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Representing a Live-Vehicle Test in a Simulation Environment

by Jamie K Infantolino, Ash Parasa, and Jared Willard

NOTICES

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14. ABSTRACT

The work presented here covers how to process live-test data into a simulated environment to use modeling and simulating to develop new combat vehicles. The test data of a vehicle driving around a test track at Aberdeen Proving Ground was provided by the US Army Test and Evaluation Command. US Army Combat Capabilities Development Command Army Research Laboratory engineers then processed the data without changing the integrity of the data to properly import it into the Autonomous Navigation Virtual Environment Laboratory (ANVEL). This report goes through the various steps required to do achieve this.

15. SUBJECT TERMS

modeling and simulation, Autonomous Navigation Virtual Environment Laboratory, ANVEL, Next Generation Combat Vehicle, Software-in-the-Loop

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1. Introduction

The focus of the US Army Combat Capabilities Development Command (DEVCOM) Army Research Laboratory (ARL) is "cutting-edge scientific discovery, technological innovation, and transition of knowledge products that offer incredible potential to improve the Army's chances of surviving and winning any future conflicts".[1] One way to innovate is to improve the ability to transition technology into the hands of the Warfighter. Future operational environments will be increasingly demanding on both Soldiers and military assets. A continuous update cycle will be required for military assets such as ground vehicles to ensure the most advanced technology and equipment is available for use by Soldier operators. Developing a new vehicle from the ground up takes a substantial amount of time, effort, and money, which continues throughout the vehicle's lifecycle. A new vehicle begins in the research and development (R&D) phase, where each component is designed, tested, and iteratively refined. Upon completion of R&D, the vehicle advances to a testing and acceptance (T&A) phase where the new vehicle system and all its components are tested to determine the viability of the solution (i.e., the new vehicle) for specific Army requirements. Streamlining the process from R&D to T&A will ensure success in future operational environments. Currently, fielding a new vehicle takes several years, thus delaying vital improvements both in operator safety and technology advancement. DEVCOM Army Research Laboratory researchers are working to improve the process of vehicle technology development by shortening the development timeline while ensuring quality and operator safety remain of primary importance.

Most Army vehicular developmental and operational testing occurs on completely assembled and fully functioning vehicles. Only after operational testing is successfully completed is a vehicle fielded to Army units. This workflow requires massive lead time due to time, costs, and delays associated with manufacturing, all occurring before testing begins. There has been a push at various levels within the Army to perform modeling and simulation (M&S) of new vehicle technologies before developing, building, and testing. ARL is exploring efficient methods using M&S approaches for vehicle technology development and testing that would shorten the R&D to T&A workflow. However, accurately depicting vehicle testing in an M&S environment presents many challenges.

This report documents an effort at ARL to adopt an M&S approach for replicating a live-vehicle testing environment. Section 2 provides background information on the Autonomous Navigation Virtual Environment Laboratory (ANVEL) M&S development environment, and the live-vehicle test environment located at Aberdeen Proving Ground (APG) in Maryland. Section 3 describes several challenges associated with representing live-vehicle test data to a simulated environment. Section 4 presents our stepwise data transformation and filtering approach mitigating the challenges detailed in Section 3. Section 5 visualizes several results of the successful data transformation process that produced a more accurate simulated environment. Section 6 concludes the report by noting a potential limitation and several future directions for this investigation.

2. ANVEL Simulation

In this investigation, live-vehicle test data collected from the Automotive Technology Evaluation Facility (ATEF) were used to simulate a vehicle test environment. Located at APG, the ATEF is a multisurface live-test track, 4.5 miles long and 207 ft wide, offering vehicle operating capabilities and operational employment speeds up to 70 mph.[2] The ATEF's test track is primarily used by Aberdeen Test Center (ATC) to test vehicles before fielding. The test track enables the Department of Defense (DOD) to test both manned and unmanned vehicle platforms in a variety of operational scenarios relevant to combat environments. Vehicle performance, endurance, and reliability testing are performed at ATEF along with testing of equipment both on and off vehicles.

