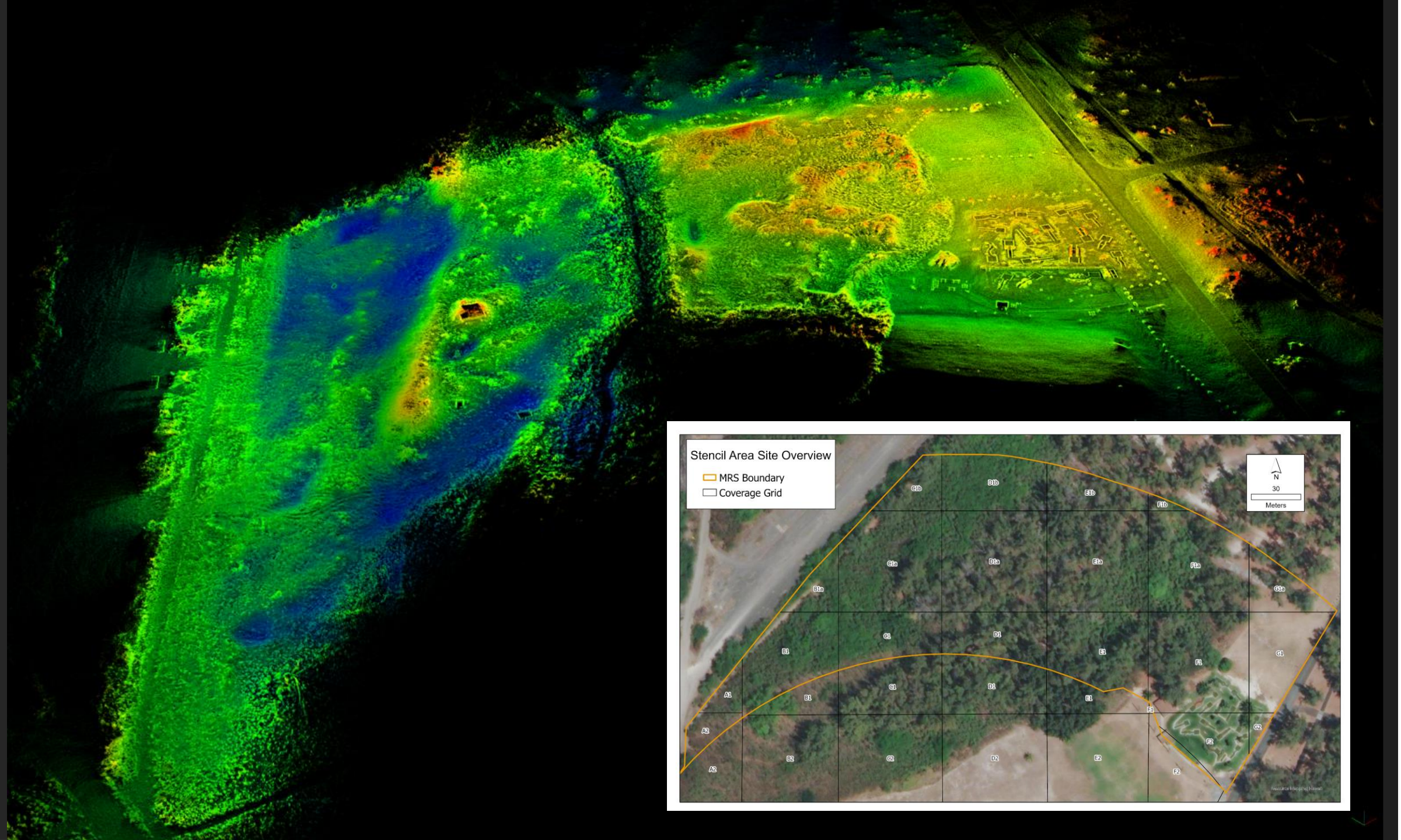
- IVS base map, mini golf area base map, two base maps in GNSS denied areas (Northeast, Northwest)
- All showed position accuracy of <8cm

