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Rapid Capture of Topography for Mobility and Situation Awareness

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ABSTRACT

To address the need for rapid capture of terrain profiles, and changes in terrain, researchers from Michigan Tech demonstrated a UAS collection system, during a live exercise, supported by the North Atlantic Treaty Organization's (NATO) Science and Technology Organization (STO). The UAS collection system was deployed to provide high resolution topography (resolution less than 1 cm) with a terrain collection rate greater than 1 meter per second and results were processed within minutes. The resulting topography is of sufficient quality to demonstrate that the technique can be applied to update mobility models, as well as the detection of traverse by ground vehicles.

1. INTRODUCTION

The NATO Applied Vehicle Technology (AVT-308) Cooperative Demonstration of Technology (CDT) for Next-Generation NATO Reference Mobility Model Development took place September 25-27, 2018 at the Keweenaw Research Center (KRC) in Houghton, Michigan. The objective was to provide a platform and audience for the demonstration of capabilities in ground vehicle modelling and simulation, with a particular focus on mobility over soft and marginal terrains, typical of ground combat operations.

As part of the physical demonstration of the KRC facility, a drone collection was to take place after vehicles were to traversed the variable hill climb element for the participants. This collection was part of a larger objective to demonstrate the rapid collection of drone imagery as well as showcase the detailed data product and potential trafficability applications. These include performing a change detection analysis to locate parts of the area of interest which have changed as well as to visualize how the scene has changed. Another to be demonstrated was to create vehicle pass profiles to identify the location and depth of vehicle tracks. Other physical features of the vehicles such as tread type and even direction of travel can be assessed from the resulting data.

2. SCENARIO

2.1. Terrain

Collections of the terrain were conducted over the variable grade hill climb at the course at KRC, which was traversed by two of the vehicles during the CDT. The variable grade hill climb is designed to assess mobility of vehicles in soft soil while attempting to navigate a steep hill. The hill climb

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Distribution Statement. Place holder for the OPSEC distribution statement. *(If required)* at KRC is 60 meters long, 7 meters wide and 8 meters in overall elevation change from base to top. The slope of the grade ranges from 0 to 30% in 5 degree increments every 10 meters (Figure 1). It is filled with a medium, poorly graded sand (SP), as classified by Unified Soil Classification System [1]. This is natural sand, referred to as 2NS [2]. The distribution of grain sizes was measured at KRC, using ASTM International D6913 / D6913M soil sieve analysis standard. Results from three separate samples are plotted in Figure 2.

Figure 1: Photograph taken from the bottom of the variable hill climb at Keweenaw Research Center during NATO AVT-308.

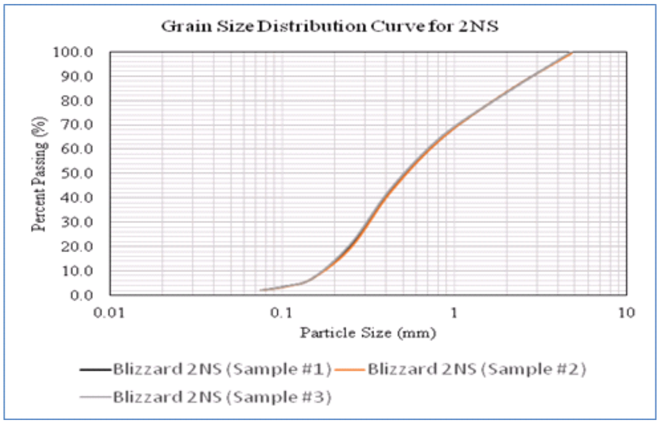

Figure 2: Sieve analysis results for variable hill climb soil.

Collections were made before and after vehicles traversed the terrain to show that the resolution of the system is sufficient to detect the passing of vehicles and identify tread types.

2.2. Vehicles and Traverse

Two vehicles traversed the variable hill climb during the NATO AVT-308 exercise: a US Armored Personnel Carrier M113, and a US Fuel Efficiency Demonstrator Alpha (FED-A). Both vehicles attempted to traverse the variable hill climb, climbing from the bottom, and then traversing down the hill from the top. The FED-A was operated at a speed, which was too low on the traverse up the variable hill climb, and did not climb all the way (Figure 3).

Figure 3: The M-113 (A) and FED-A (B) used for the demonstration.

At left, the M113 is a fully tracked armored personnel carrier developed by Food Machinery Corp. At right, the FED ALPHA by Ricardo is part of the Fuel Efficient Ground Vehicle Demonstrator (FED) program by the U.S. Army's Tank Automotive Research, Development and Engineering Center (TARDEC).

At left, the M113 tracks are shown on the vehicle and their impressions are recognizable in the reconstructed terrain models captured by the UAS collection system shown at right (Figure 4).

