EXECUTIVE SUMMARY

Live Site Demonstration of Advanced Geolocation Technology to Support Dynamic Classification of EMI Data Collect in GPS-challenged Areas

ESTCP Project MR-201418

MARCH 2019

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1.0 INTRODUCTION

Detection and removal of buried, unexploded ordnance (UXO) from past military activities are necessary to protect human lives and the environment. A key objective of the munition response program within the Environmental Security Technology Certification Program portfolio is to demonstrate the capabilities of various technologies related to UXO detection and classification. Electromagnetic Induction (EMI)-based detection of UXO has been successfully demonstrated in the recent past; for example, the US Naval Research Laboratory's (NRL) TEMTADS 2x2. The quality of the modeling results from the post-processing of EMI observations is directly related to the quality of the position and attitude information used to merge these observations into one anomaly map.

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2.0 OBJECTIVES

2.1 UXO DETECTION

Detection and removal of buried, UXO from past military activities are necessary to protect human lives and the environment. A key objective of the munition response program within the ESTCP portfolio is to demonstrate the capabilities of various technologies related to UXO detection and classification. EMI-based detection of UXO has been successfully demonstrated in the recent past; for example, the NRL TEMTADS 2x2. The quality of the modeling results from the post-processing of EMI observations is directly related to the quality of the position and attitude information used to merge these observations into one anomaly map.

The lack of practical navigation technologies for use in Global Navigation Satellite System (GNSS)-challenged areas has long hindered UXO remediation efforts, particularly for densely canopied areas. The developed geolocation solution demonstrated in this project is based on a quadruple sensor integration, including GNSS PPK (post-processed kinematic), SDR (Software Defined Radio), Inertial Measurement Unit (IMU), and UWB (ultra-wideband) sensor technologies. The high-level description of the developed advanced geolocation technology (AGT), including the sensor data streams, preprocessing modules and navigation filter is shown below. The potential benefits are enormous, as it provides the missing technology component to perform routine EMI surveys in GNSS-challenged areas.