Example results from UXO QC

Grid_ID	Time	dX	dY	dZ	dXY	dXYZ		Roll(deg)	Pitch(deg)	Yaw(deg)
SL-19 60D-SET 618	78.136	-0.033	-0.014	0	0.035	0.035		-0.648	0.172	-144.404
GSN-G1A 60D-SET 750	168.337	-0.063	0.006	-0.01	0.063	0.064		-0.648	-0.168	-152.142
SL-18	234.437	-0.002	0.007	0.007	0.007	0.01		-0.329	-0.332	173.802
SL-17 60D-SET 716	299.338	0.02	-0.014	0.003	0.025	0.025		-0.324	0.038	-144.859
BBN-28_05102022	425.64	0.013	0.061	-0.063	0.062	0.089		0.191	0.098	-57.731
SL-16 60D-SET 715	488.44	0.001	-0.006	0.045	0.006	0.046		-0.39	-0.446	160.195
SL-15 60D-SET 714	545.442	0.013	-0.027	-0.008	0.03	0.031		-0.18	-0.162	71.37
GSN-F1a	590.542	-0.017	-0.019	0.02	0.026	0.032		-0.016	-0.208	78.816
SL-12 60D-SET 711	653.143	0.007	0.003	-0.02	0.007	0.022		0.07	-0.048	18.911
SL-08 60D-SET 707	723.443	-0.012	-0.011	-0.028	0.016	0.033		0.011	0.141	25.176
BSN-11 60D-SET 752	794.744	0.007	0	0.019	0.007	0.02		-0.057	-0.406	7.201
BSN-10 60D-SET	873.545	-0.036	-0.017	0.026	0.04	0.048		-0.168	-0.495	-158.705
SL-06 60D-SET 705	937.945	0.002	0.01	-0.016	0.01	0.019		-0.159	-0.115	179.684
SL-20 60D-SET 719	1001.347	-0.002	-0.04	0.004	0.04	0.041		0.028	-0.075	-132.241
SL-14 60D-SET 713	1107.447	-0.005	0.021	-0.012	0.022	0.025		-0.405	-0.276	-100.947
SL-11 60D-SET 710	1204.748	0.036	0.011	0.029	0.038	0.048		-0.271	-0.108	9.237
SL-13 60D-SET 712	1270.049	0.002	0.024	0.006	0.024	0.024		0.057	0.097	22.111
SL-21 60D-SET 720	1337.25	0.015	0.014	-0.015	0.02	0.025		-0.147	-0.22	117.388
GSN-F1B 60D-SET 747	1431.251	-0.007	-0.006	-0.03	0.009	0.031		0.008	-0.068	30.009
BSN-08 60D-SET 748	1498.651	-0.015	-0.054	0.025	0.056	0.061		0.023	0.293	57.499
BSN-09_05102023	1575.052	-0.031	0.051	-0.034	0.06	0.069		-0.311	0.243	-4.07
SL-07 60D-SET 706	1622.452	-0.009	-0.005	0.027	0.01	0.029		-0.214	0.076	-33.766
MEAN					0.028	0.038				
STDEV					0.019	0.019				
MIN		0.001	0	0	0.006	0.01				
MAX		-0.063	0.061	-0.063	0.063	0.089				

Some of Kaarta's processing tools

Collecting Key Poses for IVS


Stencil Area Site Overview
MRS Boundary
Coverage Grid
N
30
Meters
A1
A2
A3
B1a
B1
B2
C1b
C1a
C1
C2
D1b
D1a
D1
D2
E1b
E1a
E1
E2
F1b
F1a
F1
F2
G1b
G1a
G1
G2

Integration of SLAM with APEX

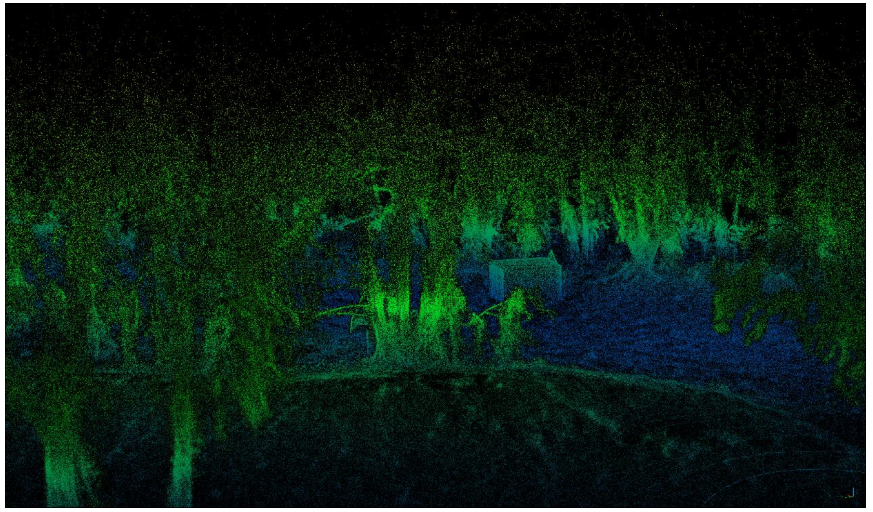
- Connects via serial to APEX computer
- Streams pseudo-NMEA string to APEXField
- IPAD used in the field to control and monitor the Stencil