ANVEL[3] was used to build a compatible 3-D environmental model of the ATEF. ANVEL is an M&S rapid-development environment for design, testing, and evaluation of ground vehicles under different environmental conditions (e.g., tactical, urban, and rural). ANVEL models the interaction between the vehicle and the terrain by taking into account physics, materials in the environment, and vehicle dynamics. ANVEL supports the development of autonomous, semiautonomous, and Advanced Driver Assistance Systems (ADAS) functionalities. Using ANVEL, engineers can construct virtual vehicle models, mount sensors on vehicle platforms, and simulate the operation of vehicles and their sensors in a virtual environment. ANVEL's rich data collection framework enables engineers to monitor simulation parameters and record a wide variety of data on vehicle operation and performance. Figure 1 shows two example vehicle virtual environments supported by ANVEL.

Fig. 1 Examples of ANVEL-supported virtual vehicle environments

An important capability provided by ANVEL is the ability to stream data from the simulated sensors as input to data-processing algorithms. For example, data streamed from a virtual camera mounted on a vehicle can be used as input into a machine learning (ML) algorithm, such as the You Only Look Once (YOLO) algorithm,[4] to recognize objects and provide situational awareness. All virtual sensor data are available to the engineer through an application programming interface (API) that allows the data to be used in a variety of applications including ML, network planning and prediction, mission planning, vehicle performance prediction, and edge-case test detection. ANVEL's graphical user interface (GUI) provides an easy drag-and-drop development environment for scenario creation. The GUI integrates with advanced mobility models for vehicles in a variety of different environments. ANVEL's M&S versatility and relevance to military applications makes it appealing to a wide variety of DOD communities such as S&T, T&E, and Program Executive Officer/Program Manager programs of record.

3. Simulation Challenges

In our initial attempt to replicate a live-vehicle testing environment, several challenges emerged pertaining to ANVEL's simulation of ATEF's live-test track. We obtained live-test data from US Army Test and Evaluation Command (ATEC) engineers along with the corresponding ATEF test-track model file. Both the test data and the model file are imported into ANVEL. When the live-test data and model file of the test track were loaded into ANVEL, the vehicle's initial position in the simulated environment was below ground level, as shown in Fig. 2 (black horizontal line is ground level). In addition, the model file defined the vehicle's movement path as about 5 m above the ground with the starting point offset by at least 30 m (Fig. 2, red lines denote movement path). The vehicle's movement path also had multiple loops with jagged segments that did not correspond to the actual movement path of the vehicle during the live-test run. These discrepancies created serious rendering issues within ANVEL and produced an inaccurate depiction of ATEF's vehicle-testing environment.

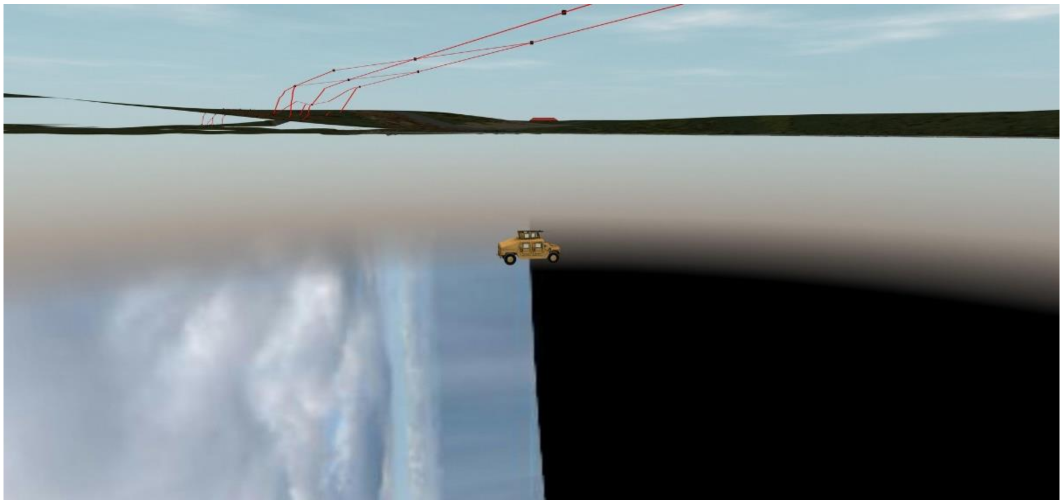

Fig. 2 After initial import of the test track raw data file into the ANVEL environment, the vehicle's position is shown below ground level (black horizontal line) and the vehicle's movement path is shown floating above ground (narrow red lines)

