QUANTITATIVE CORRELATION TESTING FROM DOD PROJECT 2851 STANDARD SIMULATOR DATA BASES

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ABSTRACT

Correlation of out-the-window visual, infrared, radar, and other sensor displays must exist in local and networked simulation environments in order for users to obtain meaningful and consistent information about the simulated world. The use of a large numbers of image generators with varying capacities and the networking of simulators capable of varying degrees of fidelity underscore the need for consistent and quantitative specifications of and automated testing tools for correlation.

This paper describes the evaluation of correlation potential from databases provided by the DoD Standard Simulator Data Base Project 2851. It presents quantitative correlation testing metrics and software developed for evaluation of Project 2851 Generic Transformed Data Bases. It also describes the application of metrics to compute the degree of correspondence between simulation databases — not only for terrain elevation but also for feature attribute data. Our results demonstrate varying degrees of correlation potential between databases and levels of detail and verify the utility of the specifications, quantitative metrics, and automated tools to predict correlation from databases.

ABOUT THE AUTHORS

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INTRODUCTION AND BACKGROUND

Advances in image generation technology have provided increased realism and fidelity of sensor and visual simulations. At the same time, modern aircraft cockpits have created a need to simultaneously simulate outputs from many sensors in conjunction with Out-The-Window visual and moving map imagery. Furthermore, networked simulations of multiple systems require coordinated sensor simulations which use a variety of image generators operating at different levels of fidelity and detail.

McDonnell Douglas Training Systems (MDTS), a sub-division of the Aircraft and Missile Support Systems division within the McDonnell Douglas Aerospace, has been conducting on-going R&D efforts to improve correlation in simulation environments. In Phase 1, described in a previous paper[1], definitions of correlation and algorithms to test and predict correlation "potential" from simulator databases were developed. In Phase 2, described in this paper, the definitions and algorithms were implemented in software and used to actually predict correlation potential of databases.

This paper describes the evaluation of correlation potential from databases provided by Project 2851 (P2851). It presents quantitative correlation testing metrics and software developed for evaluation of P2851 Generic Transformed Data Bases (GTDBs). It not only describes the computation of the degree of correspondence of terrain but also feature data between different Simulator Levels of Detail (SLODs) and between infrared (IR), radar, and Out-the-Window (OTW) visual GTDBs. The results verify the ability of the specifications, metrics, and tools to predict correlation potential from databases, and demonstrate varying degrees of correlation potential among the GTDBs.

Traditional Definitions of Correlation

In a previous paper[1], we described the results of a survey of correlation definitions for simulation use, using sources which were both internal and external to MDTS. The survey found that many terms are used to describe correlation, and that there is a lack of accurate definitions and objective metrics. In addition, there is no agreement on the meaning, specification, and measurement of correlation.

Need for Quantitative Measures

Simultaneous sensor and visual simulations often lead to a requirement for correlation. Although "correlation" has been used in signal processing, image processing, and communication theory to detect signals in noise and match patterns, the term has been used extensively in the simulation and training industry without accurately defining it. Meaning, specification, and method of the correlation measurement often causes users to be limited only to qualitative assessments of correlation over selected portions of gaming areas. The definitions and metrics proposed in our first paper provide techniques to automatically evaluate maximum achievable correlation over an entire gaming area and identify locations where insufficient correlation may be a problem.

Estimation of Correlation "Potential"

In the traditional database generation process, the user collects data from various sources, converts it into a common database, and then converts the common database into run-time databases for its target computer image generators (CIGs). Each run-time database is then processed by its CIG to produce an image or input to the users. Although correlation can be measured at several points in the process, comparisons of the input data provide the best measurement of correlation, since the correlation of the outputs can be no better than the correlation of the inputs. Thus, the databases for sensors and visuals provide the basis for measuring the maximum static correlation attainable by ideal CIGs and display simulators.

A maximum correlation "potential" can be computed from the database contents without CIG-particular processing effects and simulated display distortions. More importantly, when CIG requirements, such as surface polygonalization or object culling, affect database construction and generation, such effects of such "tailoring" will be measured via database-to- database correlation.

PROJECT 2851

Project 2851 (P2851) is a research and development program chartered by the Joint Technical Coordinating Group for Training Systems and Devices. Project 2851 develops systems and standards for the efficient generation, updating, storage, and distribution of DoD simulator databases. It seeks not only to improve efficiency and lower costs of providing databases for a very large number of DoD simulators but also to improve correlation among multiple simulators and Image Generator (IG) outputs.