SLAM mounted on APEX

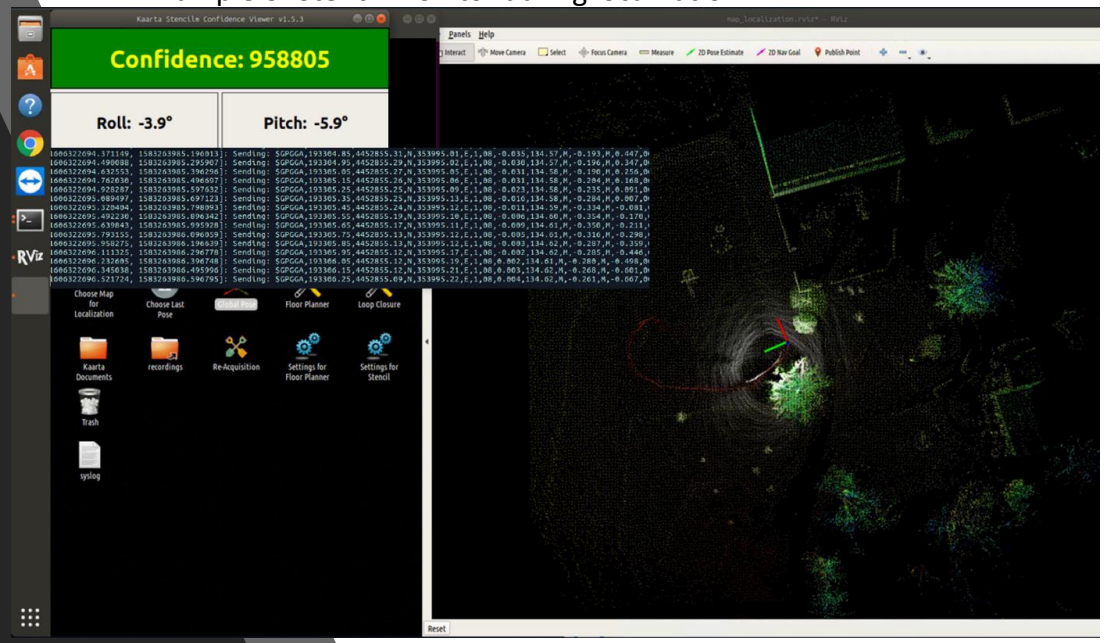
Real Time Localization

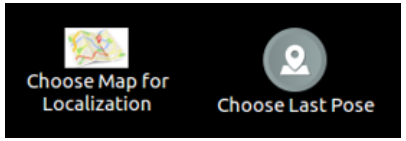
- The Stencil matches current scan against a base map
- Select a starting point from generated list and a base map
- Confidences should be over 100,000 to ensure high quality data.
  - Measure how well current scan matches base map
- Position messages are sent over USB port as a simple simulated NMEA Pseudo-GNSS message
- White dots=real time, colored dots=base map

3D Example of Base Point Cloud – Grid D1a



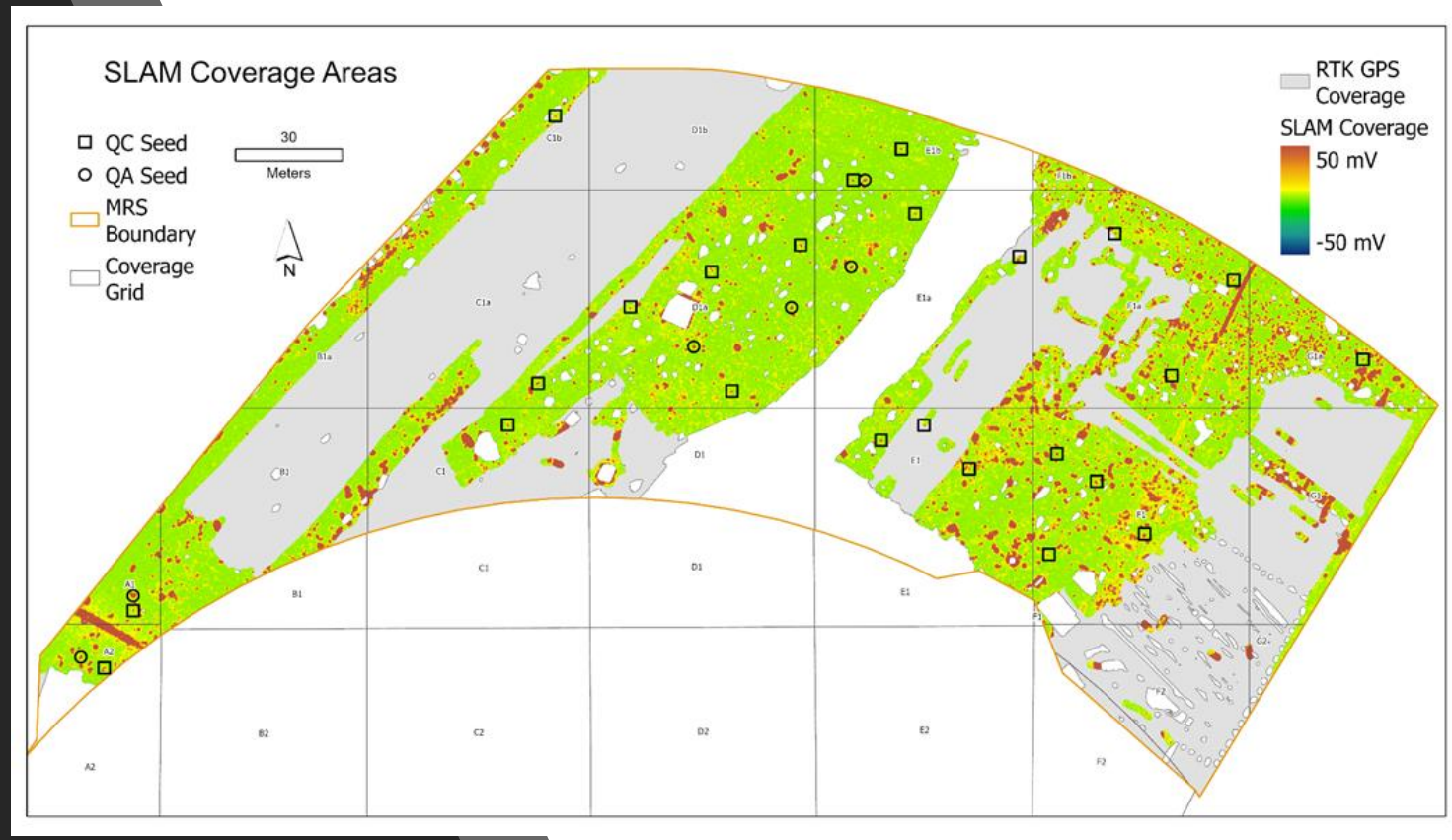
Example of Stencil monitor during localization





