

Statistical Certification of Terrain Databases

Dr. Guy A. Schiavone, Russell S. Nelson and Brian Goldiez
Institute for Simulation and Training
3280 Progress Drive
Orlando, FL 32826

Abstract

Consistency in terrain representations between run-time databases is a prerequisite for interoperability in Distributed Interactive Simulation (DIS). It has been suggested in previous research that one hundred percent alignment of databases will never occur in a simulation that utilizes distributed geometric databases. However, statistical certification of terrain database elevations offers a means of ensuring the degree of consistency necessary for interoperability. In this paper we define a statistical metric for terrain database certification. Starting with a review of the existing work on quantitative terrain database metrics, we examine a basis for specification and statistical certification of terrain elevation data. Using classical acceptance sampling, hypothesis testing will be introduced as a method by which a terrain database (TDB) is certified. A method for determining the critical error value for the desired accuracy proportion and consumers risk (Type II error) will be discussed. From these results the producers risk associated with the test is evaluated for several different accuracy proportions. Using data collected at the 1992 IITSEC as a basis for comparison, the utility of acceptance sampling is demonstrated using data collected at the 1994 IITSEC. A distinction is drawn between tests designed for TDB certification and tests with inherent diagnostic capability. As an example of the latter, the use of the cross-correlation metric is introduced for the purpose of detecting linear shifts between the terrain skins of a baseline database and a trial database. Using a portion of the Hunter-Liggett high definition area, an example of linear shift detection is provided for the case of a shift by an integer number of samples.

About the Authors

Dr. Guy A. Schiavone is a Visual Systems Scientist at the Institute for Simulation and Training. He holds a Bachelor of Engineering from Youngstown State University, and the Ph. D. in Engineering Science from Dartmouth College, Thayer School of Engineering. His current interests include spatial error in terrain databases, 2-D signal processing, image processing, scattering from random surfaces, and propagation through random media.

Russell S. Nelson is an Assistant Engineer at the Institute for Simulation and Training. He holds a Bachelor of Science in Electrical Engineering and a Master of Science in Electrical Engineering, both from the University of Central Florida. Currently, Mr. Nelson is a member of the Visual Systems Laboratory R & D of Terrain Databases for DIS project. Prior to joining the VSL, Mr. Nelson was a Graduate Research Assistant with the Distributed Interactive Simulation Lab at IST.

Brian Goldiez is the Director of Research and Development at the Institute for Simulation and Training. Mr. Goldiez's professional interests are in aerodynamic modeling, visual systems, systems design, and testing. Mr. Goldiez directed IST's efforts in the first large scale design, test, and demonstration of Distributed Interactive Simulation at IITSEC 1992. He has been in simulator research and development for over 15 years as an employee of the US DoD, industry, and academia. Mr. Goldiez has Bachelor of Science in Aerospace Engineering and a Master of Science in Computer Engineering.

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Introduction

In recent years, the effectiveness and relative low cost of applications utilizing Distributed Interactive Simulation (DIS) has made the development of DIS a focus of the US military for the purpose of training and other applications requiring real-time interactive simulation. DIS is defined as a time and space coherent synthetic representation of world environments designed for linking the interactive, free play activities of people in operational exercises [1]. Each simulator on a DIS network maintains its own representation of the world. While current technology has provided visual systems with the capability of displaying high fidelity representations of a given synthetic environment, the failure to define and properly certify an agreed-upon synthetic environment before the start of a simulation exercise can lead to significant inconsistencies between world views of individual entities. Also, while members of the simulator industry compete to simulate operational systems at minimum cost to users, there are often times when proprietary "black-box" implementations lead to interoperability problems between networked simulators. It is well known that a consistent playing field between all networked simulators is essential to a successful training mission or evaluation of a new weapon system. As recently noted by Woodard [2], a fundamental first step in addressing this problem is the establishment of a common database format and content. In order to ensure that the content remains unaltered in the transformation between source database and runtime database, it follows that the content of the individual run-time databases should be tested and certified as a necessary step to guarantee a successful simulation exercise.

There is an industry consensus that the most common sources of spatial error between virtual environment representations in networked simulators include inaccurate coordinate transforms, TDB preprocessing by graphics systems, differences between rendering algorithms, and inconsistent source TDBs [3]. As an example, data and analysis recently presented by Economy, et. al. showed inaccurate coordinate transformations to be a leading source of positional error between simulators in end to end system tests

[4]. Although progress is being made to improve the quality and consistency of rendered images through improvements in hardware technology, it has been suggested that resolution of interoperability problems by hardware improvements alone is not in the foreseeable future. However, in simulation environments consistency checks can be applied between TDBs as well as between displays. Thus, there exists an avenue on which the problem may be approached, and that is by way of certification testing of runtime terrain databases. Although, in this paper the authors concentrate on terrain skin only, the environment includes space, atmosphere, earth and sea; features and attributes as well as elevations. Ultimately, spatial coherence metrics for all features of the synthetic environment must be developed. Goldiez, et. al. have mentioned that a spatially coherent environment is an essential element to achieving non-biased simulator interaction [5]. Furthermore, any interaction that takes place in an environment that is spatially incoherent would be accidental and probably meaningless. It is understood that one hundred percent coherence between runtime TDBs is not currently feasible due to performance differences and other causes, and this suggests that applications-based acceptance criteria for runtime TDBs must be defined.

Although much attention has been recently given to the issue of interconsistency between terrain databases in the DIS world, terrain database "correlation" has been recognized as a problem in the real-time simulation community since at least 1977 [6]. Since that time many qualitative evaluations and discussions of the problem have appeared in the literature (for example, [7-12]). Other references can be found in a survey conducted by Zvolanek and Dillard [13]. Unfortunately, proposals for attacking the problem on a sound quantitative footing have been infrequent. Zvolanek and Dillard [14] evaluate terrain elevation "correlation" by calculating the statistical mean, standard deviation, and range of the elevation differences. Feature "correlation" is defined as the percentage of misclassified pixels. Dunn-Roberts et. al. propose a line-of-sight (LOS) intervisibility metric to measure differences in intervisibility between two TDBs [15]. A LOS comparison metric was also used by Fatale et. al. [16] in a study comparing DTED levels 1 and 2. Ellis [17]

recommends measuring off-line elevation errors by the statistical mean and the 90% or 99% maximum error, per unit of standard roughness.