Figure 4: Detail of the M-113 tracks and soil impression.

At left, the FED-A tread is shown on the vehicle and its impressions are recognizable in the reconstructed terrain models captured by the UAS collection system shown at right (Figure 5).

Figure 5: Detail of the FED-A tire pattern and soil impression.

2.3. UAS Collection System

Data collections were conducted using a Bergen Hexacopter with a Nikon D810 camera payload (Figure 6). The Bergen Hexacopter is capable of carrying up to 2.3 kg of payload with a flight time of up to 16 minutes. The camera is mounted to a 2-axis gimbal to compensate for roll and pitch of the drone. The gimbal also allows for the camera to be pointed at any angle from 0-90 degrees (looking forward to nadir) depending on data collection requirements [3].

Figure 6: Bergen Hexacopter with a Nikon D810 ready for deployment.

The Nikon D810 camera has a 36.3 MP sensor which provides high resolution imagery when collected from a drone. The resolution of the imagery approximately 5 mm is achieved from a flying altitude of 30 m. Collecting sufficient imagery overlap is crucial for the accurate reconstruction using Structure from Motion (SfM) [4]. This is achieved by flying at a maximum speed of 2 meters per second. At the speed, a single point on the ground is represented in at least five images.

3. METHODS

As shown in Figure 7, ground control targets were placed along the sides of the variable hill climb for improved georeferencing of the 3D models. This also reduces scaling errors in the 3D reconstruction and improves change detection comparisons between 3D models from separate collects. Six traditional 1m x 1m black and white ground control targets were used, one in each and one on either side of the center of the variable hill climb. GPS positions were collected using a Trimble GPS with decimeter level accuracy. GPS data was used by the SfM software for the reconstruction of the 3D models and the out.

Figure 7: Data collections were conducted on the variable grade hill at KRC.

Imagery was collected on four separate collects with the first two being completed with the Nikon D810 mounted to the end of a pole and walked around the variable hill climb while the second two were completed with the same camera mounted to the Bergen Hexacopter and flown over the site. Each collect consisted of two passes by starting from the bottom to the top of the variable hill climb on one side and then back down the other for increased overlap of the imagery. The camera was mounted to the end of a 2 m pole and collected oblique imagery (45 deg of nadir). For drone collects, a flying altitude of approximately 30 m above the ground was maintained throughout the collect by ascending or descending altitude as the drone was flying over the variable hill climb for the second two collects. Unlike the ground based collections the camera imagery was collected at nadir from the drone.

The first two collections were designed to test change detection over the variable hill climb. Prior to the first collect, vehicle tracks were present from both the FED-A and M-113 on the variable hill climb. A second collect was made after the FED-A attempted to ascend the variable hill climb. These collections would be used with change detection methods to automatically determine the location of the new vehicle tracks.

The third and fourth collections were completed in conjunction with the NATO demonstrations and imagery was collected using the Bergen Hexacopter. After the variable hill climb was refurbished prior to the NATO demonstrations, the third collection was competed to establish a flat baseline. The fourth collection was completed after the M-113 and FED-A traversed the variable hill climb twice (ascending and descending the course) during the NATO demonstrations. The imagery from the fourth collection would be processed immediately following collection and the results would be displayed for attendees.

The collected imagery was processed through SfM software which creates a DEM (Digital Elevation Model) and an orthoimage as products. SfM software is a collection of open source algorithms developed to produce point cloud data from any camera. The SfM algorithm must match features across multiple photos using the SIFT (Scale-invariant feature transform) algorithm, which are stable under viewpoint and lighting variations. These detected points are used to solve for camera intrinsic and extrinsic orientation parameters, estimating the camera locations and refining them later using a bundle-adjustment algorithm to create a sparse 3D point cloud. The point cloud is then densified using the PMVS (Patch-based MultiView Stereo software) to create high resolution output up the the resolution of the input imagery.

4. Results

Imagery from the first two ground based collections were processed through SfM software to create an orthoimage and DEM of the variable hill climb. Despite using oblique imagery for the 3D reconstruction, both models were generated without additional input. The final output resolution of the orthoimage was 1.3mm while the DEM was 5.3mm. The DEM was a lower resolution than the input imagery as the point cloud densification step of the SfM processing was lowered from input imagery resolution to balance DEM resolution with processing time.

The second two data collections were processed through SfM software with the Orthoimage having a 2 mm GSD and the final output DEM having a GSD of 9mm. Figure 8 shows the detail of the captured imagery as well as the 3D reconstruction of the variable hill climb through a hillshade representation of the DEM after the final collect. The model accuracy was estimated to be 3.5 cm xy and 0.6 cm z for the both collections. Deep depressions can be clearly seen in the hillshade were created as the FED-A attempted to ascend the variable hill climb and was not able to complete. The track pattern from the M-113 could also be clearly identified in the orthoimage and the hillshade.