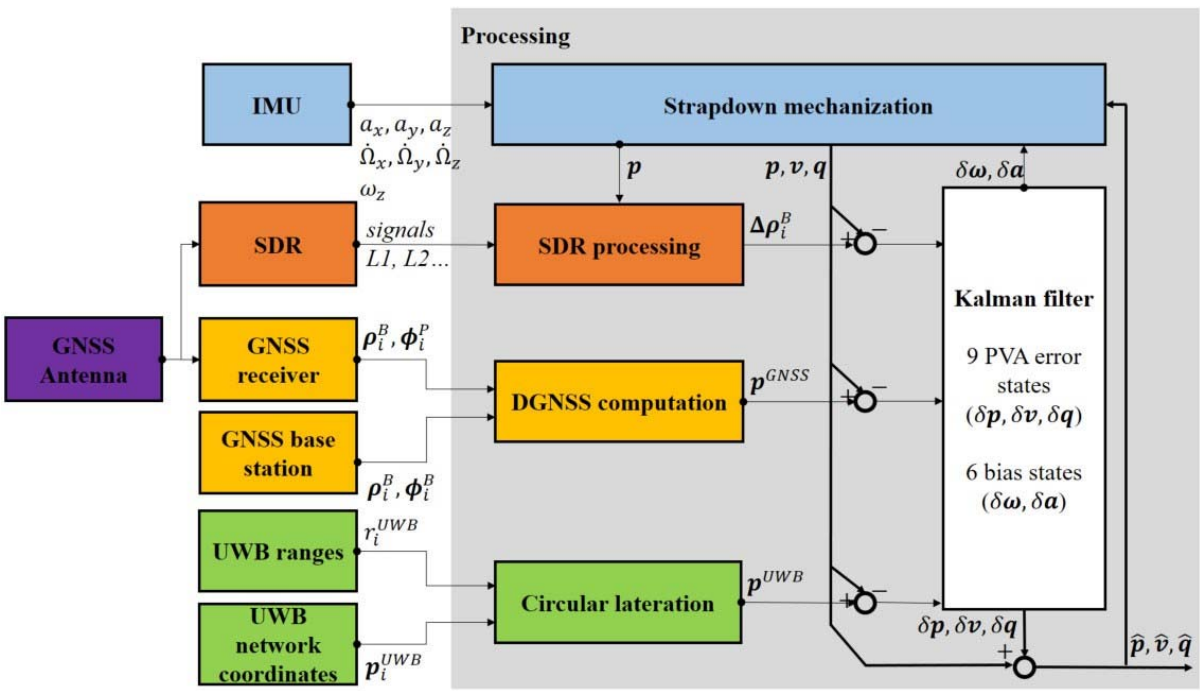

Figure 1. Schematic Diagram for Quadruple Sensor Integration Used in AGT

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3.0 TECHNOLOGY DESCRIPTION

3.1 AGT PROTOTYPE

The technology development achieved in SERDP MM-1564 project, *Novel Geolocation Technology for Geophysical Sensors for Detection and Discrimination of Unexploded Ordnance*, formed the basis for the prototype systems developed for the demonstrations in this project. As technology has advanced, the original sensor integration concept was updated to reflect the state-of-the-art in sensing, and consequently, in the data processing workflow. In short, the pseudolight and laser sensor sensors were replaced by UWB and SDR technologies. Furthermore, due to technological improvements, the first AGT prototype system was significantly upgraded for the main demonstration. The first one was based on a pushcart data acquisition system, while the second was based on a backpack configuration. Images below show the two systems.

Figure 2. TEMTADS 2x2

Figure 3. AGT first prototype (2016)

Figure 4. Configuration used in the Demonstration in 2018

In GNSS-denied areas, such as forested areas, the UWB subsystem provides positioning, which is based on using a set of UWB radios with known local or global coordinates, installed around the surveyed areas. In our tests, UWB sensors were installed on four poles, which were placed at the corners of the test site. The setup and positioning of the pole required about 10-15 minutes per site.

3.2 SITE SELECTION

US Army Research Laboratory (ARL) - Blossom Point was jointly selected by ESTCP and NRL as the demonstration site. It provides the obvious benefit of being where NRL's equipment, tools, offices, etc. are located, thus providing strong support for facilitating the development of the EMI and AGT system integration, establishing survey procedures, and creating standards for testing. Beyond that, however, the environment provided many of the features one would look for in a "typical" survey site in the Eastern United States.

The actual test areas were selected in cooperation with US Army Research Laboratory – Blossom Point Facility personnel. The decision was based on:

- Canopy thickness in the area
- Density of ground vegetation that would allow for pushcart operation
- Ability to tie survey control into area
- Ease of emplacing targets

To assure that the performance evaluation was unbiased, the development of the seed plan and the ground truth was held by a firewalled member of the NRL team, the team quality control (QC) member, and specifically held from the EMI data analyst. The location of the detected anomalies was provided to the team QC by the EMI data analyst once the measurements were finished for evaluation.

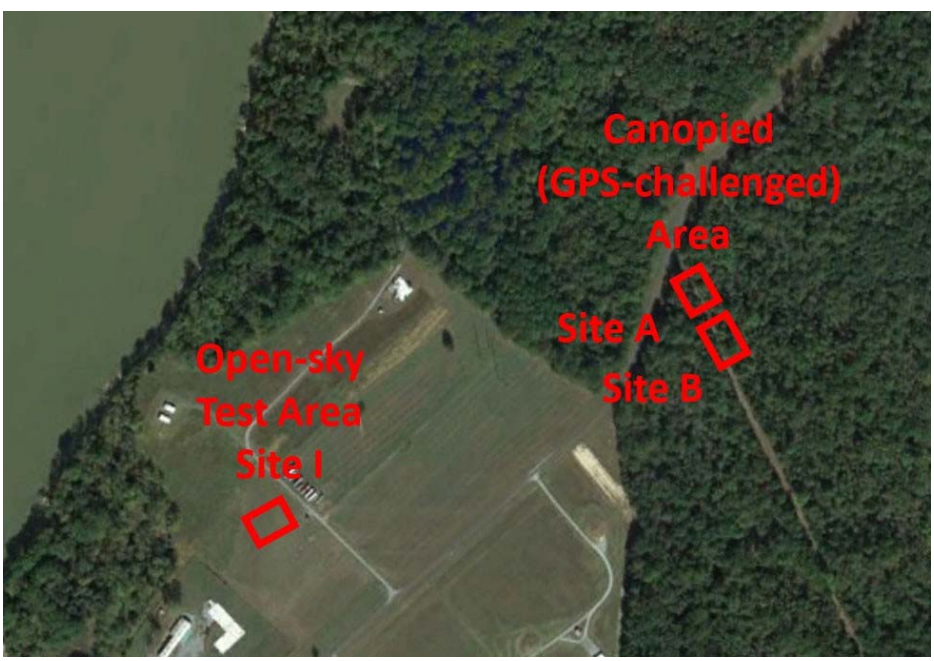

Figure 5. Test Sites at the ARL - Blossom Point Facility

4.0 PERFORMANCE ASSESSMENT

4.1 DATA ACQUISITION SESSIONS

During a four-day period, 19 measurement sessions were carried out, including 7 instrument verification strip-style measurements for the TEMTADS 2x2 sensor at the open-sky area, 11 performance tests at the two forested test sites, and one reacquisition test at site B. Typical trajectories at the open-sky and forested test sites are shown below.