Project 2851 will result in a DoD Simulator Data Base Facility which will obtain standard Defense Mapping Agency products, externally generated simulation data bases, and other source material; archive and manage this data; and provide tailored data base products to DoD training simulators.

The Generic Transformed Data Base

The P2851 Generic Transformed Data Base (GTDB) is a data base which supports real-time visual, infrared and radar sensor simulation systems. The single GTDB format is a superset of data base features required for its target simulations. This single format reduces software development and maintenance costs among users of the GTDB.

The P2851 Common Data Base Transformation Program (CDBTP) generates GTDBs for specific image generators, using the terrain, culture, model, and texture data maintained at the Simulator Data Base Facility. The CDBTP uses a set of transformation parameters to determine how to tailor a GTDB. Among other things, these parameters may specify the map projection, goodness of fit for polygonal terrain, and complexity reduction.

CORRELATION TESTING DEVELOPMENT

We have defined database correlation as the degree of correspondence among data types and their contents needed by image generators. Thus, our metric for terrain elevation is the statistical distribution of terrain elevation differences between two databases; and our metric for feature data is the percentage of zero differences in cultural pixels between two databases.

Quantitative Metrics

Our quantitative metrics determine the correspondence of data among SLODs, gridded and polygonal terrain, and areal, linear, and cultural feature attributes for OTW visual, IR, and radar GTDBs.

Elevation Correlation – The elevation correlation is obtained by producing gridded elevation representations from two databases and subtracting these to obtain a grid of elevation differences. The elevation correlation is then represented by statistical measures of the differences: the average value, the standard deviation, and the range of values.

Feature Correlation –Since GTDB features overlay each other according to their rendering priority, feature correlation will be a match in feature location, orientation, size, shape, and attribution. Thus, as illustrated in Figure 1, feature correlation is obtained by subtracting composite gridded feature attributes in two databases and obtaining the percentage of zero differences.

Our feature representation uses a pointer method to reduce requirements for attribute data storage. Instead of storing all feature attributes at each grid post, the feature gridding software stores a pointer to unique sets of feature attributes, called Feature Attribute Vectors (FAVs) (Figure 2). The FAV list is common to both databases: during feature gridding,