Even though the quantitative methods outlined above represent the current state of the art in terrain database spatial error metrics, they all suffer from various shortcomings. There exists no criteria or guidelines to determine an acceptable level of error for a given application, or how to use the results of the tests. The statistical metrics mentioned above do not allow for control or estimate of producers and consumers risk. The simple statistical measures yield no information on error locality, beyond human-in-the-loop visualization of difference maps. The LOS methods may require a large number of calculations since, in order to obtain a unique error mapping, intervisibility must be calculated from every point in each TDB to every other point in the TDB. None of the metrics mentioned thus far are diagnostic in the sense that they are able to detect shifts, rotations, warps, or other spatial or temporal characteristics of the error. Moreover, there has been limited attention given to identifying the source of the error between a source TDB and a subject TDB. A preliminary investigation of some TDB metrics that overcome some of these shortcomings was undertaken by Kilby et. al. [18]. Currently, IST is involved with a STRICOM funded project to define and quantify interoperability in the DIS paradigm. It is the intention of this paper to present a solid mathematical approach to quantifying differences between TDBs. Acceptance sampling techniques will be applied to the elevation differences between two TDBs. Thus, an accuracy proportion with an associated confidence level can be determined and used to establish the degree of error of the subject TDB. Examples of acceptance sampling will be given using data collected at the 1993 IITSEC. Moreover, the use of the cross-correlation for the purpose of linear shift detection between TDBs will be investigated.

ACCEPTANCE SAMPLING THEORY

Acceptance sampling is the branch of statistical quality control that is concerned with calculating the risks associated with accepting or rejecting product lots based on information provided by a sample of the lot. Originally developed for industrial purposes, acceptance sampling was first used for map accuracy certification by Ginevan in 1979 [19]. As a background to testing for TDB elevation accuracy using acceptance sampling, we begin by examining a sample of terrain skin sample points and calculating the elevation differences, Δz_i , between the source database and the runtime database under test. The sample elevation differences are then compared to a given maximum elevation error criteria Δz_0 . For

example, denoting $\Delta z_1 \dots \Delta z_N$ as our elevation samples, and choosing $\Delta z_0 = 0.5$ meters as our maximum allowable elevation error, we conduct a Bernoulli trial for each sample elevation difference Δz_i , $i = 1, \dots, N$, where the trial is counted as a success if $\Delta z_i < \Delta z_0$, and otherwise is counted as a failure. The N Bernoulli trials form a binomial probability distribution, where the binomial probability density function is given by

$$f(Y;N,Q) = \frac{N!}{Y!(N-Y)!} Q^N (1-Q)^Y \quad (1)$$

where Q is the accuracy proportion, N is the total number of elevation difference samples, and Y is the number of failures.

A hypothesis testing criteria will be used in this statistical approach in which the null hypothesis H_0 states that the actual accuracy proportion of the TDB Q_a under test is less than the desired accuracy proportion Q . The possible outcomes of such a hypothesis test are listed below in Table 1.

Hypothesis $H_0: Q > Q_a$	H_0 is TRUE	H_0 is FALSE
Test Conclusions		
Do not reject H_0 (Do not certify TDB)	Correct	Type II Error
Reject H_0 (Certify the TDB)	Type I Error	Correct

Table 1 Hypothesis Test Outcomes

As Table 1 shows, the test yields correct results either if H_0 is true and the test rejects the database or if H_0 is false and the test certifies the database. Type I error occurs if the test certifies an unacceptable database. This is known as the consumers risk, which occurs with a probability β . Alternately, Type II error occurs when a good database is rejected by the test. This second type of error is known as the producers risk, and occurs with a probability α .

To apply acceptance sampling for TDB accuracy certification β and Q_L are chosen, where Q_L is a low accuracy proportion that will be rejected with a probability $(1 - \beta)$. Note that $Q_L = Q$ in Table 1. After determining an appropriate sample size N , find the largest value X such that

$$\beta \geq \sum_{Y=0}^X \frac{N!}{Y!(N-Y)!} Q_L^{N-Y} (1-Q_L)^Y \quad (2)$$

For a given N and β , the resulting value of X is known as the critical value. By ordering our elevation difference samples Δz in decreasing order, and counting down to the Xth sample, we determine our maximum error criterion $\Delta z(X)$ for which we may make the statement that the trial TDB agrees with the source TDB to within an error of $\Delta z(X)$ with an accuracy proportion of Q_L and a confidence of $(1-\beta)$. For example, choosing $N=2000$, $Q_L=0.95$ and $\beta=0.05$, we find that $X=83$. In this case we will count down to the 83rd largest error $\Delta z(83)$. If we find that, say, $\Delta z(83)=0.5$ meters, then we may say with 95% confidence that 95% of the trial TDB agrees with the source TDB to within 0.5 meters.

Once the critical value X has been determined, the producers risk α can be determined for various high accuracy proportions Q_H from the relationship

$$\alpha = \sum_{Y=X+1}^N \frac{N!}{Y!(N-Y)!} Q_H^{N-Y} (1-Q_H)^Y \quad (3)$$

Terrain skin elevation tests conducted by IST at the 1993 I/ITSEC utilized a sample size of 2000. To maintain continuity with last years test, participants in the 1994 I/ITSEC demonstrations were also asked to supply a sample of $N=2000$ elevations points from their run-time databases. Using Eqn. 2, the critical values associated with sample sizes ranging from 1897 to 2093 were calculated for a nominal $\beta=0.05$ and a low accuracy proportion $Q_L=0.95$, and are shown in Table 2, below.