When considering these challenges in the data-import stage, using ANVEL to accurately simulate the ATEF test track came into question. However, upon further investigation, most of the problems appeared associated with mismatching origins: what ANVEL called the origin (the default values), what the ATEF's model file called the origin, and what the live-test equipment called the origin. The GPS data from a sensor located on the test vehicle, which was provided by ATC test engineers, contributed significantly to the mismatching of the origins. Figure 3 shows the ANVEL environment after importing the GPS data from the vehicle sensor. The vehicle's movement path (red lines) constructed from the GPS data is not positioned on the virtual road (wide gray line) because of the mismatching origins and offsets in the model file. This is a common problem when importing files into a simulation environment such as ANVEL. The GPS data also generated the unrealistic jagged segments of the vehicle's movement path. According to the test engineers, for this particular test run, the vehicle's operators drove in a straight line as one would drive on a normal highway. Explanations for the movement path inaccuracy could be associated with normal GPS errors or even a malfunction in the GPS sensor. This highlighted a potential level of accuracy issues when reconstructing the live-test routes within the ANVEL environment.

For the inconsistencies associated with mismatching origins, we employed a multistep data-transformation process to match the live-test data to the ANVEL simulated environment. This process involved manipulating the data into a format for input into the simulated ANVEL environment without loss of any important data elements; matching up the data elements (for example, the vehicle movement path to the virtual road) within the simulated environment; and developing a vehicle-matching algorithm to match the live-test GPS data to the ANVEL-simulated environment's GPS.

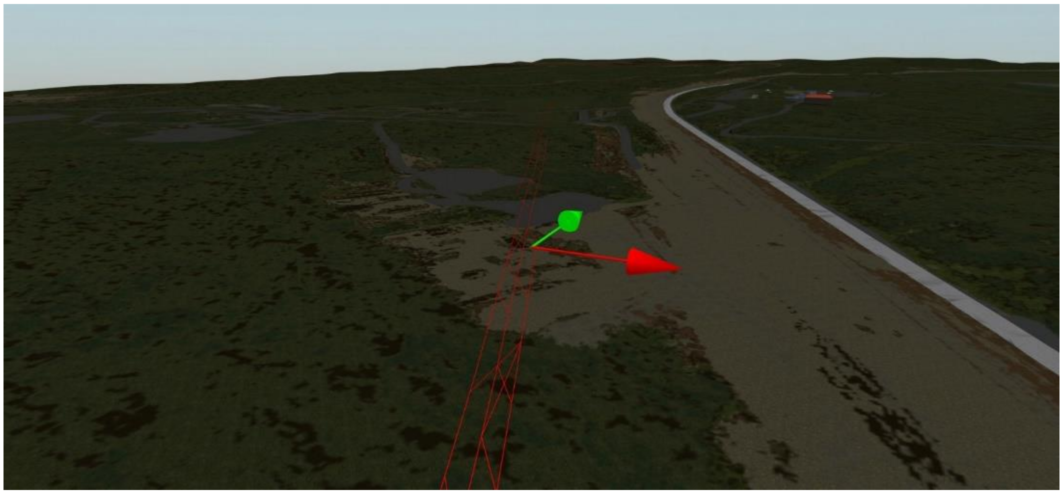

Fig. 3 Incorrect vehicle movement path (red lines) not positioned on the virtual road (wide gray line) after initial import of raw data file

4. Data-Transformation Approach

Without addressing the challenges detailed in the previous section, the real-world GPS data and the ATEF test-track model file could not be used as input to generate an accurate simulation of the vehicle's live test. The multistep data-transformation process described in this section ensured the ANVEL's simulated environment accurately represented the real-world vehicle test environment.

We determined the best approach for producing an accurate simulated environment would be to correct the unrealistic movement path first, and then address the mismatching origins between ANVEL and ATEF's model file. It is important that the model file maintains accuracy; therefore, adjusting the simulation origin was required. The realignment of the simulation origin would ensure that any vehicle placed in the simulation environment is accurately positioned as the engineer specifies.