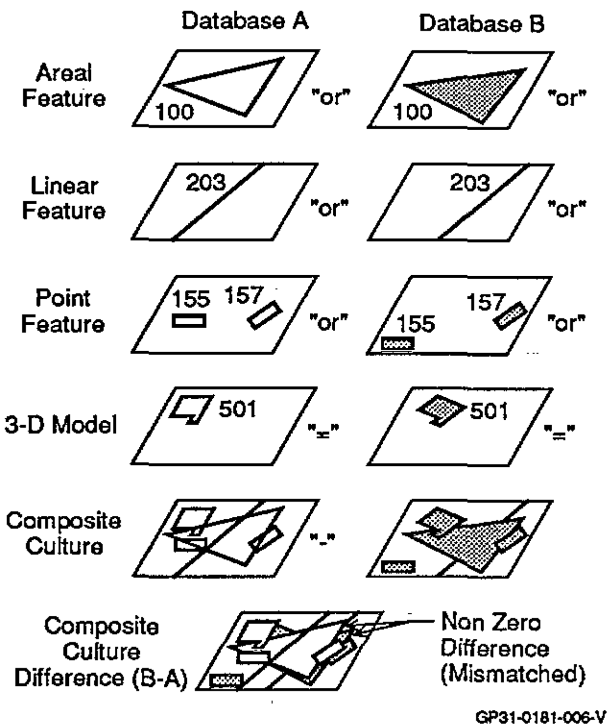

Figure 1. Cultural Feature Correlation Grid Generation

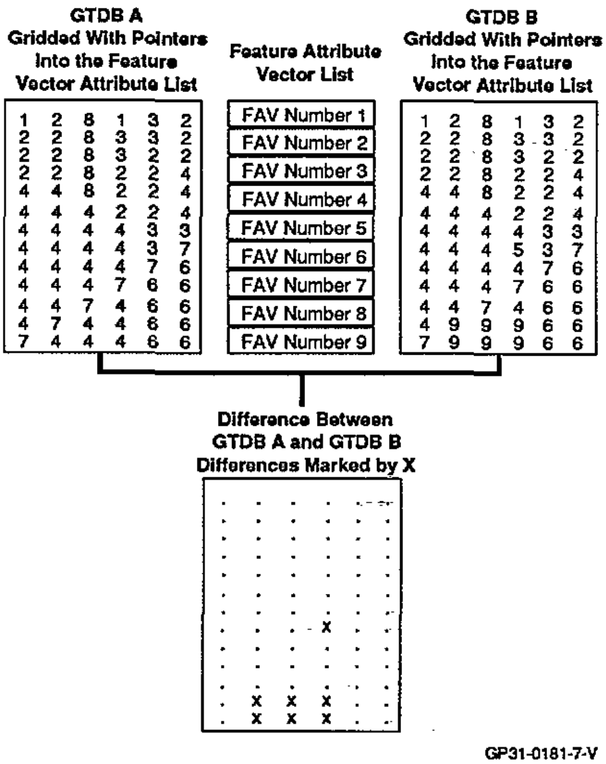

Figure 2. Cultural Correlation From Feature Attribute Vectors

current feature attributes are compared to the attributes already in the FAV list. If a matching FAV is found in the list, the associated list pointer is stored at the grid location. If none of the list FAVs matches the current feature attributes, the current attributes are added to the FAV list with the list pointer incremented and stored at the grid location.

Therefore, a tremendous reduction in feature storage is achieved by using only one FAV per feature. Cultural feature match is a percentage of zero differences in FAV pointers, or the percentage of zero differences in selected elements of the FAVs. Table 1 shows examples of attribute combinations stored in FAVs containing from 2 up to 23 attributes.

Table 1. Feature Attribute Vector Contents

Feature Attribute Vector (FAV)	FAV Contents	
FID/SMC (2)	Feature Description Surface Material	
Height (1)	Feature Height	
Infrared (7)	IR Directivity Exitance Emissivity Self-Emitter Flag	Reflectivity Absorptivity Transmissivity
Visual (6)	Visual Directivity Color Specular Flag	Hue Chroma Translucency
Radar (4)	Radar Directivity Diffuse Reflectivity Feature Onset Flag Low Level Effects Flag	
Complete (23)	Infrared Set + Visual Attribute Set + Radar Set Surface Material Feature Description Correlation Priority	 Material Subtype FID Value Feature Height

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Software Tools

Our GTDB processing involves three stages. Preprocessing, the first stage, is depicted in Figure 3. The second and third stages are visualization and analysis. In visualization, images of two gridded databases are compared using image processing and analysis tools. In the third stage, described below, the tools compare two gridded database representations.

Figure 3 shows the preprocessing steps used for each GTDB. First, program "Read2851" reads the

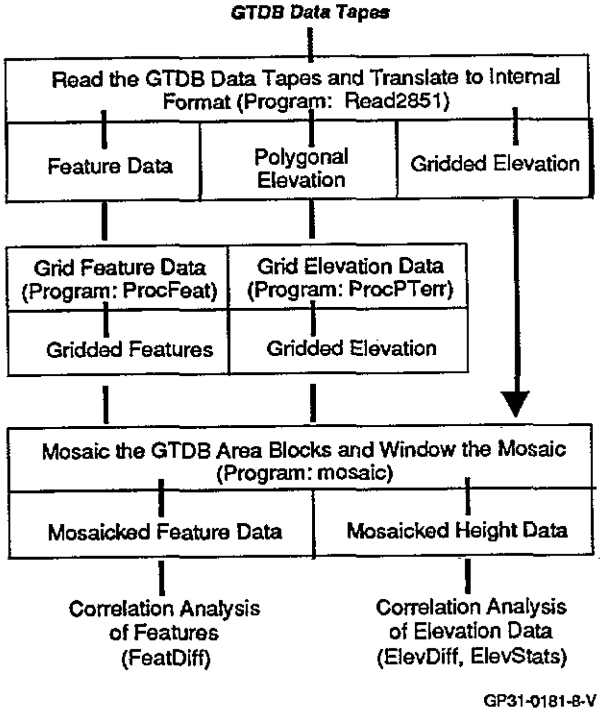

Figure 3. GTDB Preprocessing Before Correlation Testing

data tapes and transfers the data to disk files. This program produces three types of files for each area block. One file type contains contain binary representations of the cultural and feature data; another contains a binary representation of polygonal elevation data; and a third type contains gridded elevation data.

The program "ProcFeat" processes the feature data; and the program "ProcPTerr" processes the polygonal elevation data. Each program produces gridded representations of one area block. The "ProcPTerr" program produces gridded elevation data which has spacings of 3 arc seconds. The program "ProcFeat" grids areal, linear, and point features and produces feature attributes for each pixel.

The "mosaic" program combines its input files by positioning adjacent area blocks next to one another in a seamless mosaic of the database and clipping the resulting mosaic to the edges of a specified window.