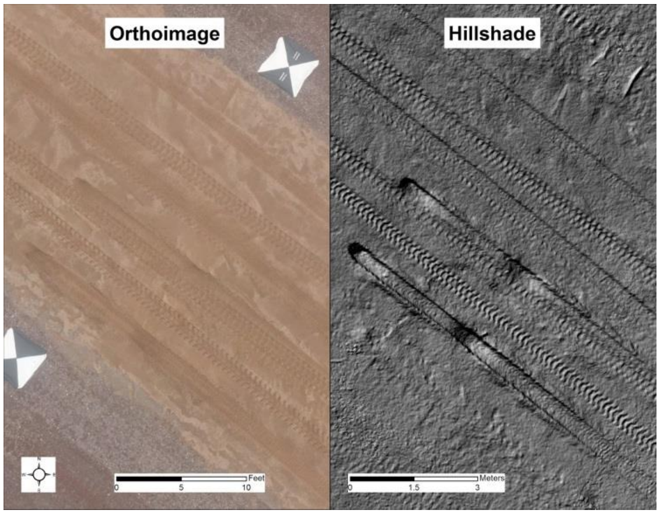

Figure 8: Comparison between the Orthoimagery and Hillshade representation of the DEM from the fourth data collection.

3D models constructed from collections using a handheld camera and drone mounted camera were used for comparison. Scans taken at different times are subtracted to locate changes in the scene. Figure 9 shows the results of the difference raster from the handheld collects where vehicle tracks existed prior to the first collection. The FED-A then attempted to drive across the variable hill climb prior to the second collect leaving depressions where it could no longer continue driving up the grade.

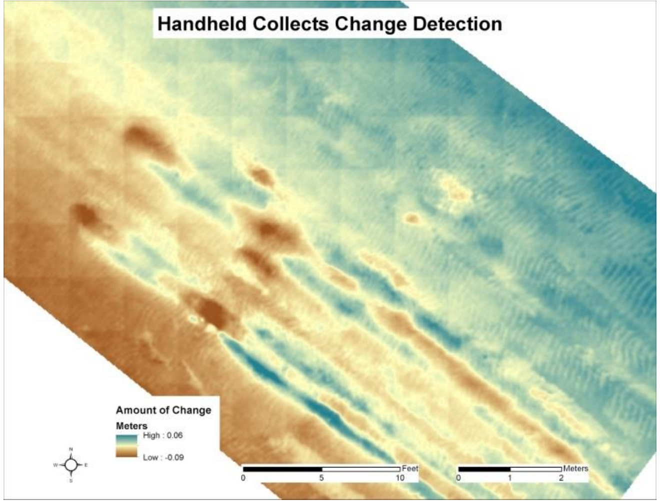

Figure 9: Change detection results between the handheld collects over the variable hill climb.

Figure 10 shows the results of the difference raster from the drone collects. Prior to the first drone collect the variable hill climb was freshly refurbished and relatively smooth (without vehicle tracks) while the second collect captured multiple vehicle traverses from the live demonstration. Both vehicles climbed from the bottom, and then traversed down the hill from the top creating multiple tracks. As with the previous attempt, the FED-A was unable to successfully climb and left depressions where it could no longer continue.

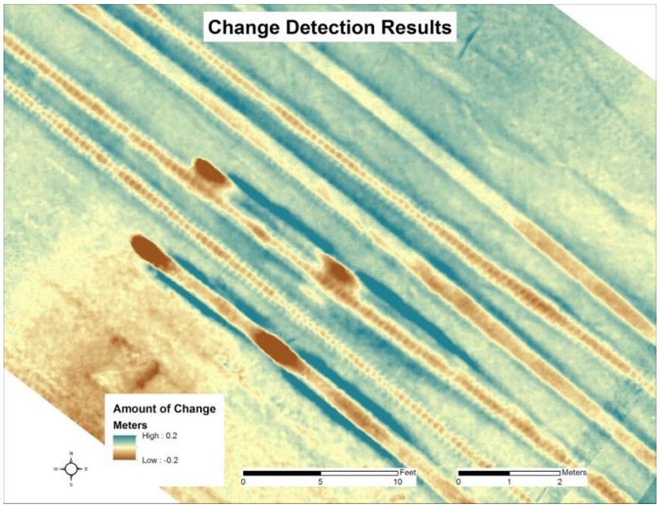

Figure 10: Change detection results between the drone collects over the variable hill climb.