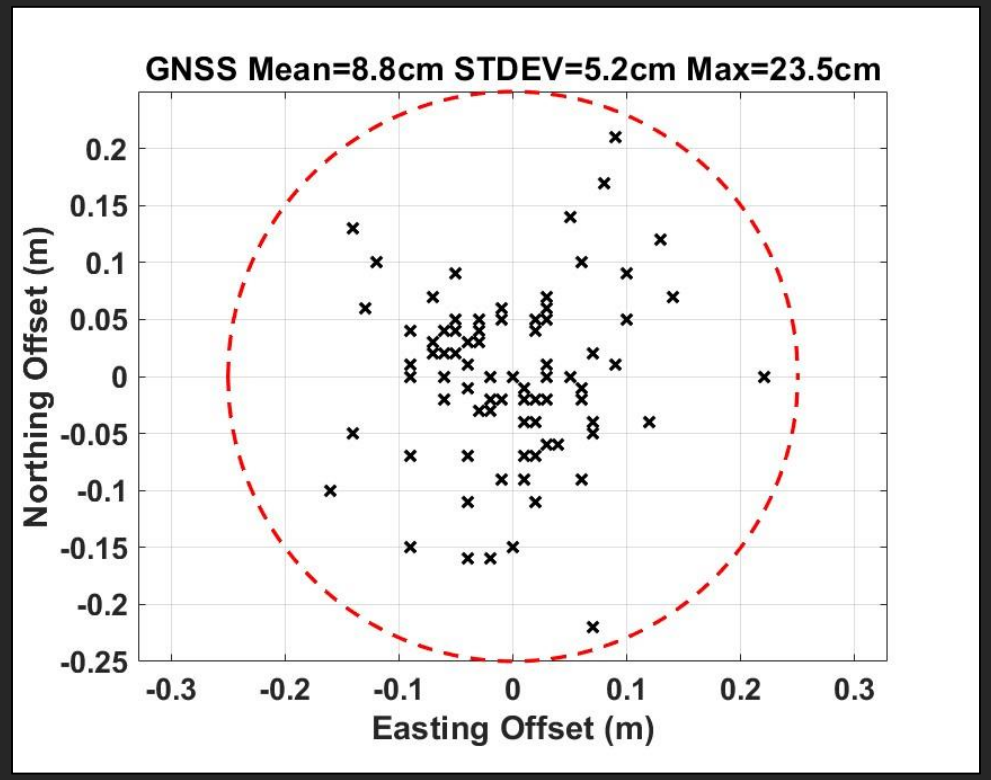
Mapping Results

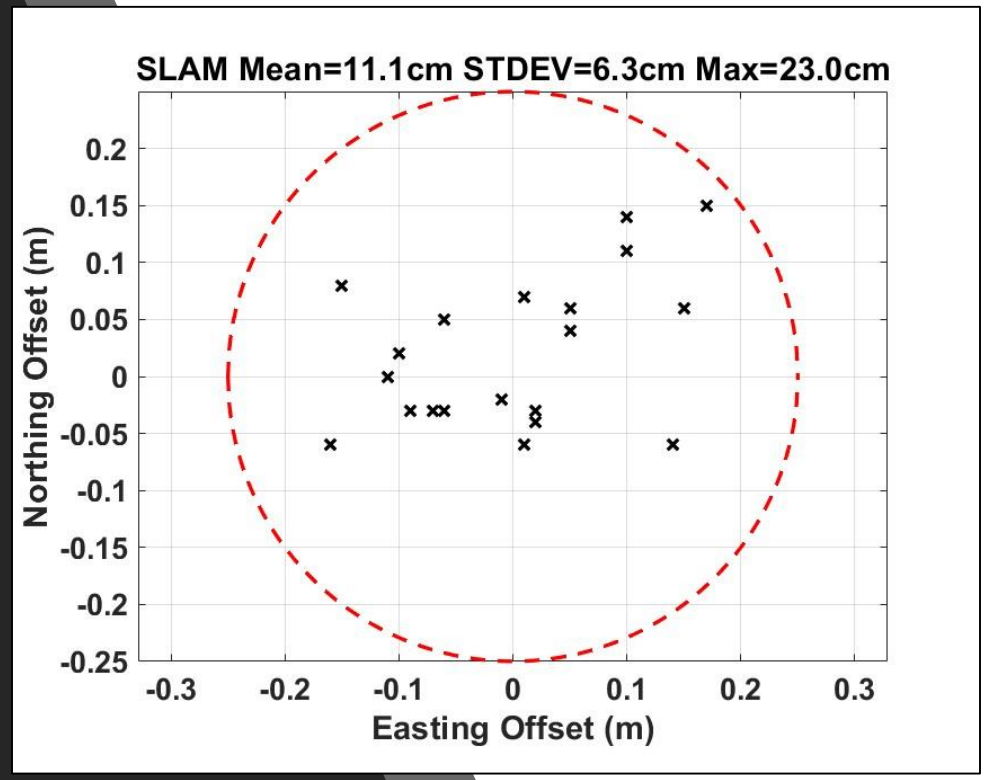
- QC seeds placed by GSI and QA validation seeds placed by the government.
- TPMC-WRT collected APEX One Pass data in 4.6 acres of GNSS-denied area with SLAM
- Point cloud base maps were created with an accuracy less than 8 cm
  - based on QC Tool results.
- 24 Blind QC seeds and 6 QA validation seeds were detected and classified correctly which met the position MQO's