The "FeatDiff", "ElevDiff", and "ElevStats" programs analyze the mosaicked gridded databases. The "FeatDiff" program reads gridded mosaics from two sources, computes the correlation, and outputs the percent correlation between its data inputs. It computes differences between FAV pointers; it does not compute differences between elements of FAVs. Figure 4 shows the two formulas which are used to compute correlation. If the gridded mosaic is totally covered with data, the formula for "Total Coverage With Valid Data" is used. If only a small part of the gridded area contains valid data, the "Small Coverage With Valid Data" is used.

For Total Coverage With Valid Data

$$\text{Correlation} = \frac{\text{Total Number of Image Pixels} - \text{Number of Mismatched Pixels}}{\text{Total Number of Image Pixels}}$$

For Small Coverage With Valid Data

$$\text{Correlation} = \frac{\left[\begin{array}{l}\text{Number of Non-Zero A-Pixels} + \\ \text{Number of Non-Zero B-Pixels} - \\ \text{Number of Mismatched Pixels}\end{array}\right]}{\text{Number of Non-Zero A-Pixels} + \text{Number of Non-Zero B-Pixels}}$$

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Figure 4. Calculation of Correlation Value

The "ElevDiff" program reads gridded elevation mosaics from two databases or Simulator Levels of Detail and computes gridded differences. The "ElevStats" program computes the average value, the range, and the standard deviation of the difference.

GTDB CORRELATION TESTING RESULTS

We evaluated correlation for F-16, B-2, and Kuwait (Desert Shield) GTDBs. We measured terrain correlation between gridded and polygonal elevation representations; and we determined feature correlation as a function of database, simulator level of detail (SLOD), and multi-sensor attributes.

For a GTDB with two SLODs, SLOD1 represents more feature detail than SLOD2, effectively increasing the spatial resolution. Table 1 illustrates the FAVs used.

When discrepancies in correlation were found, the missing or badly aligned features could be found by inspecting the visual images of the gridded mosaics. For example, the F-16 LANTIRN GTDB, G000665, lacked several large areal features which are in the F-16 VISUAL GTDB, G000671. The numeric results for these GTDBs are low and reflect this disparity. Likewise, the visual comparisons of the two LANTIRN SLODs for G000665 indicate only minor differences involving linear and point features, a fact which is reflected by the high values of correlation for these GTDBs.

Combinations of areal, point, and linear features were used in the measurement of feature correlation. When polygonal terrain data was available, measurements were also made for gridded and polygonal terrain. Since the heights of features were a small percentage of the terrain heights, no attempt was made to measure differences between composite elevations. In these GTDBs, point and linear features covered relatively small areas, and made insignificant contributions to correlation when large areal features were considered. Therefore, the formula for large features was used to compute the values presented in the following tables.

F-16 Infrared vs. Visual GTDBs

The F-16 GTDB evaluation used one visual GTDB and two LANTIRN IR GTDBs. The data bases were:

F-16-LANTIRN, G000665 (two SLODs)
F-16-LANTIRN, G000754 (one SLOD)
F-16-VISUAL, G000671 (one SLOD)

One of the LANTIRN databases, GTDB G000665, had no linear features because linear features had been expanded into areal features. The two other GTDBs, G000754 and G000671, contained areal, linear, and point features. The Northeast and Southwest corner points of the area over which comparisons were made are 39.42166666N, 118.7225000W and 39.20000000N, 119.2216666W.

Features – Feature correlation between SLODs and between sensors was evaluated for all three F-16 GTDBs. The common areas of the databases were evenly gridded at intervals of 0.3 arc-seconds (about 30-foot resolution).

Table 2 summarizes the percent agreement between SLODs and GTDBs when areal, linear, and point features were gridded. The same correlation measures were obtained for the complete, visual, and IR FAVs (Table 1). When areal, linear, and point features were processed over the feature grid, the percent correlation varied between 79.9 and 99.7 percent. It is obvious from the 99.7 percent agreement between the visual GTDB, G000671, and the LANTIRN GTDB, G000754, that these two databases are nearly identical. The poor agreement between the LANTIRN GTDB, G000665, and

Table 2. F-16 GTDB Feature Correlation

Sensor-Sensor and SLOD-SLOD Correlation

Features Gridded:
Areal, Linear, and Point

Feature Attribute Vector Contains:
Complete Set or Visual Set or IR Set

	LANTIRN G000665 SLOD 2	Visual G000671 SLOD 1	LANTIRN G000754 SLOD 1
LANTIRN G000665 SLOD 1	89.98	79.97	79.96
LANTIRN G000665 SLOD 2	N/A	79.94	79.90
Visual G000671 SLOD 1	N/A	N/A	99.74

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G000671 was due to the fact that G000665 did not have several large areal features which appeared in G000671.

