Automated Runtime Terrain Database Correlation Assessment

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ABSTRACT

As the US Navy and US Marine Corps move toward integrating existing flight simulators into common training environments, the importance of having a correlated, correct environmental representation is vital for achieving a fair fight and a high training value to the warfighter. Many of these simulators are operating off different versions of source data and using different image generator (IG) vendors, which can result in interoperability problems. Although correlation between visual terrain databases and simulation terrain databases have been investigated in the past, there is a lack of research on correlation between large synthetic environments using runtime visual and sensor databases in Navy and Marine Corps flight simulators. Many current practices involve manual inspection and limited area of interest (AOI) testing to determine correlation, resulting in ineffective correlation assessments, which may cause negative training. In an effort to address this gap, preliminary research has been conducted to develop a tool that can perform automated correlation and integrity assessments on runtime formats, including visual and sensor databases, using standard interfaces such as the Common IG Interface (CIGI) within a distributed simulation environment. Utilizing these standard interfaces along with standard data formats, such as the U.S. Navy Naval Air Systems Command (NAVAIR) Portable Source Initiative (NPSI), the research framework facilitates tests to identify integrity and correlation conditions that may negatively affect training. The details of the investigation, its outcomes, and future research are reported.

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INTRODUCTION

Naval flight simulators are often run in isolation, but there is growing interest in networking multiple simulators together. While portions of the interoperability puzzle are well addressed in the Naval air domain, such as compliance with network interactions through a Federation Object Model as discussed in the Naval Aviation Simulation Master Plan, others are not as well understood or mitigated. In aircraft simulators, synthetic environment (SE) representations have large extents and contain AOIs such as airfields, landing zones, confined area landing (CAL) areas, terrain flight (TERF) paths and urban areas. Establishing the integrity of each one of the SE databases as well as the degree of correlation between all the environment representations is necessary in order to avoid training anomalies. Today the Navy relies on manual inspection and limited testing to determine the integrity of the overall system. As the Navy moves to include multiple simulators that include different representations of the training environment, it becomes increasingly important to use common SE areas for training exercises that are well correlated.

Although SE correlation does not guarantee interoperability, it is necessary to have a high degree of correlation between the environment representations for meaningful training to take place (Woodard, 1992). Although some metrics and tools have been proposed in the past (Schiavone et al., 1997; Simons, 2004; Clarke & Wonnacott, 2004; Palmer & Boyd, 2011; Santiago, 2012; Graniela, 2011, 2012) the degree of correlation needed for interoperability between the terrain databases is still an area of research.

The aim of this study was to research and prototype a terrain database validation and correlation assessment system that works from both direct and indirect data sources, including NPSI dataset to NPSI dataset, NPSI dataset to runtime, and runtime to runtime comparisons.

Terrain Database (TDB) Correlation

The correlation between TDBs and the consistency of simulation models has been investigated over the years (Schiavone et al., 1997; Simons, 2004; Clarke & Wonnacott, 2004; Palmer & Boyd, 2011; Santiago, 2012; Graniela, 2011, 2012). No clear solution exists at this point for the assessment of correlated and interoperable environments. The current approach used to mitigate correlation between heterogeneous TDB representations includes techniques such as the generation of runtime from source data in real-time and dedicated facilities, which generate static representations of the different environments based on the number of simulators. The U.S. Special Operations Command Common Database (CDB) was developed to generate runtime representation in real-time from pre-processed source data stored in a repository (Simons, 2004). The TDBs are distributed before the exercise starts or published in real-time to all the simulators therefore minimizing correlation error associated with the difference in source data. This approach requires a dedicated facility with a high-bandwidth network which can support real-time publishing. Other approaches like the Army's SE Core Database Virtual Environment Development program concentrate on the offline generation of a common set of correlated terrain databases (Shufelt, 2006). TDBs are generated as necessary to support specific training scenarios. This approach requires the support of a dedicated TDB generation team and a facility which can support the development of correlated TDB in a timely manner.