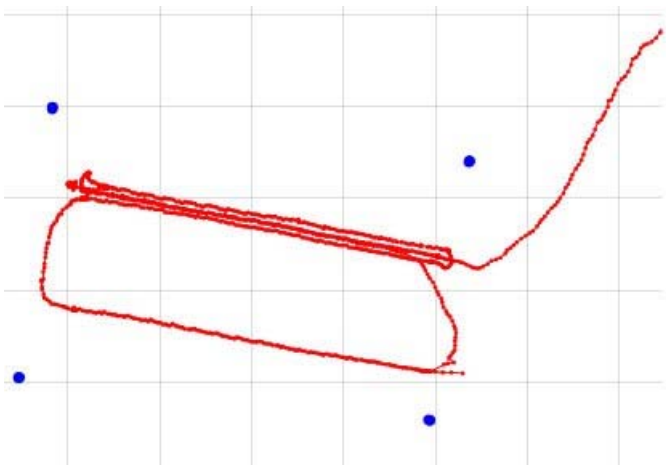

Figure 6. Open-sky Area

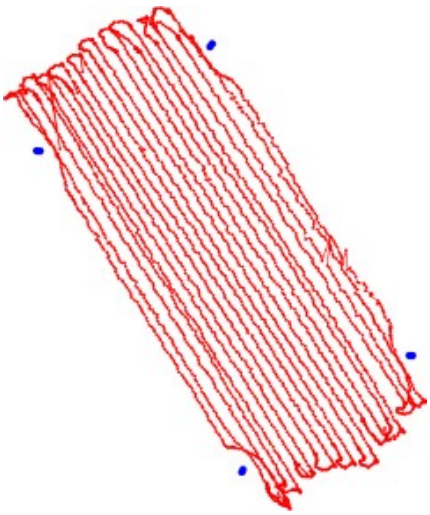

Figure 7. Canopied Area

One data acquisition session, excluding site and system preparation, lasted about 25-30 minutes. Switching between test sites required repositioning of the UWB poles and downloading data acquired in the previous session, and typically took 15-30 minutes. Data acquisition in progress is shown below.

Figure 8. Data Acquisition in Progress

4.2 PERFORMANCE RESULTS

The processing of the data sessions included data integrity checking, preprocessing, creating the refined AGT solution, and applying the AGT georeferencing to the EMI processing to position the detected targets. Then, the performance evaluation included the comparison of the results to the ground truth and the statistical evaluation. The visualization of TEMTADS 2x2 system results based on AGT georeferencing is shown below.