Sample Size	Critical Value	Consumers Risk β
N	X	
1897	79	0.0500
1919	80	0.0498
1941	81	0.0498
1963	82	0.0496
1984	83	0.0500
2006	84	0.0499
2028	85	0.0497
2050	86	0.0497
2071	87	0.0500
2093	88	0.0499

Table 2. Optimum sample sizes N for given critical values of X and a nominal $\beta=0.05$, with the low accuracy proportion Q_L set to $Q_L=0.95$

Using Eqn. 3 and the sample sizes and critical values shown in Table 2, we may then calculate our producers risk, α , for some relevant values of Q_H , as shown in Table 3.

Sample Size	Critical Value	α for $Q_H = 0.925$	α for $Q_H = 0.950$	α for $Q_H = 0.975$
N	X			
1897	79	1.0000	0.9500	0.0000
1919	80	1.0000	0.9502	0.0000
1941	81	1.0000	0.9502	0.0000
1963	82	1.0000	0.9504	0.0000
1984	83	1.0000	0.9500	0.0000
2006	84	1.0000	0.9501	0.0000
2028	85	1.0000	0.9503	0.0000
2050	86	1.0000	0.9503	0.0000
2071	87	1.0000	0.9500	0.0000
2093	88	1.0000	0.9501	0.0000

Table 3. Values of the producers risk α for various high accuracy proportions Q_H , for the values of β and Q_L used in Table 2.

We note in Table 3 that for these relatively large samples the range of significant producers risk about $Q_L=Q_H$ is very small. In the above table we see that for $Q_H = 0.925 < Q_L=0.950$ we have $\alpha=1.0000$, which indicates the near certainty that a TDB with accuracy proportion of 92.5% will be rejected. On the other side, we see that for $Q_H=0.975 > Q_L = 0.950$, we get $\alpha = 0.0000$, which tells us that there is virtually no chance of rejecting a TDB with an accuracy proportion of 97.5%. Finally, we note that when $Q_H=Q_L$, we have the case where $\alpha=1-\beta$.

Since the binomial distribution is discrete, there exists several values of N for each critical value X. Based on our test procedure of the previous year, we have chosen our sample size as $N=2000$, which falls between $N=1984$ and $N=2006$ in Table 2. Our critical value is therefore 83. The results of our application of the acceptance sampling theory to samples obtained from participants in the 1993 I/ITSEC will be detailed in a later section.

At the Interservice and Industry Training, Simulation, and Education Conferences (I/ITSEC)

As a part of the preparation for the 1993 I/ITSEC DIS demonstration, IST generated and distributed 2000 uniform random sample points within a geographic area of Fort Hunter Liggett, CA. This area was designated the "high detail area" because it was the only area in the data base where ground interaction was allowed. The high detail area was 10km X 30km. The latitude and longitude of the sample points were chosen at random using a bivariate uniform random distribution. Sampling of the 1992 Hunter-Liggett high detailed area was done on a grid with a minimal spacing of one arc second between samples. These points were chosen within boundaries that are one arc second toward the inside of the boundaries to avoid the effects of feathering at

the boundaries. As a result of the post 1992 I/ITSEC TDB testing, a discussion on an acceptable TDB metrics followed at the 1993 I/ITSEC planning meetings. It was requested by I/ITSEC planning meeting members that the resolution of the grid from which the random points were chosen have a spacing of 0.01 arc seconds, which results in sampling with a minimum possible spacing of 0.3 meter (approximately one foot).

I/ITSEC 92

As a result of the data gathered from the I/ITSEC '92 demonstration, development of an analysis tool that allows a database engineer to locate regions of spatial error while building a database was indicated. If the differences in elevations between two databases are recursively examined and adjusted while building a database then the error in elevation can be minimized (see Fig. 1).

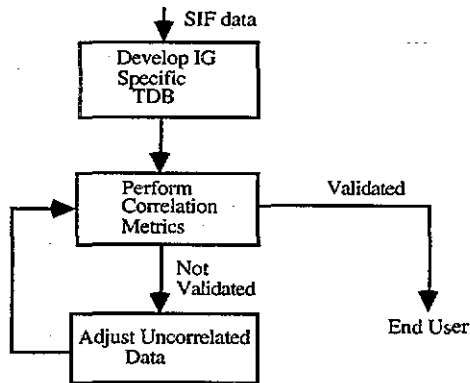


Fig. 1. Reducing Error in TDBs

The area of interest for the terrain correlation study was the high detailed inset area of the Hunter-Liggett database agreed upon for I/ITSEC 92. The area consisted of a patch of land that was bounded by a 30km easting and a 10km northing.

Based upon initial recommendations from the I/ITSEC 93 planning meeting attendees, a maximum desirable variance between a subject database and PRC's database was 0.5 meters. 1992 I/ITSEC data was analyzed to determine the suitability of 0.5m. However, after reviewing the data it became evident that a 0.5 meter error threshold would not allow anyone to participate according to the hypothesis test requirements set for 95% confidence and 95% probability for success. A filtering mechanism was used to find the number and location of the coordinates that exceeded this half-meter threshold. As seen in Table 4 very few of the participants met the 95 percent success rate at 1.25 meters.

The wide variation in 1992 data drove IST to recommend using the mean and standard deviation as criteria for 1993. We did not know at the time that in 1992 participants used gridded data as source material, when polygonal data would have been more appropriate. The polygonized SIF data was used as the standard database for I/ITSEC in 1993. Statistical analysis on the discrepancies between the subject and datum (PRC P-2851) databases showed a mean and standard deviation of the errors, as shown in Table 5.