Navy Requirements

The Navy has a set of unique requirements for correlation that needs to be considered as a correlation and interoperability approach is selected. The approach used by the Navy today concentrates on reducing development cost by capturing the source data used in the development of the runtime into a NPSI source dataset. NPSI provides a foundation for simulator interoperability but does not assure correlation. The data set reuse allows each program to enhance and republish the new runtime databases to fulfill the program requirements. Due to long Navy acquisition cycles, program requirements, cost, and other factors; the runtime environment at distributed training sites, although derived from the same source, may vary. This can be caused through introduction of additional source data, enhancements, differing TDB development processes, and tools or rendering hardware.

There is a lack of tools that can assess the fidelity of the generated runtime representation with respect to the delivered NPSI datasets. In addition, tools that can assess the correlation between fielded runtime representations are not available. Furthermore, integrity tools or methods of assessing correlation within the different US Navy and United States Marine Corps (USMC) simulator environment representations are not available.

The work presented in this paper was performed as part of a Navy Phase 1 Small Business Innovation Research (SBIR) program topic N141-006 Distributed SE Correlation Architecture and Metrics. The next section provides information on previous work on TDB correlation and why and how this work is different. This paper then provides a description of the research process and proposed architecture. Finally, preliminary results, followed by a brief discussion of the research implications, and an outline of future work is presented.

PREVIOUS WORK

Over the years, several common environment representation models and formats have been developed in an effort to solve the interoperability and correlation problem faced by distributed and heterogeneous modeling and simulation (M&S) applications. In the 1980's, the Department of Defense (DoD) initiated a development program to address generation costs of visual databases. The resulting Standard Simulation Database Interchange Format attempted to reduce the amount of data transformations required to generate various visual databases. Although this approach worked for aircraft simulation environments, it was not as successful for a larger set of M&S applications that involved ground level navigation and negotiation of the environment by avatars and agents (Schiavone et al., 1997). Subsequently, the US Defense M&S Office initiated a project to develop a richer Synthetic Environment Data Representation and Interchange Specification (SEDRIS) to address representation and interchange problems of these more demanding heterogeneous networked and distributed applications. Among other things, SEDRIS defined a data model, application programming interfaces, classification and attribute standards, and tools for the unambiguous representation and interchange of TDB (Carson, 2000). More recent trends such as the NPSI (Nichols, 2003) and the CDB (Simons, 2004) are focusing on the use of commercial standard formats for the representation of the TDB using open and widely used source formats.

Correlation tools have been developed in the past to address various programs and sets of formats. Some of these tools are particularly tuned to support specific program objectives and data formats.

ZCap (Hardis & Sureshchandran, 1995) is a suite of software tools developed by UCF IST to address terrain database interoperability. It provides capabilities for terrain and culture correlation testing, terrain and image registration, database analysis, and terrain database visualization.

The SEE-IT tool was developed for the M&S community under the SEDRIS program. The tool focused on geometric comparisons and attribute quality.

The Close Combat Tactical Trainer (CCTT) toolset provided a broad, comprehensive, multiple sample points, and good graphical/interactive capability. However, the tool was specially developed in Ada for CCTT and its use reduced over time. It can be considered obsolete and not supported.

The Institute for Defense Analysis Geospatial Analysis and Inspection Tool (GAIT) is a quality assurance analysis tool developed for the National Geospatial-Intelligence Agency and the Multinational Geospatial Co-production Program. GAIT builds on the SEE-IT tool. GAIT considers contemporary geospatial data formats, data visualization, data query, and indivisibility; as well as network analysis capabilities such as Line-Of-Sight (LOS), terrain masking, and networks.

The Side-by-Side tool is a visualization tool, developed by AcuSoft, which imports a variety of formats (including SEDRIS and OneSAF Terrain Format (OTF)) and renders them simultaneously from the same point of view. The tool provided visualization of data for manual comparisons between supported formats, however, no automation or test support was provided.

The original OneSAF program included a toolset with test capability, centered on a textual tool and gnuplot. SE Core added a visual test tool and automated test driver. New toolsets provided visualization and some automated tests. These tools were limited to SE Core formats and program specific test needs.

The Venator (Clarke, 2004) toolset provides a detailed analysis of terrain formats, including cross-format comparisons. The tool provides good context sensitivity and detailed reports however it was highly specialized and required lots of manual intervention.