Unlike the handheld collects, the imagery was collected directly overhead rather than an oblique angle from the ground. This resulted in better alignment between the drone collections for a more accurate difference raster. Figure 9 shows relatively large changes in elevation on the edges of the collected scene which were produced by inaccuracies in alignment rather than actual elevation change. Alignment between the DEMs created from each drone collect are closer thereby reducing the amount of error in the difference raster.

The processing of the fourth drone collect was completed during the NATO demonstration as participants watched the drone based collection. After the imagery was collected, it was taken back to the exhibitors table of the test course viewing area and processed into a 3D model while the participants completed the tour of the facility. Within 30 minutes of collecting the imagery, a full 3D reconstruction of the variable hill climb was completed and a DEM generated. The final DEM was ready for display and analysis before the participants returned. This demonstrates the ability to rapidly collect and process 3D models from the field for analysis, making this technique tactically relevant. The final model was used to compare the final condition of the variable hill climb to previous conditions as well as being incorporated into a driving simulation of the KRC test facility.

In addition to the change detection, an analysis of the compaction due to vehicle traverses was performed (Figure 11). Profiles of the vehicle passes were created at various locations along the variable hill climb element. Detailed measurements can be made of the depth and width of created by the vehicle tracks or wheels, with the high resolution of the DEMs used to create the profiles.

Figure 11: Four vehicle pass profiles created across the variable hill climb element from the final drone collection.

Figure 12 shows an example of profile three where tracks are labeled from each vehicle as they ascended and descended the variable hill climb element. The most dramatic example was created from the FED-A as it attempted to ascend the variable hill climb element and became stuck in the sand. The left front tire scoured a 15cm deep impression in the sand and the right front tire was 13cm. Other depressions created from the successful traverses were all approximately 5cm deep.

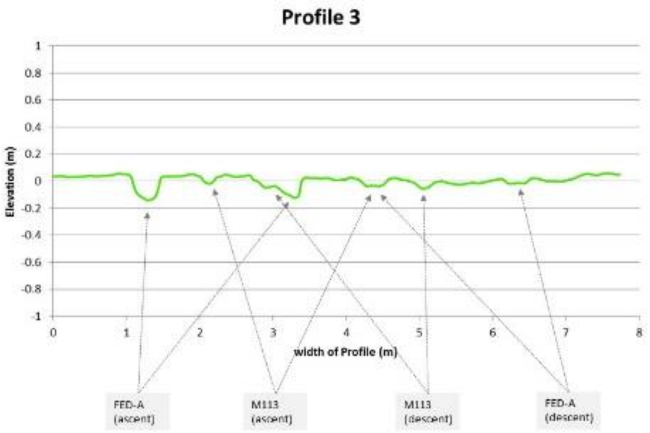

Figure 12: Sample vehicle pass profile showing the ground compaction from each vehicle.

5. CONCLUSIONS

The objective of our participation in the NATO CDT was to demonstrate the capability for the rapid capture of terrain topography, to increase the mobility of ground vehicles with special consideration of soft and marginal terrains, typical of ground combat operations. The ability to capture topography rapidly is crucial for ground vehicle operations in territory that is changing, or adversaries have successfully denied access to terrain measurements. Topographic representations are one part of the successful characterization for any mobility model [5].

An aerial collection system was used to develop three dimensional topography with resolution sufficient to detect the traverse of vehicles. By designing the collection system and observation geometry to achieve sub-centimeter resolution, the resulting reconstruction shows resolution capable of identifying vehicle tread types, within minutes, making the system tactically relevant.

Further research is needed to define the collection requirements and reconstruction quality for scenes in contested environments, which lack known reference targets and variable visibility constraints. As demonstrated with the two collection styles, alignment between the input DEMs is critical for achieving accurate results in change detection analysis. Ground control targets used during the demonstration aided in the alignment of the input DEMs. Change detection in environments in which ground control is not possible would benefit from high accuracy onboard GPS and the development of automated methods for alignment specialized for this scenario to be successful.

1. REFERENCES

[1] ASTM Committee D-18 on Soil and Rock. (2017). Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) 1. ASTM international.

[2] MDOT (Michigan Department of Transportation). (2012). Standard specifications for construction.

[3] R. J. Dobson, T. Colling, C. Brooks, R. Roussi, M. K. Watkins, and D. Dean, “Collecting Decision Support System Data Through Remote Sensing of Unpaved Roads” Transportation Research Record, vol. 2433(1), pp. 108-115, 2014.

[4] Resch, B., Lensch, H., Wang, O., Pollefeys, M., & Sorkine-Hornung, A. (2015). Scalable structure from motion for densely sampled videos. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (pp. 3936-3944).

[5]Papadakis, P. (2013). Terrain traversability analysis methods for unmanned ground vehicles: A survey. Engineering Applications of Artificial Intelligence, 26(4), 1373-1385.