Company	0.5m	0.75m	1.0m	1.25m
A	1719	1546	1380	1265
B	1012	641	473	340
C	1878	1815	1743	1688
D	811	422	0	0

Table 4 Failure Rate at Various Threshold Levels I/ITSEC '92 Results

Company	Mean (m)	Standard Deviation (m)
A	.456	.286
B	.451	.961
C	.632	5.67
D	1.322	14.01

Table 5 Statistics for I/ITSEC '92 Databases

The data that was returned by participating organizations in the 1992 I/ITSEC revealed that the largest errors were found in geographical regions with a large variance of elevation (mountainous regions). The scatter plot of one participant indicating the points filtered from the 2000 random points that exceeded the tolerance level, defining an error, is plotted in Fig. 3. This figure represents the tolerance threshold being set at 10m. Results from other organizations reflected similar error responses.

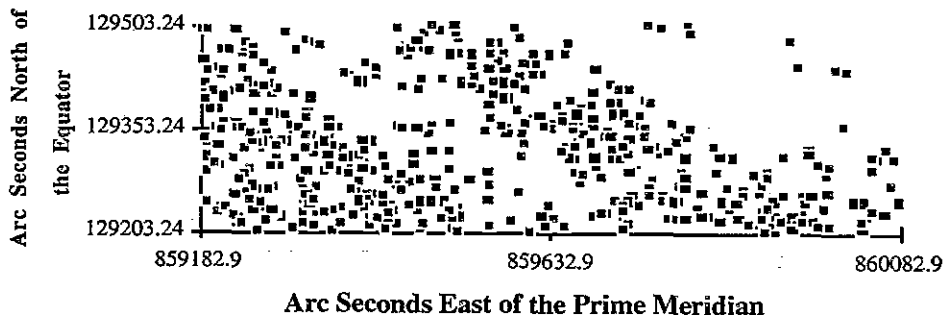


Fig. 3. Tolerance = 10m

I/TSEC 93

Again, the area of interest for the terrain correlation study for I/TSEC 93 was the high detailed inset area of the Hunter-Liggett (HL) database agreed upon for I/TSEC 92. However the boundaries of the database changed from the previous year. The new boundaries were shifted north by 2km from I/TSEC 92. Again, the area consisted of a patch of land that was bounded by a 30km easting and a 10km northing. The area for I/TSEC 93 correlation study can be seen on a UTM map projection in Fig. 4. The distribution of the points for I/TSEC 93 was uniform just as the sample

points in 1992. In Fig. 5 notice that the range of values for elevation differences has been reduced drastically from the data collected from I/TSEC 92, as seen in Tables (4)(5)(6). Thus, most '93 databases contained mean elevation errors on the order of a few centimeters, and errors located in the mountainous regions were greatly reduced as compared to the previous year. After reviewing the results one can note that the sample distributions for I/TSEC 93 participants indicates that the TDBs were built with more precision than in the previous year. Fig. 5 shows the distribution of the elevation differences between the original SIF 3D

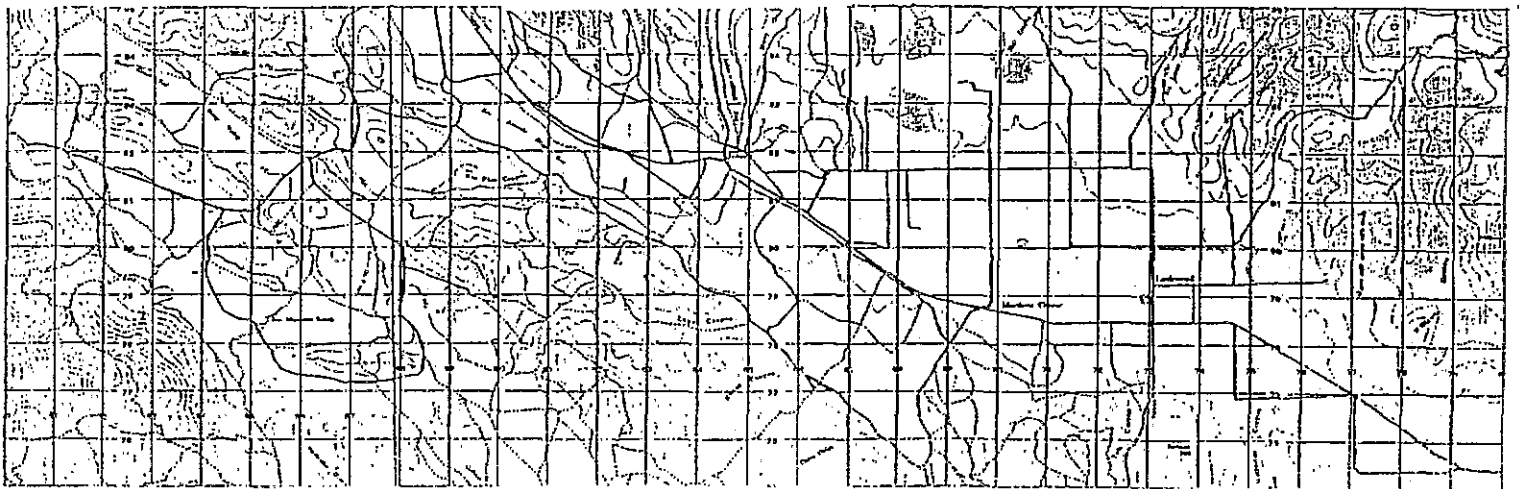


Fig. 4. Hunter-Liggett UTM Map

are within some tolerance (in meters) of the source terrain database. For each database the tolerance level will be different. For example, the critical value for company I was 0.162333m and the critical value for company D was 0.000163m. This means that the accuracy proportion for company I is much smaller than that of company D at any given elevation difference, while assuming a 95% level of confidence. Another interesting result of this experiment shows that although a TDB might have a negligible mean elevation