SLAM vs. GNSS

- Seed position offsets (QC seeds)





Dual purpose IVS location

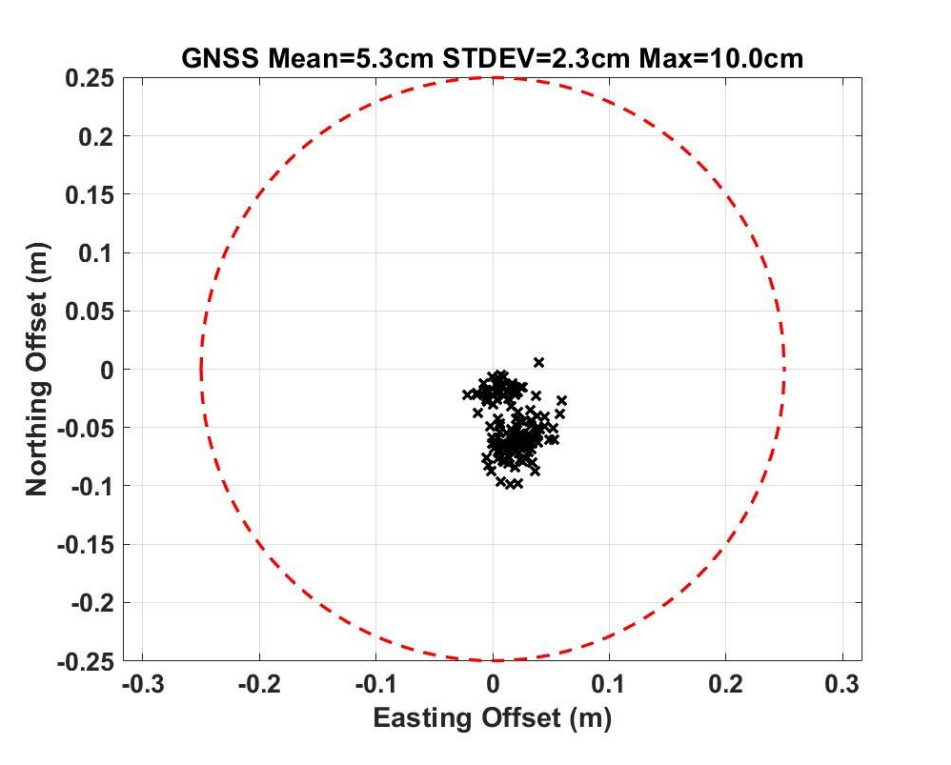
- Can select IVS location to be used for SLAM and RTK-GNSS
- Considerations:
  - Lighting conditions, bright or variable lighting due to absence of canopy may affect ability to localize
  - Sufficient objects for base map
  - Variability of objects (ie people, cars, etc.) if located in area of high traffic