4.1 Reformatting GPS Data

As a starting point for correcting the vehicle's movement path, the GPS data were reformatted by converting the GPS sensor location into an ANVEL-mutable format. This allowed the engineers to shift the origin of the GPS data as needed without changing the results of the live test. The GPS data includes X, Y, Z coordinates of the vehicle along with the time at which the vehicle is at each specific coordinate.

The GPS data was reformatted from its original file format to a JavaScript Object Notation (JSON) format. A Python script was developed to convert the unstructured GPS text file into a JSON file. During this process, the timestamps were also realigned to start with a value of 0. This was done to make visualizing the data easier in the next several steps.

4.2 Visualizing and Filtering the GPS Data

Using only GPS data for visualization in ANVEL often involves prolonged loading times and an inability to get a clear bird's-eye view of the scene. There was a need to more easily visualize the GPS coordinates in a medium other than ANVEL to identify patterns and check accuracy. We used simple 2-D plots, a scatterplot and bar graph, to visualize the GPS data.

Figure 4 visualizes the unfiltered GPS data after the JSON file conversion in a scatterplot. The scatterplot allowed us to quickly examine the state of the GPS data outside of the ANVEL's simulation environment. The scatterplot showed two problems in the GPS data: inaccurate jagged segments in a stair-step pattern, and a second small loop outside the main test track.

Fig. 4 **Scatterplot of GPS data after JSON file conversion showing jagged segments in a stair-step pattern and a small loop outside the main test track**

Figure 5a shows a bar graph of the distance between the vehicle and the starting position (Y-axis) in relationship to time (X-axis). The graph shows the specific times when the vehicle returned to the starting point (Y = 0) and stayed there for a measurable amount of time (white space along X-axis) during the testing while the GPS sensor was tracking. Some of these times when the vehicle was at the starting position and not moving might have been due to adjustments in equipment, rotation of vehicle operators, or discussions among field test engineers.

Vehicle stoppages, whether at the starting position or on route, needed to be removed from the data using a filtering process. By plotting the distance from the starting position over time, it was possible to see when, and how often, the vehicle's path passed through or near the starting position, which enabled identification of each pass around the track. The bar graph identified when the vehicle stayed in the same location for a significant period of time (Y-axis, consecutive height of bars). First, the vehicle's stationary times at the starting position (Y = 0) were removed with the difference shown before removal in Fig. 5a and after removal in Fig. 5b. Additionally, the times when the vehicle was stationary at points not at the starting position were filtered by removing the consecutive identical points on the Y-axis shown in the bar graph. The difference is shown by comparing Fig. 5b to 5c. Removing the times when the vehicle was not moving allowed more efficient computer processing during data import while not impacting the test results. Alternatively, these stationary periods could be left in the data, possibly representing times when the vehicle was idling. Using simple 2-D plots to visualize the GPS data allowed us to filter out two types of vehicle stoppages causing potential inaccuracies before importing the data into the ANVEL simulation environment.

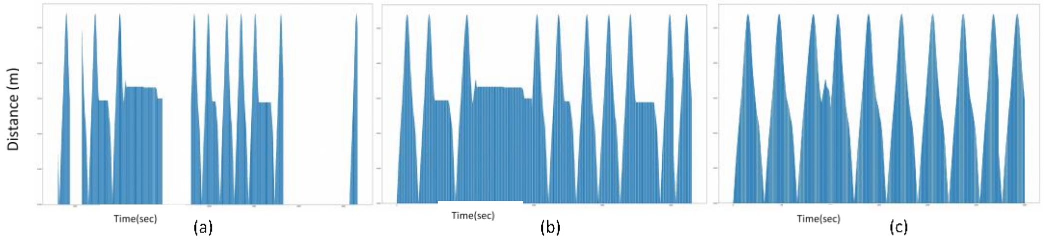

Fig. 5 GPS data (a) before filtering for stoppages, (b) after removing starting position stoppages, and (c) after removing nonstarting position idling showing final cleaned data when the vehicle was in motion

4.3 Adjusting Vehicle and Object Placement

After the GPS data-filtering techniques described previously were completed, the vehicle's movement path could be imported into ANVEL. When a movement path is loaded into ANVEL, the altitude coordinate (Z-value) of each data point needs to be adjusted so the path is laid directly on the ground. The altitude value changes based on the elevation of the ground. Not applying the Z-value adjustment, or applying it incorrectly, leads to objects placed in ANVEL beneath ground level or floating in the air (see Fig. 2).