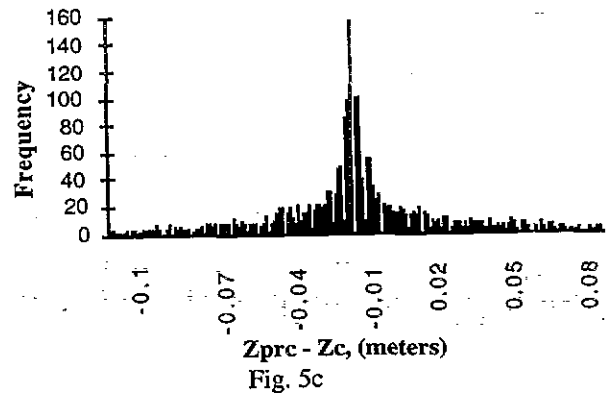
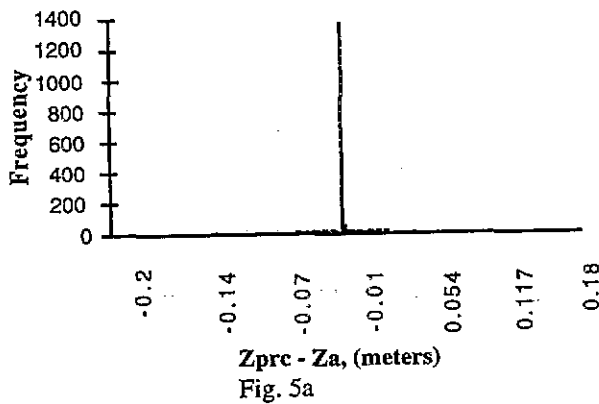
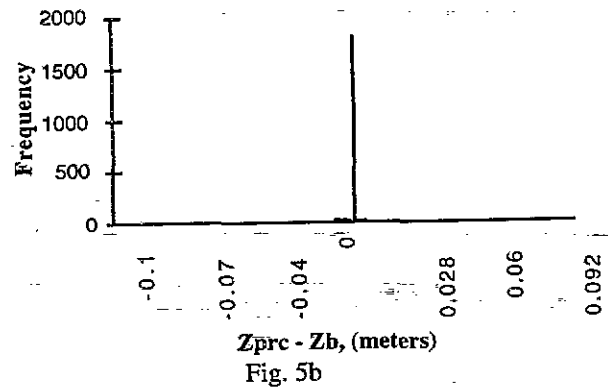
polygonal terrain database and the subject terrain databases. Table 6 shows the mean elevation differences, elevation difference standard deviations and the critical values. The critical value represents the 83rd largest value after finding the descending rank order of the magnitude of the elevation differences. Referring back to our previous discussion on acceptance sampling (see Table 3), the 83rd value represents the maximum number of errors allowed in a sample size of 2000 for 95% confidence that 95% of the sample points

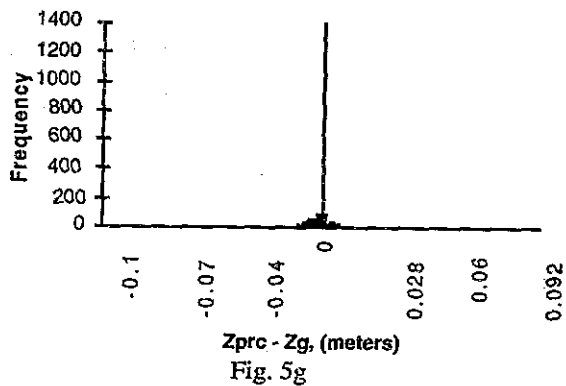
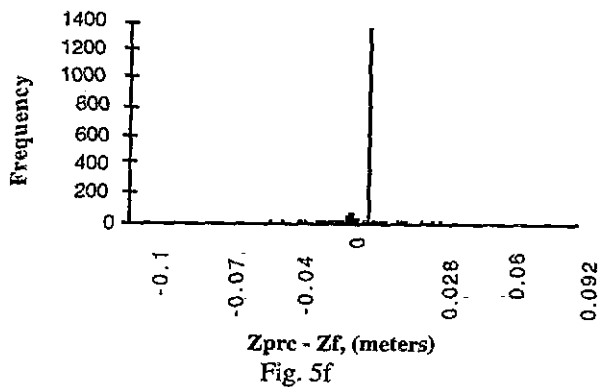
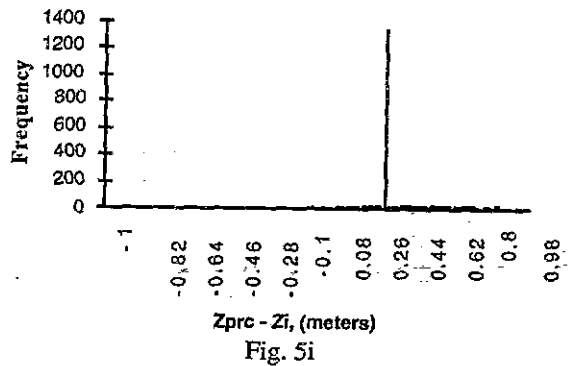
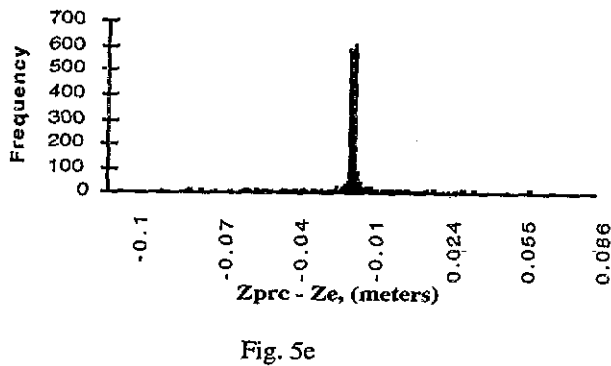
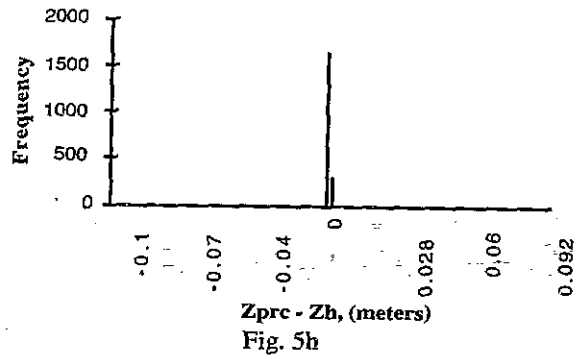
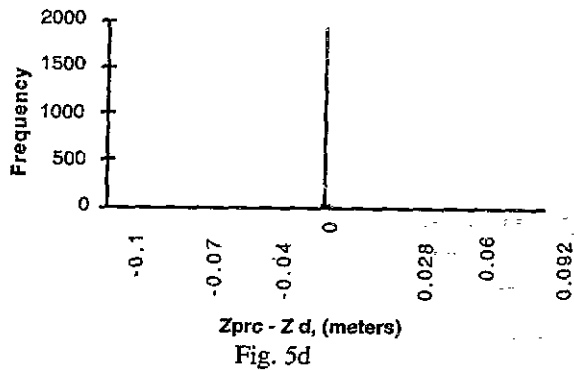
difference the critical value could remain relatively large. For example, let's consider the results for company F. The mean elevation difference for company F was 0.000097m, where as the corresponding critical value was 0.029338m. Notice that the standard deviation of the elevation differences for company F is relatively large also. This indicates that there are outliers present in the elevation difference distribution.. This is shown in Fig. 5f and Table 6. In one respect, the histograms in Fig. 5 show a high correlated database with a negligible elevation shift. However, the corresponding data in Table 6 indicates that the mean elevation difference for company B was -0.019578, while the histogram in Fig. 5b appears to be shifted to