Point feature correlation, as measured by the formula for small coverage, ranged from 93 to 99% for the F-16 LANTIRN GTDB 665 SLOD 1 versus SLOD 2 and GTDB 665 SLOD 2 versus the Visual GTDB 671 SLOD 1. It was 100% for the F-16 LANTIRN GTDB 754 versus the VISUAL GTDB 671.

Elevation – Terrain elevation correlation was measured between combinations of all three F-16 GTDBs. The common areas of the three databases were evenly gridded at intervals of 3 arc-seconds (about 300-ft resolution). All the gridded representations were identical. The polygonal elevation database of SLOD 1 of G000665 was nearly equivalent to the polygonal elevation database of G000754. Table 3 summarizes the results for gridded versus polygonal terrain representations.

B-2 Radar vs. Visual GTDBs

The B-2 GTDB data bases were:

B-2 VISUAL, G000774 (two SLODs)
B-2 RADAR, G000781 (one SLOD)

Table 3. F-16 GTDB Elevation Correlation

Gridded vs Polygonal Terrain

LANTIRN G000665 SLOD 1	LANTIRN G000665 SLOD 2	LANTIRN G000754 SLOD 1
A = 1 D = 12.11 R = 313	A = 7 D = 21.88 R = 328	A = 1 D = 12.15 R = 234

Legend: A = Absolute Value of Elevation in Meters
D = Standard Deviation
R = Range of Values (Max-Min)

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The visual database had areal, linear, and point features. The radar GTDB contained only areal and point features; the linear features had been expanded into areal features. The Northeast and Southwest corner points of the area over which comparisons were made are 32.50000N, 116.750W and 33.000N, 117.250W.

Features–Feature correlation between levels of detail and between databases was evaluated for both GTDBs. The databases were evenly gridded at intervals of 0.3 seconds, so they had 6,001 points along the northern and southern borders and 6,001 points along the eastern and western borders.

Table 4 summarizes correlation between SLODs and GTDBs when various combinations of areal, linear, and point features were gridded with pointers to four FAV sets. The same correlation values were obtained using four different FAVs - the complete, visual, IR, and radar attribute sets (Table 1). It shows that when areal, linear, and point features were processed over the feature grid, the percent correlation varied between 68 and 99 percent.

Table 4. B-2 GTDB Composite Feature Correlation

Sensor-Sensor and SLOD-SLOD Correlation

Features Gridded:
Areal, Linear, and Point

Feature Attribute Vector Contains:
Complete Set or Visual Set or IR Set

	Visual G000774 SLOD 2	Radar G000781 SLOD 1
Visual G000774 SLOD 1	68.39	68.27
Visual G000774 SLOD 2	N/A	98.90

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Point feature correlation, as measured by the formula for small coverage, was 97% for the B-2 GTDB, VISUAL SLOD 2 versus the B-2 Radar GTDB.

DESERT STORM (KUWAIT) GTDB

Feature correlation was evaluated between the two SLODs available in the GTDB. Mosaics which encompassed the entire 1-degree by 1-degree database were used for all evaluations. The database was evenly gridded at intervals of 0.6 arc-seconds, so the mosaics had 6,001 points along the northern and southern borders and 6,001 points along the eastern and western borders. The best correlation, 99.1%, was obtained when the FAV contained only feature height. For other FAVs, the correlation depended on the contents of the FAV; and correlation of the composite of Areal, Linear, and Point Features ranged between 93 to 94 percent.

CONCLUSIONS AND FUTURE DIRECTIONS

Our investigations have resulted in the following conclusions:

1. We have verified the validity of automatic correlation testing between two GTDBs or SLODs by visual inspection of the databases.
2. We have measured varying degrees of correlation between P2851 GTDBs. Very low correlation values indicate that large features are missing in a SLOD or GTDB. Values greater than 90% indicate that small features are missing or that there is some misalignment of features.
3. We have observed that several differently constructed Feature Attribute Vectors produced nearly equivalent feature correlation values.

In the future, we will implement automated tools for database texture and model correlation testing. We will also investigate tools for correlation testing from image generator video displays and relate the results to the correlation "potential" from databases.

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REFERENCE

1. Zvolanek, B. and Dillard, D. "Database Correlation Testing for Simulation Environments", Proceedings of the 14th I/ITSEC Conference, November 1992., pp. 867-875.