The altitude point of the ANVEL environment data was adjusted down so that when the path data was visualized within ANVEL, the path was correctly positioned at ground level. The adjustment down was done so the origins between the ANVEL environment and the live-test data matched. The vehicle is then placed at the first point of the movement path to mimic the starting position of a test on the ATEF live-test track.

4.4 Identifying the Map Offset

After the altitude and vehicle placement adjustments, we found an additional discrepancy between the course map and the movement path loaded into ANVEL based on the GPS coordinates. The vehicle's plotted path did not match up with the virtual road. For example, Fig. 6 shows the vehicle running over vegetation and hitting trees (white wireframe rectangles).

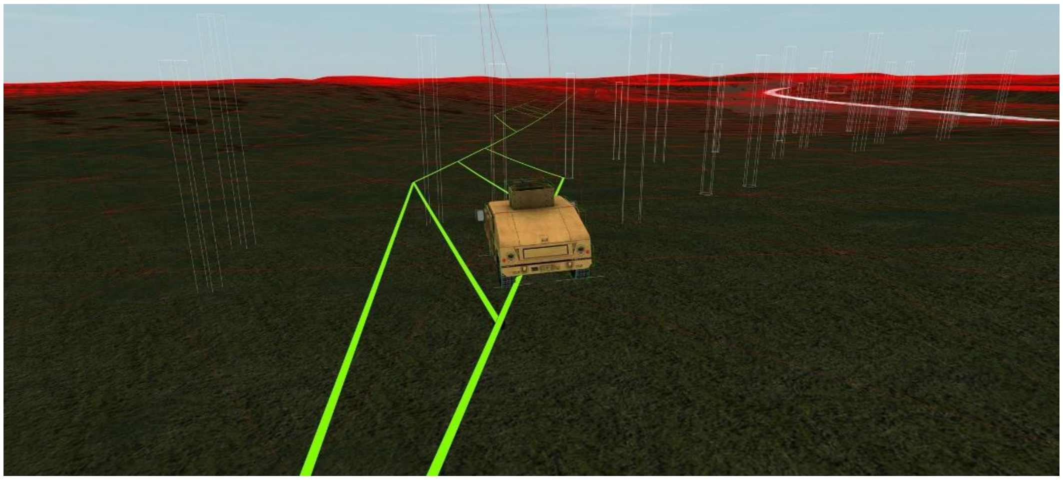

Fig. 6 Misaligned vehicle movement path (light green lines) go through vegetation and trees (white wireframe rectangles). Vehicle path should be aligned with virtual road (gray line, upper right corner).

To eliminate the discrepancy between the course map and the vehicle's path, the offset between the map and the path had to be identified and then used to properly align the map and the path. This offset value was found by iteratively experimenting with several realistic offset values, then slowly refining the offset value based on the results displayed within the GUI.

After the offset value was identified and applied to the GPS coordinates, the ANVEL map, terrain data, and objects could be successfully moved through the ANVEL API. Even in the case of our small-sized map with sparse details, moving all the data components through the API was a time-intensive manual operation. This type of approach could potentially be computationally prohibitive when applied to a large, detailed map. Figure 7 shows the results of applying the offset value compared to Fig. 6 (before the offset adjustment). Using the offset value to adjust the map aligned the vehicle's path in relation to the virtual road and the environment.