LightBox (Palmer & Boyd, 2011) provides a direct comparison between two or more geospatial datasets. The tool identifies differences in elevation or feature coverage. Supported formats include formats such as OTF, OpenFlight, and VBS2. The tool does feature intersection analysis, identifies slivers and steep triangles, identify correlation between road triangles and road features in the road network database and vice-versa.

C-nergy (Santiago et al., 2012) which stands for “Correlation Synergy” is a framework that allows disparate applications, tests, and database formats to work together and augment each other’s testing capabilities. The application itself is composed of a toolset of small applications that are meant to give users and developers a comprehensive look at the state of their databases’ correlation. Visualization tools include overlay and Side-by-Side visualization tool. Tests include LOS, height of terrain (HOT), and collision detection.

A gap exists in the automated assessments of correlation errors between large SEs composed of large amounts of geo-specific imagery as far as it relates to visual and sensor simulation for Naval/Marine Corps flight simulators. In general, the tools were developed to solve program specific needs with an emphasis on the comparison between virtual and semi-automated forces database representations. No support for the comparison of visual attributes such as textures and materials exists. No support for NPSI or Navy virtual and threat systems is provided. R&D is expected to provide for the assessment of correlation between different NPSI datasets, between NPSI datasets and runtime databases as well as between runtime databases and other runtime databases. The evaluation of differences between source datasets and runtime databases can save time and money in the procurement of visual and sensor database as well as in the execution of distributed live, virtual and constructive training exercises.

APPROACH

This section covers the approach for creating the tests and metrics, as well as the thresholds for Navy and USMC tasks and AOIs. The first sub-section presents the concept of Fit-for-Use which is used to establish the mapping. The next sub-section provides justification and description of the main classes of tests and metrics. The next two sections provide information on data access and sampling.

Fit-for-Use

Use cases were developed based on the specific needs of Navy and USMC flight simulators to ensure the necessary level of integrity and correlation. Instead of looking for a solution for the use cases from the perspective of measuring miscorrelation and integrity concerns in esoteric metrics, the authors worked from the perspective of understanding how the Navy desires to use the combined simulators and created a solution to verify the SEs of the connected simulators are fit for that usage. Research performed by the National Geospatial-Intelligence Agency resulted in the Content Maturity Model to categorize source data quality in order to determine the appropriate use of that data (Strebeck et al., 2014*).* The Fit-for-Use concept was adapted to identify the set of categories that the Navy can use to determine what training missions are appropriate for a set of input simulators and TDBs. For example the following list is a set of training missions identified for the CH53 helicopter trainers: familiarization, instruments, navigation, formation, CAL, external loads, TERF, ground threat reaction, defensive measures, aerial refueling, field carrier landing practice, carrier qualification, tactics, nuclear, biological, and chemical, core skills check, evaluation, and flight leadership. This set of Fit-for-Use categories can be mapped to a set of correlation tests and corresponding thresholds by Navy flight simulation subject matter experts, who represent the requirements for a specific SE training use. For example, for an instrument training mission the correlation between elevation data across simulators will have a low priority, because datasets or systems with elevation correlation deficiencies are still fit for instrument training. The combination of Fit-for-Use mission and AOI category provides the mission type and area of interest type that are the key factors in determining the rigorousness required for the test (Table 1).

Table 1: Sample Fit-for-Use Spreadsheet and AOI Mapping

		Tests and Parameters		Required Thresholds	
Fit-for-Use Mission	AOI Category	Feature Presence (Boolean)	Feature Attributes (Boolean)	Feature Presence (Percentage)	Feature Attributes (Percentage)
Familiarization					
	Airfield	TRUE	TRUE	80%	75%
	Flight Path	TRUE	TRUE	80%	75%
	Urban Area	TRUE	TRUE	80%	75%
	Forest	TRUE	FALSE	60%	N/A
	Mountainous	FALSE	FALSE	N/A	N/A
	General	FALSE	FALSE	N/A	N/A

The Fit-for-Use missions and AOI category are then mapped to a set of tests and corresponding configuration parameters (if applicable) which specify the important tests for that combination. The Required Thresholds section provides the minimum required levels for acceptable correlation between TDBs. For example, Table 1 illustrates that for a familiarization mission over an airfield, the Feature Presence and Feature Attributes test must be run and the results must be greater than 80% and 75%, respectively. These thresholds were notionally assigned based on the knowledge of an internal Subject Matter Expert (SME), a former Navy pilot, for testing purposes only. The thresholds were assigned based on his idea of importance and will be further examined by current Navy SMEs in future phases.