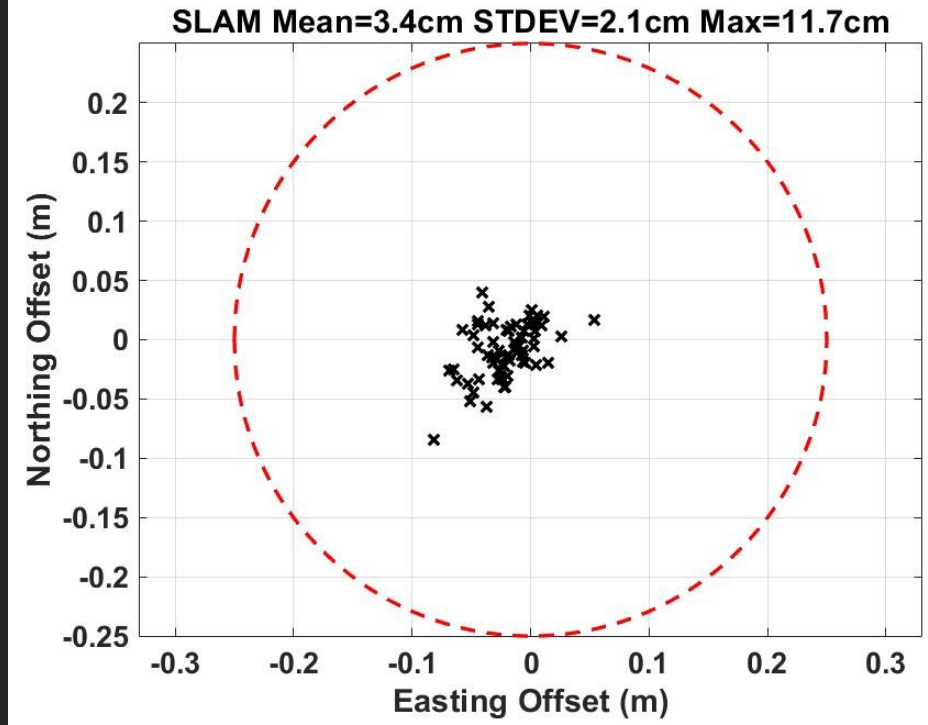
Base map of IVS area

Collecting daily IVS with SLAM

IVS SLAM vs. GNSS

- Seed position offsets



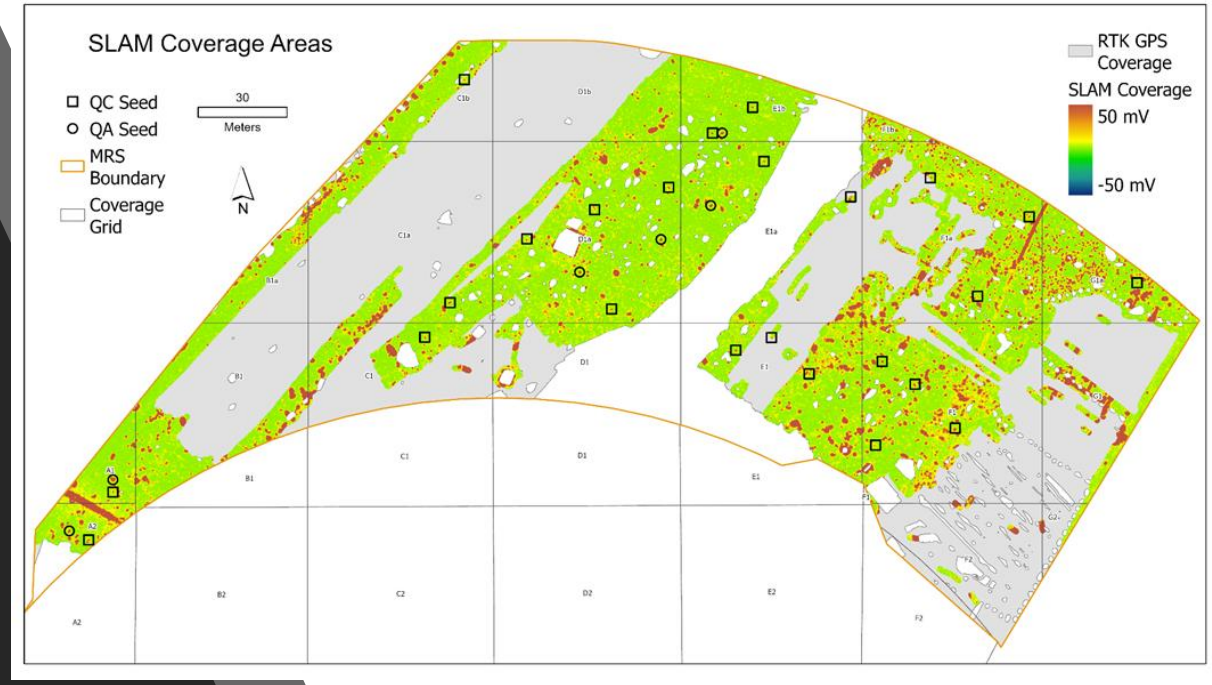


Survey Considerations and Best Practices

- Batteries need to be switched about every 1.5 hours (more often in cold temps)
- Can use “Localization from last”

Survey Set Up

- Takes time to switch between RTK-GNSS and SLAM, tried to do just one each day
- Did not go grid by grid to more efficiently survey with SLAM
- Tree circles



Survey Considerations and Best Practices