the right of zero. This is caused by outliers that are present but are not within the range of the graph, which probably are indicative of anomalies in the TDB construction such as sliver polygons. Let's now compare elevation difference distributions for companies C and I. Companies C and I have relatively close statistical values (as seen in Table 6), however, the histograms in Fig. 5 show that the error in the company C database is less central than that of company I. Company I could shift the elevation of their entire database by their average Δz to correct the error between their database and the source database. However, since company C's elevation differences are not as central, the correction procedure is not as simple.

Company	Mean Delta-Z (meters)	Std Deviation (meters)	Critical Value (meters)
A	-0.00079	0.029533	0.011836
B	-0.019578	1.382213	0.069666
C	0.022796	0.603328	0.015828
D	-0.000002	0.000212	0.000163
E	-0.000065	0.015944	0.007024
F	0.000097	0.073186	0.029338
G	0.000000	0.004332	0.001501
H	-0.000090	0.009548	0.005330
I	0.487752	0.361715	0.162333

Table 6. Statistics for LITSEC 93 Databases





CROSS-CORRELATION TESTING

As opposed to the probabilistic statements as to the TDB spatial error made possible by acceptance sampling theory, a diagnostic metric should not only provide a measure of spatial error but should also extract information as to the type of error. Discrepancies specifically mentioned by Kilby [18] are shifts, skews, warping and resampling. Economy [3] observes a linear shift due to a suspect coordinate transformation. The ability to detect, say, the magnitude and direction of a simple linear shift in coordinates may allow one to easily determine the source of the error.

Our initial approach in developing run-time CIG-specific database correlation diagnostics is to consider the full cross-correlation on the gridded elevation data. A requirement of this approach is that a symmetric and uniform grid of elevation values must be extracted from the run-time database. Given G, a K x L set of baseline data, and H, an M x N set of trial data (with M < K and N < L), the normalized correlation of lag (k, l) between G and H is

$$R_{k, \ell}(g, h) = \frac{\sum_{i=1}^N \sum_{j=1}^M (g_{i+k, j+\ell} - \bar{g})(h_{i, j} - \bar{h})}{\sqrt{\left(\sum_{i=1}^N \sum_{j=1}^M (g_{i+k, j+\ell} - \bar{g})^2 \right) \left(\sum_{i=1}^N \sum_{j=1}^M (h_{i, j} - \bar{h})^2 \right)}} \quad (4)$$

R will range between -1 and 1, with $R=1$ describing perfect correlation, $R=0$ describing a complete lack of correlation, and $R=-1$ describing perfect anticorrelation. The initial approach is to compute R for every possible lag (k,l) . The method could possibly be refined by investigating methods of determining the path that leads to the global maximum, without having to compute every possible lag. This form of the correlation will be most useful in determining linear shifts in the xy-plane. Other forms can be developed to measure other types of discrepancies. We expect this method to succeed for any reasonable data sets, although certain special cases can be constructed where, in the absence of special provisions, the method would fail, such as cases where in the windowed region the terrain elevations are doubly periodic or periodic in one dimension and constant in another.

An example of the utility of the cross-correlation metric comes from a preliminary test conducted at IST. Fig. 6a shows a portion of the terrain skin from the 1993 IITSEC high-detail source database, slightly upsampled at every 100 meters. The terrain extends 6.4 kilometers north and east from the southwest corner of the Hunter-Liggett highly detailed area. In the test, the data used as the baseline data was the first 60 by 60 samples, while the trial data used was also a 60 by 60 sample of the terrain skin, but shifted by 400 meters (4 samples) both to the north and to the east. The cross-correlation of these two data sets is shown in Fig. 6b. The maximum value, as given by Eqn. 4, is found as $R_{5,5} = 1.0$. Thus, the correlation returns the exact linear shift for this case involving a shift by an integer number of sample intervals.

Fig. 6 a) Southwest corner of Hunter-Liggett high-detail area. b) Cross-correlation of two different sample sets from Fig. 6a, with the second set shifted both to the north and east by 400 meters.