Figure 1 shows the boundaries of an AOI which can be used to identify areas of importance during correlation testing. These areas may be weighted differently to indicate the level of importance.

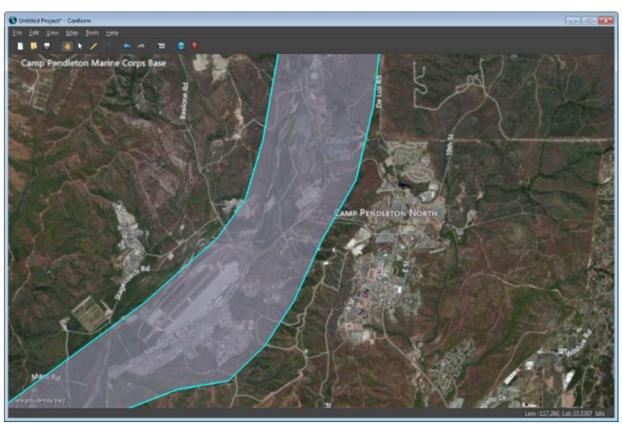


Figure 1: AOI bounds representing a possible approach for planes taking off and landing at Camp Pendleton. This AOI will use tests and parameters that represent stricter scrutiny.

Tests and Metrics

Research on the integrity and correlation issues faced by Navy flight simulator programs led to an initial set of tests and metrics categories illustrated in Table 2.

This table provides a prioritized list of tests that the proposed system shall support. These tests range from terrain elevation correlation to IG sensor mode visualization matching. Table 2 illustrates the categorical tests identified and prototypically implemented in the SBIR Phase 1 along with the form of measurement, data sources required, metrics being collected, and format of the results.

Table 2: Tests Identified and Implemented

Specific Test	Validation Plugin	Measurement	Relevant Direct Data Sources	Relevant Indirect Data Sources	Metric	Results
Elevation to Elevation	Elevation	Elevation	NPSI, Source digital elevation model (DEM) Formats	CIGI, HLA, DIS	Difference	Specific Points, Descriptive Statistics
Elevation Spikes (and Cliffs)	Elevation	Slopes	NPSI, Source DEM Formats	CIGI, HLA, DIS	Spikes (slope that exceeds threshold)	Specific Points, Descriptive Statistics
Elevation Gaps	Elevation	Gaps	NPSI, Source DEM Formats	CIGI, HLA, DIS	No terrain areas	Specific Areas, Descriptive Statistics
Feature Presence	Feature	Feature Existence	NPSI, Vector Files, Arc Databases	CIGI, HLA, DIS	Missing Features	Feature Locations, Descriptive Statistics
Imagery to Imagery Correlation	Imagery	Resolution and Content	NPSI, Image Formats	CIGI	Image Discrepancies	Locations, Descriptive Statistics

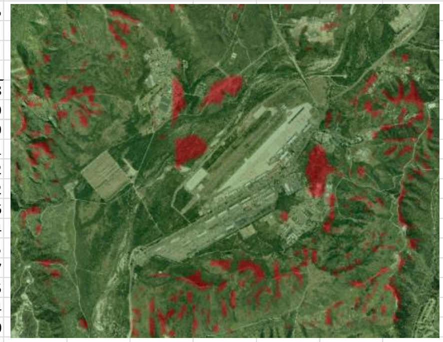
Direct and Indirect Data Access

A core aspect of executing these tests is ensuring that the system can access the environmental content, even when the content is stored in a proprietary runtime format. Therefore, in addition to supporting open formats such as NPSI and OpenFlight, environmental data can be gathered through network interfaces, such as CIGI, HLA, and DIS.

Tests Executed in Statistical Sampling Mode

Using network interfaces to assess the environment can be a time-consuming process of determining correlation of a very large region if an application takes the tactic of performing a brute force set of tests across the entire area. If time is not an issue, performing this sort of thorough analysis is ideal. However, when time is a concern, it is better to rely upon statistical methods that use random samples. These samples can be substantially smaller than the entire population and still have a level of confidence in its accuracy. The sample size can be quantified by the required confidence interval and level along with the finite population (in this case, the area of the enclosed AOI) and is assumed to be a standard normal distribution. The statistical results of an elevation comparison test over an airfield are shown below in Figure 2.