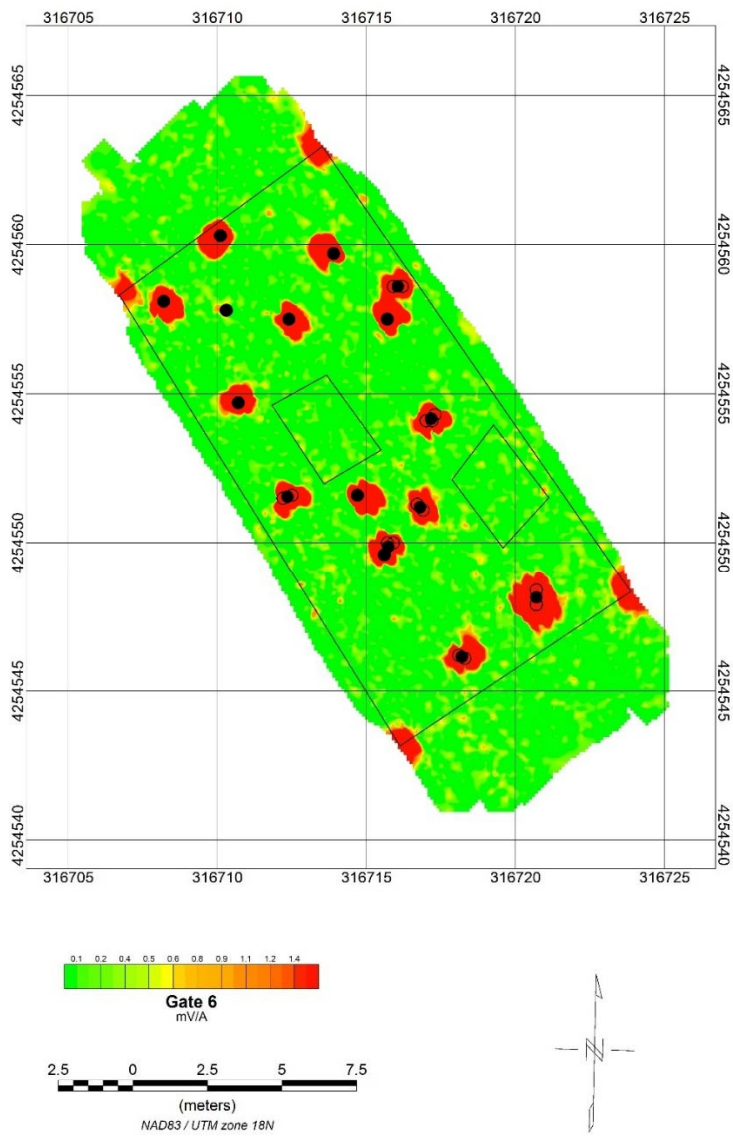

Figure 9. Located and Leveled Dynamic Data from the TEMTADS 2x2 System, Site A; Black Circles Mark Target Locations Obtained by Clustering.

Target localization errors are listed in the table below. Except for sessions A5, B3 and B4, the performance criterion of 30 cm at 95% CEP was achieved. The overall performance including all sessions was 32.4 cm, slightly above the required performance; note that the 30 cm localization accuracy for all sessions was achieved at P = 94.0%.

Table 1. Target Localization Errors

Session	Average [cm]	STD [cm]	Median [cm]	95th Percentile [cm]	Max [cm]
A3	12.1	3.5	11.0	17.0	18.0
A4	15.3	7.7	13.0	28.5	30.0
A5	20.7	11.8	19.0	41.5	48.0
B3	17.8	12.1	13.0	37.8	45.0
B4	13.8	10.8	11.0	30.6	39.0
B5	12.7	6.4	12.0	22.8	27.0
B6	16.9	7.8	16.0	26.0	26.0
Total	**15.6**	**9.2**	**14.0**	**32.4**	**48.0**

4.3 REACQUISITION PERFORMANCE

The reacquisition was an optional item in the original objective, and only one session was carried out at Site B. During the test, the known target coordinates were provided to prototype software that provided real-time positioning; thus, by moving the UWB antenna, the target location was flagged. Note that this software was used for the first time yet provided an easy and accurate way to stake out the target location. The positioning accuracy was assessed by carefully excavating the targets, and then comparing the distance between the target center and the flag positioned by the AGT system. The results of the evaluation are listed in the table below.

Table 2. Evaluation Results

# of targets	12
# of detected targets	11
Average	8.6 cm
STD	6.3 cm
Median	6.6 cm
95th percentile	20.4 cm

Figure 10. Two Sample Images Show the Reacquisition Measurements.

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5.0 IMPLEMENTATION ISSUES

The ESTCP project, *Demonstration of Advanced Geolocation Technology to Support Dynamic Classification of EMI Data Collect in GPS-challenged Areas* has delivered consistent performance during the demonstration session at ARL - Blossom Point. The quadruple sensor integration-based system was able to accurately geolocate the EMI platform in forested areas, where GNSS reception was not available or of poor quality. In general, all relevant project objectives, such as detection and acquisition accuracies are achieved or are within a small margin. Furthermore, the reacquisition test has also shown excellent results.

Two AGT prototype systems have been tested, and while even the second one was not fully optimized for normal operations, the system worked well and imposed very little extra effort and attention on the field crew; note that the AGT system was operated by the developers, so their understanding was significantly higher than that of a typical technician. It is important to mention that with a moderate engineering effort, the AGT system can be almost entirely integrated to the existing TEMTADS 2x2 system; GNSS, recording, power, sharing the tablet for user interface, etc., can be shared. The only extra element is the UWB network, which is based on poles with the two UWB transmitters placed at the site corners. Since these sensors are small, they can be easily integrated into a standard surveying pole. The use of these sensor poles increases the preparation time by about 30%. Since the AGT data processing is an additional step, there is a small increase in the processing time.