Elevations (meters)

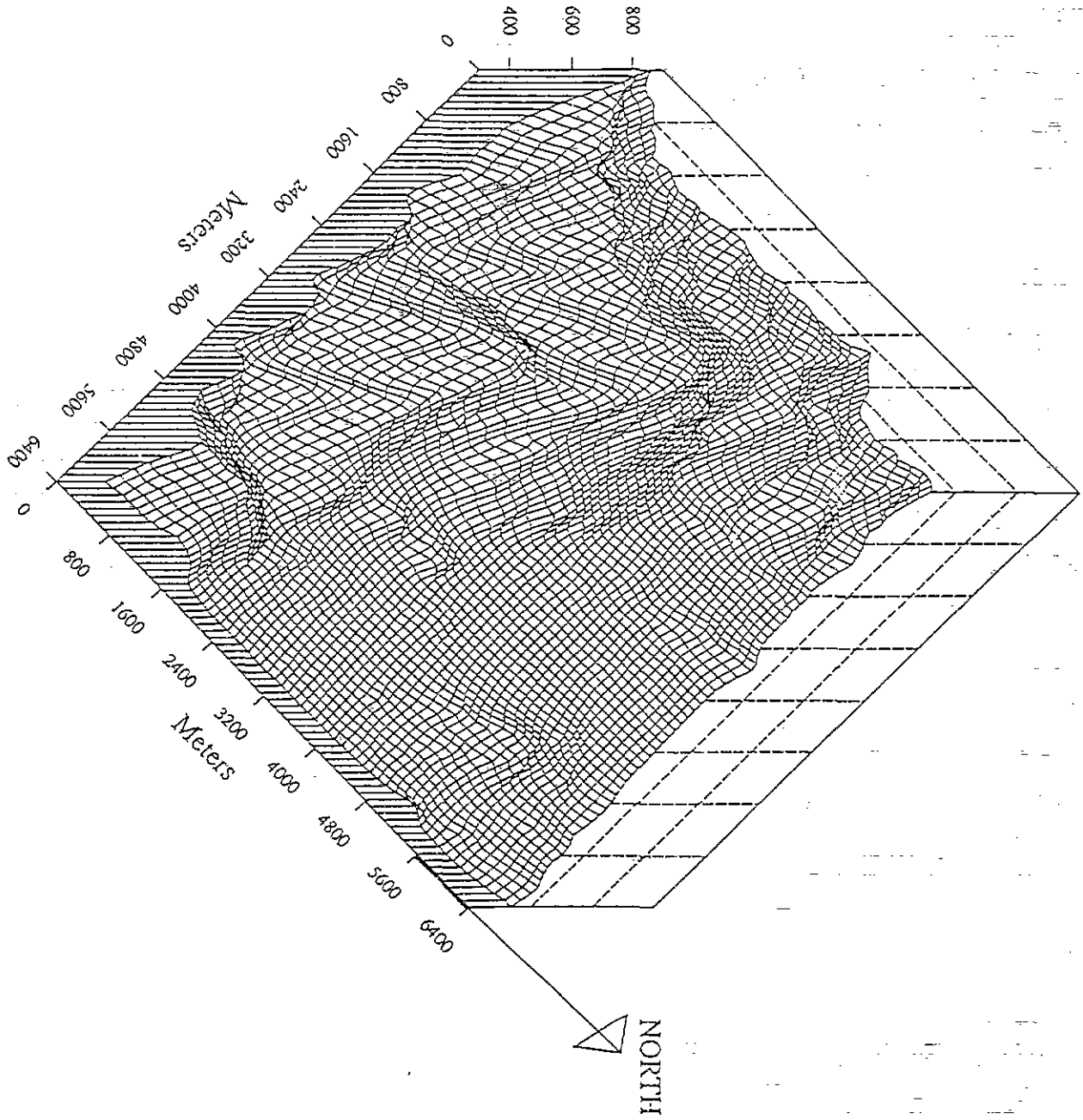


Figure 6a

Correlation

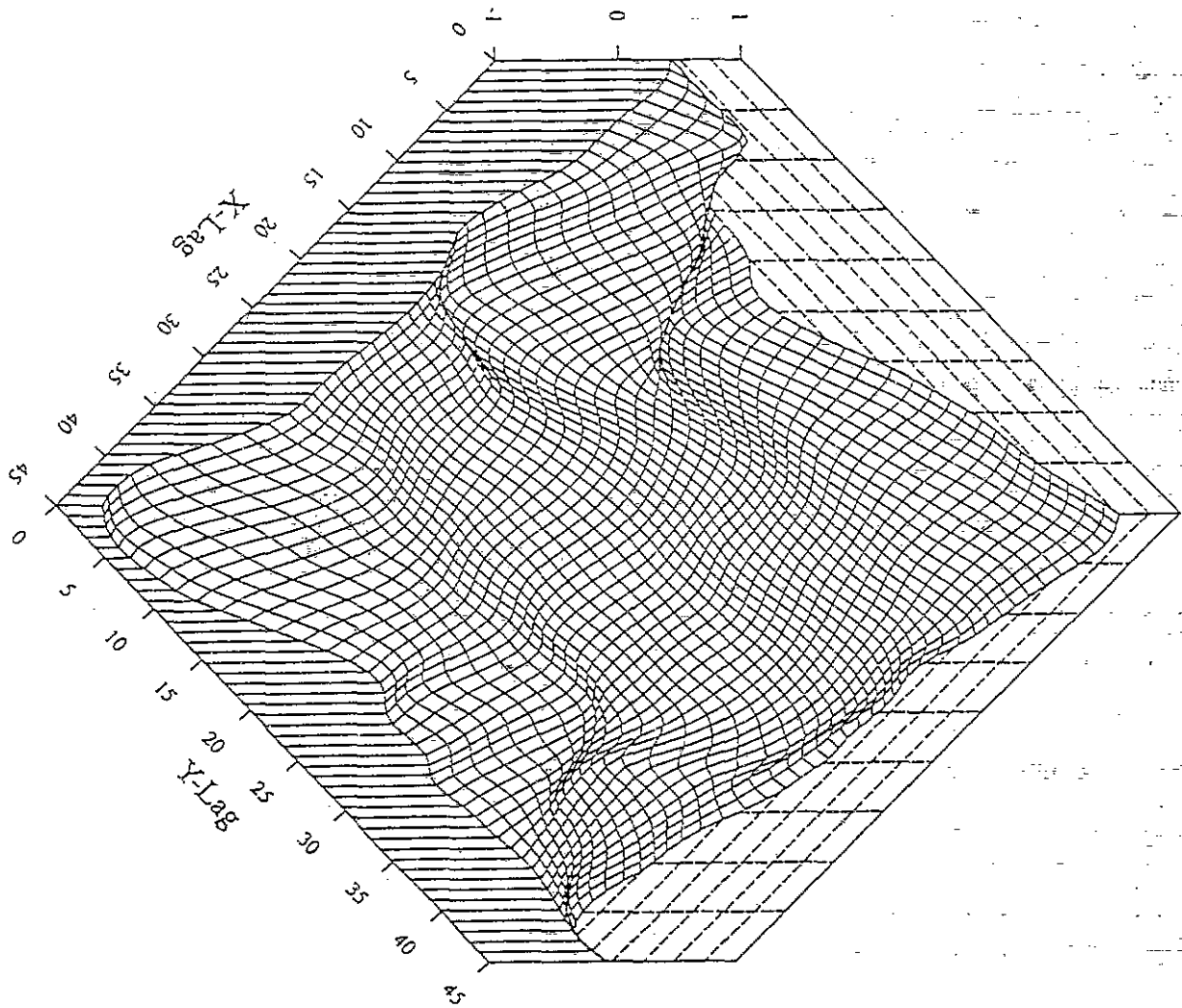


Figure 6b

REFERENCES

- [1] Standard for Distributed Interactive Simulation -- Applications Protocols, Version 2.0, Fourth Draft, Institute for Simulation and Training Document IST-CR-93-40, February, 1994.
- [2] Pamela S. Woodard, "Requirements for Interoperable Environments", Proceeding of the IMAGE VII Conference, pp. 258-271, Tucson, Arizona, 12-17 June 1994.
- [3] Brian Goldiez and Russell S. Nelson, "Terrain Database Correlation", presented at ITEC in The Hague, Netherlands, April 1994.
- [4] Dr. Richard Economy, Robert Ferguson, and Dr. Eytan Pollak, "Geographic Position Accuracy in a Distributed Simulation Environment", Proceeding of the IMAGE VII Conference, pp. 258-271, Tucson, Arizona, 12-17 June 1994.
- [5] Brian Goldiez, Simulator Networking Handbook, Institute for Simulation and Training Doc. IST-TR-93-08, Univ. Central Florida, March, 1993.
- [6] James D. Basinger and Stephen D. Ingle, "Database Requirements for Full Mission Simulation", Proceedings of the 1977 Image Conference, pp. 24-33, May, 1977.
- [7] Thomas W. Hoog, "Correlated Data Bases for the Present and Future", AIAA Flight Simulation Technologies Conference, pp. 73-78, Arlington, Texas, Sept. 18-20, 1978.
- [8] Barbara Townsend, Beth Stovall, and Cheryl Colbert, "Correlation of Sensor Data Bases in the Full-Mission Training Simulator", 7th IITSEC Proceedings, pp. 84-90, Orlando, FL, November 19-21, 1985.
- [9] Maureen Hrabar, John Joosten, and Patricia A. Widder, "Data Base Conversion/Correlation Issues", 11th IITSEC Proceedings, pp. 343-348, November 13-16, 1989.
- [10] Dale H. Fawcett, "Sensor Data Base Correlation", 13th IITSEC Proceedings, pp.106-112, Orlando, FL, December 2-5, 1991.
- [11] Karl A. Spuhl and David A. Findley, "Correlation Considerations in the Simulation Environment", Proceeding of the 1994 IMAGE VII Conference, pp. 300-306, Tucson, Arizona, June 12-17, 1994.