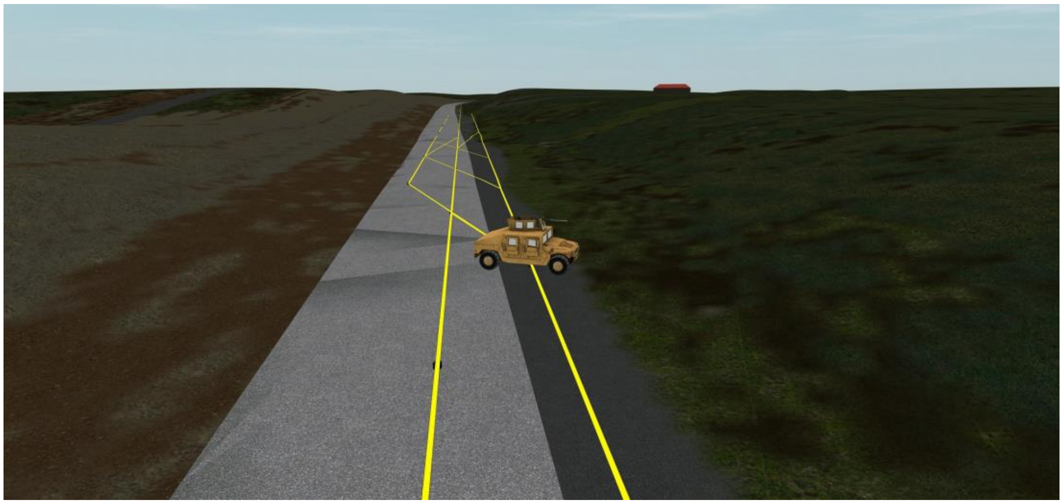

Fig. 7 Vehicle's movement path correctly aligned with the course map and virtual road after offset value adjustment

4.5 Orienting the Vehicle

With the corrected alignment of the map to the vehicle path, another problem emerged. Figure 7 shows the starting orientation of the vehicle not pointed in the direction of the path. Since the vehicle's orientation was not pointed toward the next point in the path, the vehicle had to first turn around to orient itself correctly on the path. During this reorientation process, the vehicle never touched the first point in the path, causing it to loop around in the same location. Figure 8 shows the vehicle in the process of driving in a circle trying to find the next point in the path.

Fig. 8 Vehicle turning in circles while trying to locate the next point on the path. This path movement caused the jagged segments on the scatterplot (see Fig. 4).

We corrected this orientation problem by identifying the orientation needed to point the vehicle toward the path and setting that orientation at the start of the ANVEL simulation. This resulted in the vehicle proceeding along the path to the next point without any issues.

4.6 Vehicle-Matching Algorithm

The series of preprocessing steps described previously produced a simulated environment that accurately represented the ATEF vehicle-testing environment. At this point in our investigation, we focused on matching a simulated vehicle to a real-world vehicle. In this case, the test vehicle was a Humvee.

During our earlier preprocessing steps, we observed that the GPS coordinates could be approximated during the loops driven by the Humvee on the test track. With nine passes around the track, it was highly likely more than one point would fall along the same X or Y value after being rounded. Taking the average of these points resulted in X- and Y-coordinates located approximately in the middle of the movement path described by the test-track model file provided by the test engineers. Using this algorithmic approach, all nearby points along the same Y coordinate were recorded and their X-values were averaged.

A new, empty data set was created to store the filtered point values. A range of XY values that created one complete path were chosen from the unfiltered GPS data set. For each point in the range, the algorithm found all nearby points along the same Y-value within a certain set distance (0.0002) from every pass of the vehicle—not just one selected path, thereby, essentially drawing from the complete data set. After finding all nearby points, the algorithm takes the average of the

X-values of the points. Then, a new point is calculated by using the average X-value and an average Y-value. This new point is added to the filtered data set.

This filtering and averaging approach produced tight clusters of points that when combined, formed a single set of points representing the Humvee's passes around the simulated test track. Figure 9 shows the results of the original unfiltered data (red data points) compared to the filtered and averaged data (green data points) that were used to approximate the Humvee's track.