AOI Category:	**AirField**
Test Information:	**Elevation Comparision**
Datasets Tested:	**EPX-5, NPSI**
Correlation	**92.53%**
Descriptive Summary	
	Difference
Mean	2.93659488
Median	1.298400879
Mode	1.298400879
Minimum	0.000506401
Maximum	54.70159912
Range	54.70109272
Variance	15.4876
Standard Deviation	3.9354
Coeff. of Variation	134.01%
Skewness	5.1987
Kurtosis	45.0945
Count	8004
Standard Error	0.0440



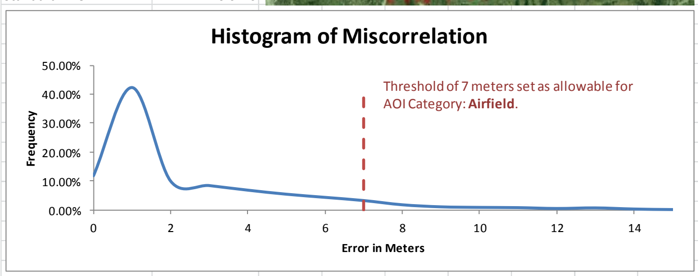


Figure 2: Statistical Output for an Elevation Comparison Test. The imagery uses a red overlay to represent areas that have miscorrelation exceeding the allowable tolerance, which was set at 7 meters for this execution.

ARCHITECTURE

This section provides a description of the architecture which allows for the implementation of a flexible and expandable tool for measuring correlation in Navy and USMC aircraft simulators.

The tool, code named *Validate*, is built as a plugin for the geographic information system visualization software application, *Conform*. The architecture of the correlation tool is shown in Figure 3. libValidate, the underlying validation library, is designed to work standalone so that it can be integrated into any application. For the purposes of the SBIR, it is integrated into *Conform*.

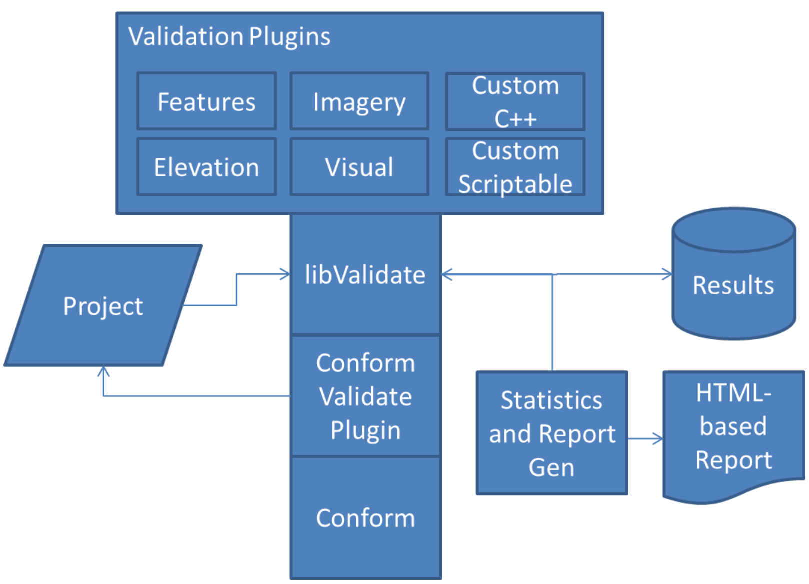


Figure 3: Validate Architecture Diagram

The primary input for libValidate is a project. The project contains information on the data sources (e.g., an NPSI database and a CIGI connection to an IG) and what is called a session. The session includes the validation tests and metrics, AOI (i.e., area of the terrain to be tested) as well as the allowed thresholds (e.g., elevation testing at 0.1 meter allowable threshold). The output of the Session includes a results database (a database that stores the validation results) and an output report (an HTML-based report that presents the results of the validation).