- [12] Steven R. Schwalm, "Correlation of Environmental Databases for Networked Simulators", Second Conference on Standards for the Interoperability of Defense Simulations, Vol. III, Institute for Simulation and Training Document IST-CF-90-01, University of Central Florida, January, 1990.
- [13] Budimir Zvolanek and Douglas E. Dillard, "Database Correlation Testing for Simulation Environments", 14th IITSEC Proceedings, pp.867-875, Orlando, FL, November 2-4, 1992.
- [14] Budimir Zvolanek and Douglas E. Dillard, "Quantitative Correlation Testing from DOD Project 2851 Standard Simulator Data Bases", 15th IITSEC Proceedings, pp.829-836, Orlando, FL, November 2-4, 1993.
- [15] Richard Dunn-Roberts, Curtis Lisle and Bruce McDonald, "Recommended Approach for Standardizing DIS Terrain Data Bases", Summary Report of the Sixth Workshop on Standards for the Interoperability of Defense Simulations, Vol. II, Institute for Simulation and Training Document IST-CR-92-2, University of Central Florida, March, 1992.
- [16] Louis A. Fatale, James R. Ackeret and Jeffrey A. Messmore, "Digital Terrain Elevation Data (DTED) Resolution and Requirements Study: Phase 2 Report", U.S. Army Topographic Engineering Center Technical Report TEC-0035, July, 1993.
- [17] John Ellis, "Terrain Modeling Error Measurement", Summary Report of the Sixth Workshop on Standards for the Interoperability of Defense Simulations, Vol. II, Institute for Simulation and Training Document IST-CR-92-2, University of Central Florida, March, 1992.
- [18] Mark Kilby, Glenn Martin, Larry Crochet, Chen Jinxiong, and Tinahui Fu, "Correlation Studies for Loral ADST", IST Technical Report 93-17, June 15, 1993.
- [19] Michael E. Ginevan, "Testing Land-Use Map Accuracy: Another Look", Photogramm. Engr. Rem. Sens., Vol. 45, No. 10, pp. 1371-1377, Oct., 1979.