- Lidar won’t reflect back in water (fog, lakes, puddles, etc)
- Ability to install GCPs if there is no satellite coverage
- Unit not waterproof yet
- IPAD overheats easily
- Variable lighting conditions

Survey Considerations and Best Practices

- Processing needs to be done on Stencil computer (can’t send data back to the office unless they also have a Stencil)
- Large files generated

Daily QC

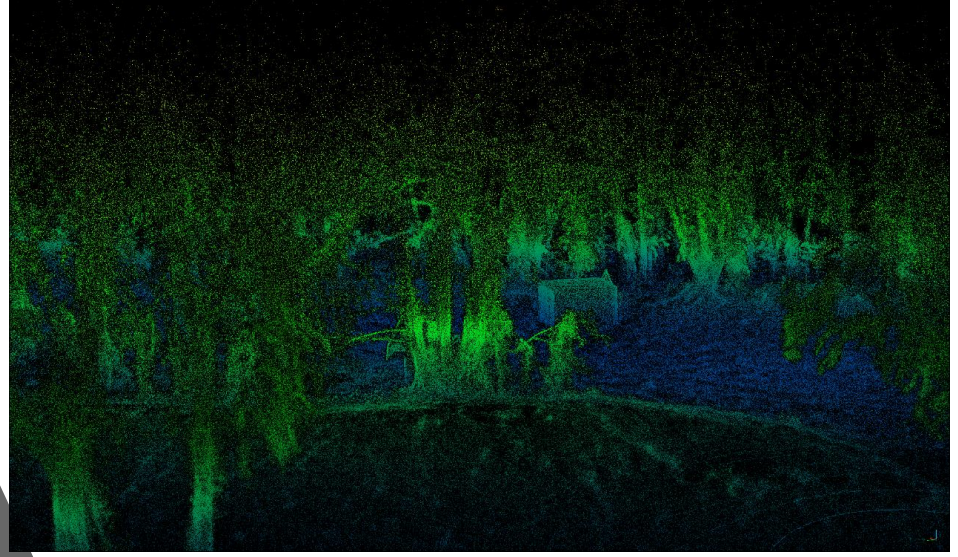
- Verify Stencil positioning on benchmark (done daily at IVS)
- Monitor confidence during survey
- APEXField can be set up to monitor confidence values