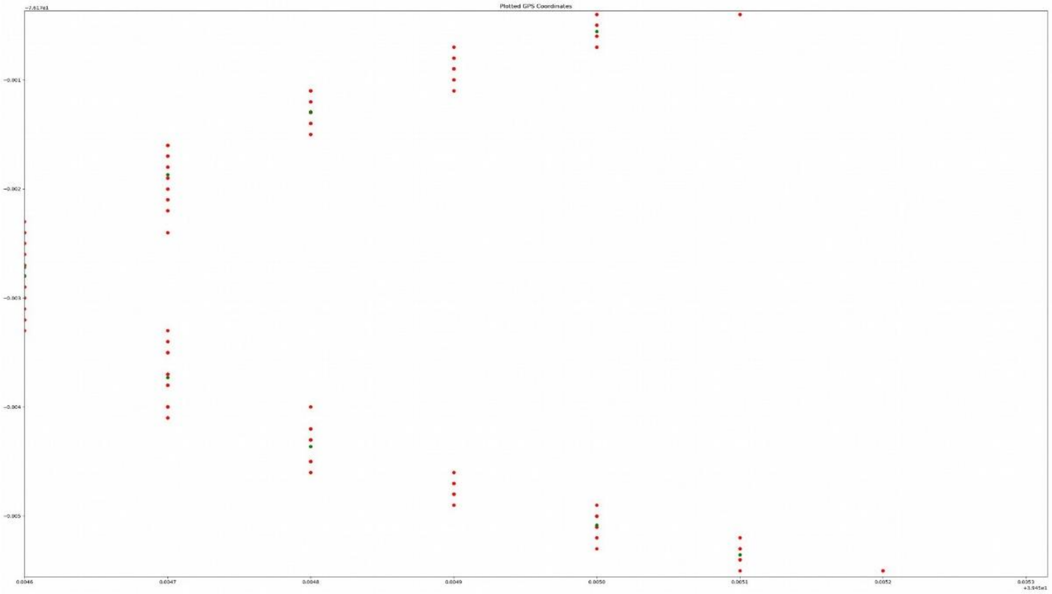

Fig. 9 Comparing unfiltered data (red) and simulated GPS data (green). The X and Y axes both represent distance from the starting point (0,0).

5. Results

Our data transformation and filtering steps described in the previous section successfully produced an accurate simulated environment of ATEF's vehicle test track and an accurate simulation of the Humvee's movement path around the test track. Figures 10, 11, and 12 capture the adjustments to the ANVEL-simulated environment after applying the data transformation and filtering processes. Figure 10 shows the Humvee correctly oriented at the starting position on the movement path. Figure 11 displays a scatterplot of the adjusted movement path of the Humvee after correcting jagged segments and the small loop representing the vehicle spinning at the starting position. Figure 12 visualizes an example of a straight section of the virtual road with the red line representing the correct movement path of the Humvee on the simulated ATEF test track.

Fig. 10 **Humvee's corrected orientation at the starting point of the simulation**

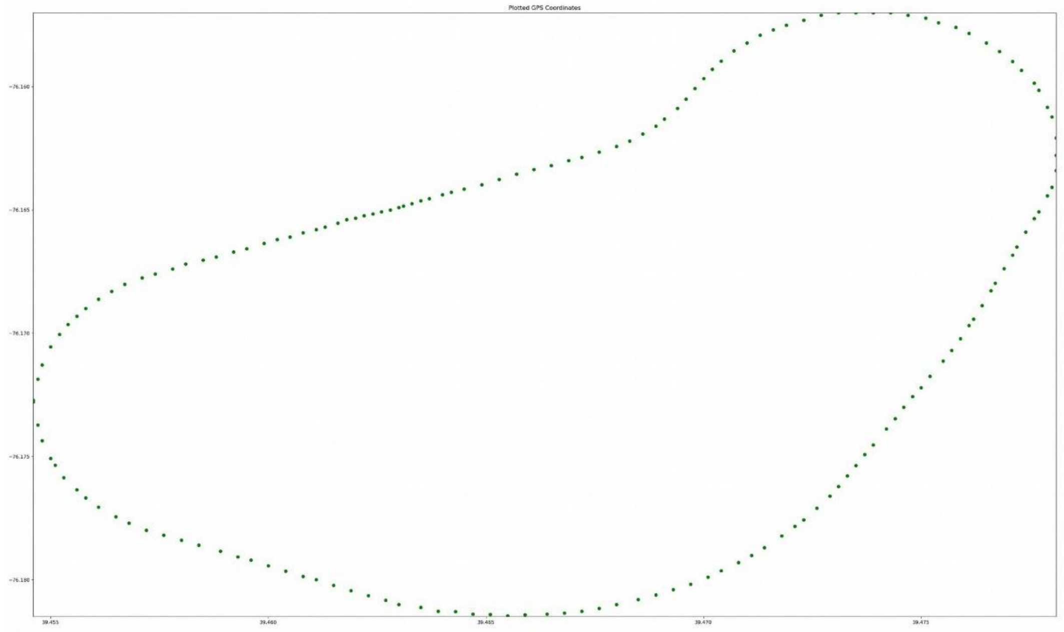

Fig. 11 **Simulated movement path of the Humvee after correcting jagged segments and small loop caused by spinning vehicle orientation at the starting position**