Project Creation

The project drives the test and metrics as well as the thresholds. Ideally this project should be easily generated with the minimum amount of SME input. At this point, there are four inputs that drive the creation of the libValidate project; these include the domain, data formats, scenarios, and user input. Parameters such as domain, training mission and AOIs map predetermined settings which may include tests, metrics and thresholds. For example, if performing ground based training, elevation correlation may be deemed a higher priority than imagery correlation. The data formats include information pertinent to the types of data being correlated, which may drive the inference of the types of relevant correlation tests that apply. The scenario inputs are used to identify regions of higher importance automatically. Ultimately user input interfaces will be provided to manually configure all project settings.

Validation Plugins

Each validation test is executed as an individual plugin. The purpose of using a plugin approach is to make the system expandable for new validation tests to be added to the system. There are two approaches for new plugins to be added into the system; these include a C++ Plugin software development kit (SDK) and a scripting language (such as Python). For plugins that have very high performance needs, or require a level of access to a third system or hardware functionality, using the C++ SDK will be the appropriate choice. In most circumstances, the scripting language will be the simplest approach for end users to add new tests into the system.

PRELIMINARY RESULTS

This section provides a summary of some of the preliminary results obtained during Phase I. The results of the preliminary CIGI data acquisition are presented as well as image resolution tests. Feature detection testing results are also presented.

Visualization of IG Gridding

During correlation testing with a Rockwell Collins EPX-5 IG, it became important to visualize the data returned from the IG. For the purposes of comparing elevation data a test application was developed that returned IG HOT information over CIGI. This functionality was tested in the West Coast NPSI Camp Pendleton area. The application presents a polygonized view which provides the IG's representation of the runtime surface elevation. The elevation information is used for correlation against the original DEM file (see Figure 4, Figure 5, and Figure 6).

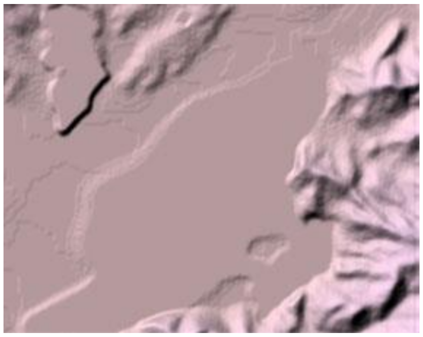


Figure 4: Original Camp Pendleton DEM focused on an airfield

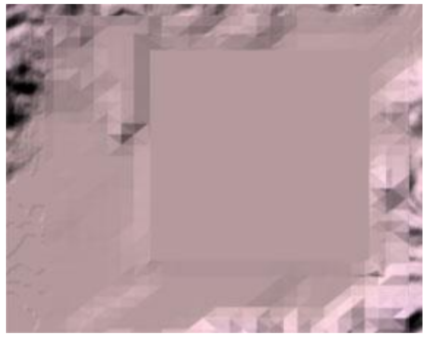


Figure 5: DEM generated from sampling IG runtime, via CIGI

Figure 6: Comparison Results; Red indicates miscorrelation

The overlay demonstrated a miscorrelation where the IG has a portion of the terrain flattened in the top center of the image where the original DEM shows mountainous terrain. The overlay helps in the visualization of the triangulation method used by the IG. The authors found that if a small change occurred within one of the triangular divisions, the IG would not report the elevation difference.

Image Resolution Detection

An AOI in correlation is guaranteeing proper image resolution in the IG as compared to the source imagery.

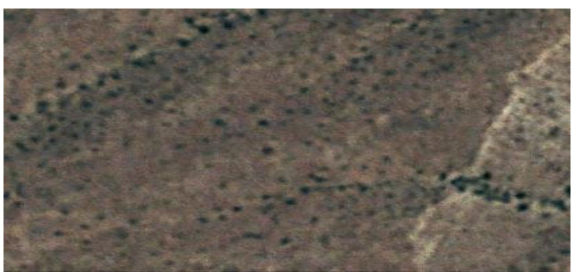


Figure 7: EPX-5 Screenshot for Image Resolution Test

In this phase, a strategy was developed to position the camera in an orthographic view of the terrain and took a screenshot of the imagery from that point of view (Figure 7). This imagery was analyzed for pixels/meter match to the source to determine correlation between the NPSI source and EPX-5 IG.