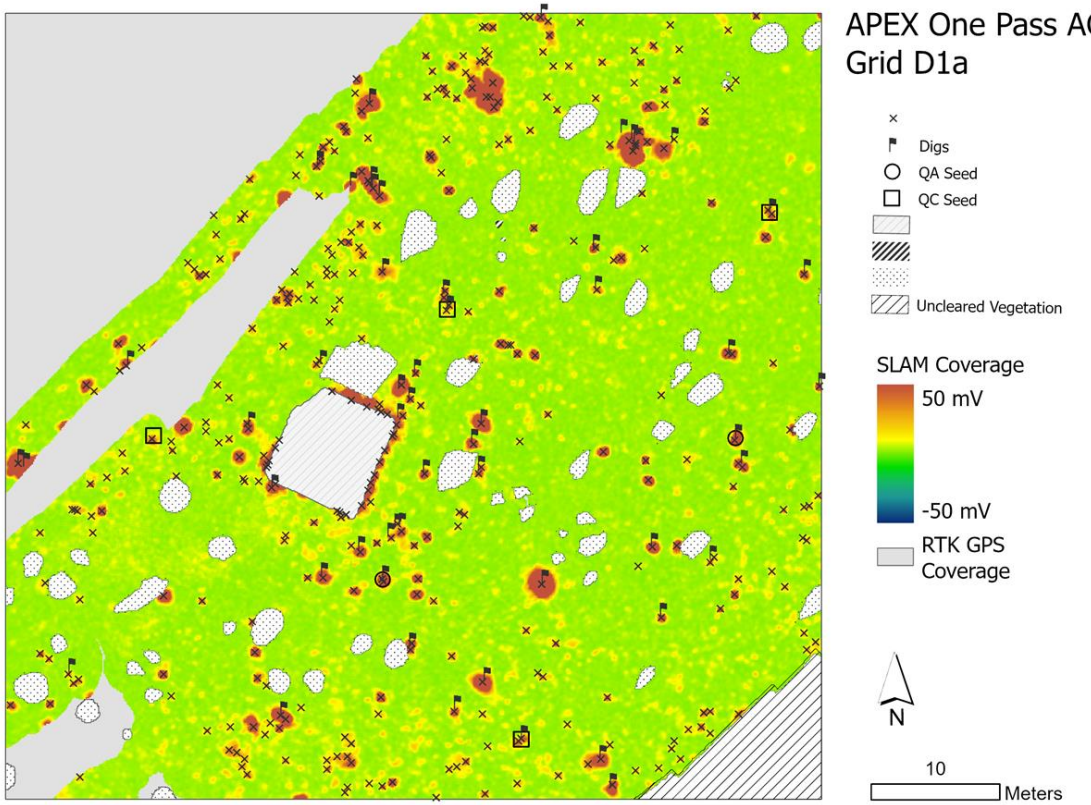
Questions?

- Contact info:

SLAM Advantages

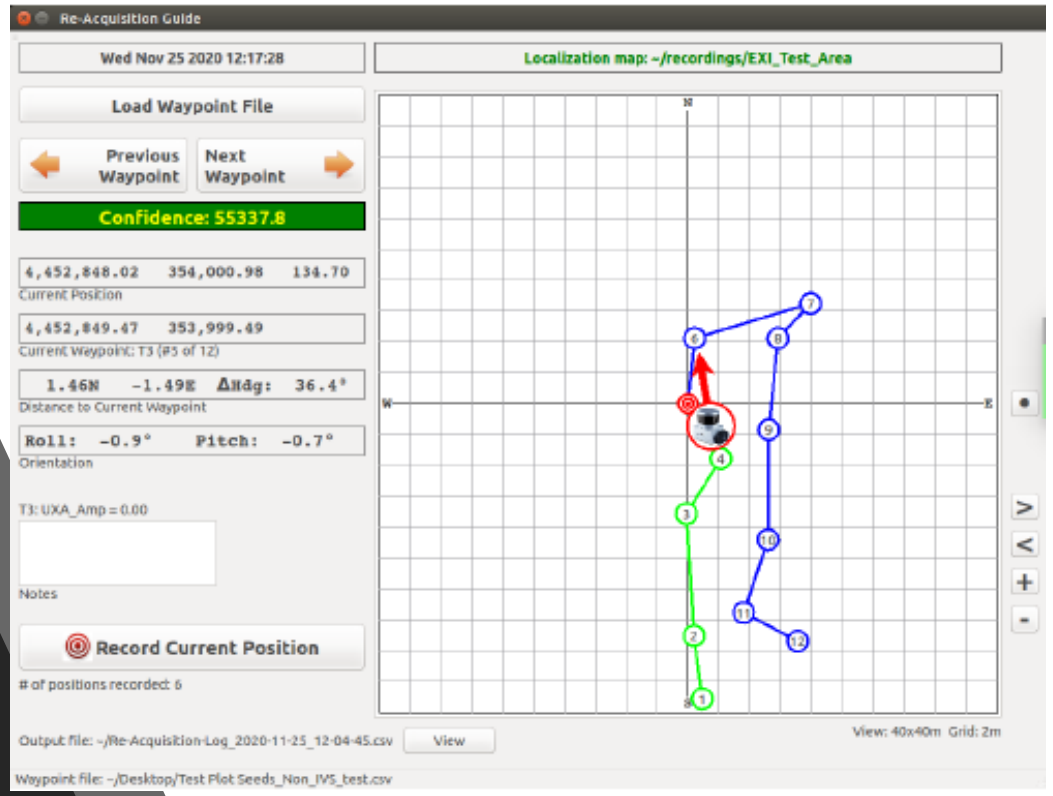
- QC gaps





SLAM Advantages

- Reacquisition tool
  - Can be used for positioning/location of seeds
  - reacquisition of targets in GNSS denied areas



SLAM Advantages

- Bare earth model showing ground surface elevation
- Potential sensor heights
  - Variable sensor height