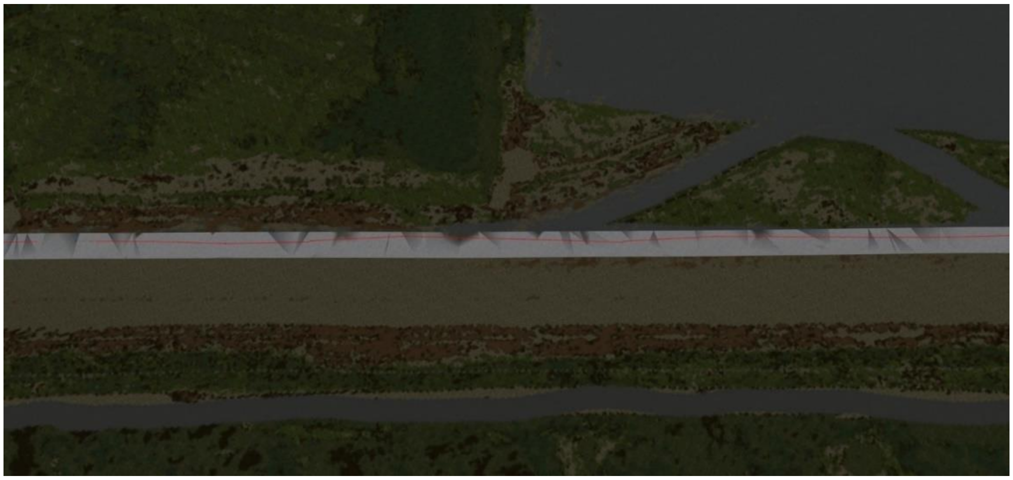

Fig. 1 ANVEL simulation of straight section of the virtual road (wide light-gray line) with the red line representing the Humvee movement path

6. Conclusion, Limitation, and Future Directions

The purpose of this investigation was to simulate a live-vehicle test run at the ATEF APG test track using ANVEL's M&S environment. Our approach consisted of implementing a series of preprocessing data transformation and filtering steps applied to real-world data collected by ATEF test engineers to most accurately represent a vehicle's live-test run. The approach was generally successful and, most importantly, is reproducible, enabling accurate M&S of other types of vehicles on the ATEF test track and other vehicle test tracks located at APG. Our data transformation and filtering process holds potential for streamlining the vehicle's R&D to T&A workflow. This approach could shorten the timeline for fielding a new vehicle.

We encountered a possible limitation when pushing the data components through the ANVEL API as this proved to be a lengthy manual operation. In the case of a larger simulated environment containing more fine-grained map details, this step might prove computationally prohibitive. Additional investigations focused on this specific step in the data transformation process need to be performed.

Several future directions for this investigation have been identified that would improve the quality of both the simulated vehicle environment and the vehicle itself. Live-vehicle test runs produce a wide variety of data; exploring other types of data collected from the test vehicle could enhance the overall simulated environment and further validate our data transformation and filtering approach. For example, incorporating the time-step data supplied within the GPS file to model the speed of the vehicle within the simulation environment instead of using a default vehicle speed defined by ANVEL would produce a more realistic vehicle live-testing run. Incorporating the time-step data would also allow a comparison of vehicle runs with and without accounting for time across multiple movement paths around the track.

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List of Symbols, Abbreviations, and Acronyms

2-D	two-dimensional
3-D	three-dimensional
ADAS	Advanced Driver Assistance Systems
ANVEL	Autonomous Navigation Virtual Environment Laboratory
APG	Aberdeen Proving Ground
API	application programming interface
ARL	Army Research Laboratory
ATC	Aberdeen Test Center
ATEC	US Army Test and Evaluation Command
ATEF	Automotive Technology Evaluation Facility
DEVCOM	US Army Combat Capabilities Development Command
DOD	Department of Defense
GPS	global positioning system
GUI	graphical user interface
HPC	high-performance computing
JSON	JavaScript Object Notation
ML	machine learning
M&S	modeling and simulation
R&D	research and development
S&T	science and technology
T&A	testing and acceptance
T&E	test and evaluation
YOLO	You Only Look Once

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