Feature Correlation Detection

The training objectives heavily focused on airfields as the primary AOI. As such the authors spent a significant amount of time on the algorithm for detecting feature correlation, specifically buildings (illustrated as red squares), at the primary airfield in Camp Pendleton (Figure 8).

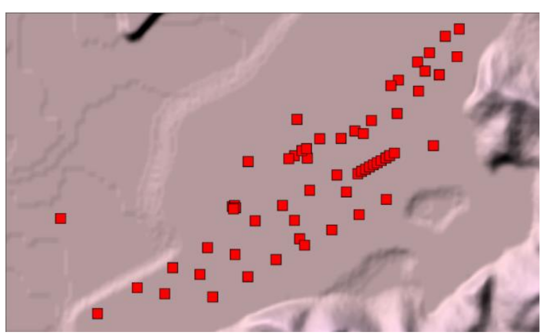


Figure 8: Building Point Features in Original NPSI Shape File (stylized as red squares for visualization)

In this case the test indicated an acceptable level of correlation between the NPSI source dataset and the EPX-5 IG runtime. As an additional test of the algorithm, the original NPSI source file was modified to remove one of the building points (Figure 9). Afterward, the IG model presence test was performed on the IG runtime to verify that the algorithm detected the changes. This algorithm sends a series of LOS requests over CIGI to the IG. Each LOS request correlates with a particular location of a building in the source. The resultant intersection points are then compared to the source to determine whether the expected building was found or if it found a building that was not in the source. The results are then displayed in a green overlay with a red dot indicating the miscorrelation (Figure 10).

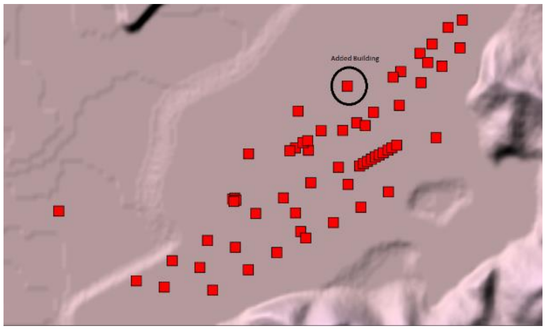


Figure 9: Modified source file; Circled building has been added

Figure 10: Results Overlay for IG Model Presence Test. The circle around the red dot is showing the model present in the modified source and not in the IG.

DISCUSSION

This paper provides a brief overview of the research performed to identify requirements for the correlation of Navy aircraft simulators. The previous work on environment representation and correlation indicates that the trends are leading to the reuse of common datasets such as NPSI and CDB. However, this does not guarantee correlation between the runtime databases. For that reason correlation between the source data and the runtime databases must be determined. The research on correlation tools shows that a gap still exists on automated assessment between large SEs composed of large amounts of geo-specific imagery, and in particular, on visual and sensor databases used by the Navy / USMC. The SBIR Phase I R&D resulted in a framework which has the potential to quantify TDB correlation through the concept of *Fit-for-Use*. The proposed architecture will implement a number of elevation, feature and imagery tests to determine the suitability of the TDBs for a number of tasks. The preliminary results of the prototype architecture indicate that it is possible to identify correlation between source data and runtime representations using CIGI. The authors believe that this architecture has the potential to address the identified gaps and provide a fair fight during Navy / USMC distributed simulation training.

FUTURE WORK

Three sets of technical objectives have been identified for Phase 2 of the SBIR. First, tool R&D will address the necessary design and develop the tool. Second, interoperability research will develop a system that will effectively integrate with existing Navy flight simulation programs. Finally, a fielding study is proposed for testing the system against those flight simulators to further evaluate the effectiveness of the research and make the necessary enhancements. The task under tool R&D will be gathering use cases to refine the current set of requirements. R&D on correlation tests will capture the necessary correlation metrics, prototype the system's output report, research the use of a sampling mode for executing rapid tests, conduct scalability studies, and automate system project creation. Interoperability research is planned to research and publish CIGI extensions, and the mapping between Fit-for-Use tasks, tests, metrics and thresholds for using Navy / USMC flight simulation. The fielding study will include tasks to package, distribute, and gather feedback from Navy users.

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DISCLAIMER

The views expressed herein are those of the authors and do not necessarily represent the views of DoD or its Components

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