

DATABASE CORRELATION TESTING FOR SIMULATION ENVIRONMENTS

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INTRODUCTION

Advances in state-of-the-art image generation technology for sensor and visual simulation over the past decade have focused on improvements in providing realism, or fidelity, of simulated imagery at real-time rates of the simulated sensors. At the same time, advances in advanced cockpit technology have created a need to simultaneously simulate multiple sensors, both imaging (infrared, radar, and moving map) and non-imaging (e.g., radar altimetry and line-of-sight ranging), in conjunction with Out-The-Window (OTW) visual imagery.

The need for simultaneous sensor and visual simulations requires that the simulations be "correlated", or correspond without conflict, among each other in various ways. The problem is that while "correlation" has been used in signal processing, image processing, and communication theory to detect signals in noise and match patterns, the term "correlation" has been used extensively in the simulation and training industry without accurately defining its meaning, specification, and method of measurement.

An excellent example of a radar-to-visual correlation problem, presented by Spuhl¹, demonstrates the result of requiring absolute correlation in terrain elevation while simulating a radar image from terrain elevations derived from a polygonal visual image generator database. By requiring identical terrain elevations for the radar and visual simulations, the radar image, full of triangular shadows and flat surfaces due to visual image generator surface triangularization, is not an accurate rendering of the real world and yet accurately correlates with the visual imagery.

This paper surveys and analyzes correlation references from existing McDonnell Douglas Training Systems (MDTS) and government simulation specifications

and defines correlation for sensor and visual simulations. It suggests several definitions of correlation, describes man-in-the-loop and automated correlation testing processes, and proposes correlation metrics. Finally, the paper presents conclusions and suggestions for future efforts in improving correlation definition, specification, and measurement.

CORRELATION SPECIFICATION SURVEY

The following paragraphs critically survey existing correlation definitions and specifications. The survey is based on correlation work external to MDTS^{2-4,12,13} and MDTS training, mission rehearsal, and simulation applications⁵⁻¹¹.

Townsend et al² describe radar-to-infrared correlation as the ability of the simulator pilot to recognize significant objects in both sensor displays at the same latitude, longitude, and elevation while observing detailed object characteristics and establishing object correspondence in both displays. Hrabar et al³ point out the need for a better definition of correlation and suggest that it may require specifying polygon size and shape correspondence, cultural feature correspondence, and locations of mission-critical terrain features. Oda⁴ describes the correlation issues involved in generating databases for a large variety of image generators and mission applications.

Correlation definitions for the A-6E S/WIP and A-6F aircraft Weapons Systems Trainers (WSTs)^{5,6} call for observable display of specific objects at the same geographical locations in visual and sensor imagery. All displays need to indicate the same range from ownship and image the object of interest at the same aspect (orientation). Moving object position and velocity need to correspond in all displays. Defense Mapping Agency Data and other real world data is used as ground truth for correlation of specific regions. Correlation among simulated non-imaging flight instrument outputs (radar altimeter,

terrain clearance, radar warning receiver masking) and imaging displays (optical sight, Forward Looking Infrared, OTW visual) is expressed using the general term "coordination".

A definition of "correlation" in the context of mission rehearsal for A-12 WST development⁷ implied a requirement for being able to detect and discern the geospecific location of ground objects from imagery simulated by a multiple-sensor suite. The measurements of object locations from sensor images simulated by multiple image generators need to correspond to each other and to the real world. Furthermore, the definition called for correlation between on-board sensor displays and the visual display. "Signature management training . . . with no discernible disparities between realism and simulation" indicated a requirement for high-accuracy sensor image (or signature, if non-imaging sensor output) rendering of the real world, i.e., high fidelity.

The A-12 WST Image Database Development System Procurement Specification⁸ defined correlation by specifying feature visibility in all sensor and visual displays. But this document specified neither the quality of feature rendering sufficient for correlation nor the type of information unique for targeting and navigation. Although the specification⁹ made clear the significance of cues from sensor and OTW visual displays, listing the types of cues would have improved the specification. The correlation in location (latitude, longitude, altitude) was again specified as was size and orientation.

The correlation of visual and radar displays for the F-14A WST¹⁰ defines correlation again by the location and range of objects in radar and visual images relative to the ownship. In addition, aspect angle (rotation in the ground plane) of objects with respect to a standard direction (e.g., magnetic North) of objects in radar and visual imagery must be the same. Furthermore, the degree of correlation is specified by the geometric accuracy and resolution ("image sharpness") limits of the visual (not radar) system.

In the F/A-18 C/D Training System Specification¹¹, the correlation specification is identical to the one for the A-6E S/WIP⁵.

The DoD Project 2851 Standard Simulator Data Base (SSDB) handbook on the Generic Transformed Data Base¹² explicitly defines correlation as

"the correspondence and synchronization of multiple simulator sensor displays (e.g., visual and radar) over the gaming area. At a minimum, correlation implies the absence of conflicting information across multiple displays."

Lacking are accurate specifications of "correspondence" (note: the American Heritage Dictionary¹⁴ lists "correspondence" as one of several definitions for "correlation") and "synchronization" (in space and time, respectively?). A related definition of "Correlated Data Bases" is also given¹² as

"multiple simulator data bases which, by their structure and content, support an acceptable degree of correlation among multiple simulator displays."

Notable in both definitions above is the reference to "displays" as possibly the ultimate media for observing correlation characteristics. The problem is to define the "degree of correlation". A related definition refers specifically to "radar correlation"¹³ as the

"process of electronically relating real-time radar images with stored digital data on the position and radar reflectance of terrain and features, used for navigation and guidance."

CORRELATION DEFINITION: BACKGROUND

While the referenced correlation specifications are different, they share several common features which form a basis for our correlation definitions. The definition of correlation from the American Heritage Dictionary¹⁴ is a starting point in our correlation definitions for simulation environments:

"A structural, functional, or qualitative correspondence between two comparable entities."

In simulation environments, such correspondence, or matching, can exist among sensor and visual databases as well as among the displays simulated from them. The degree of match can be used to define and compute the degree of correlation. While not defining correlation in measurable terms, Oda⁴ stresses the importance of a degree of correlation rather than a binary "correlated-or-not" decision about simulation results. The problem is how to specify and measure such a degree of matching.

Typical simulator requirements need to specify and measure correlation of digital map, real-beam radar, Synthetic Aperture Radar (SAR), visual, infrared, and inverse SAR imaging sensor simulations, as well as radar altimetry and other range-finding, non-imaging terrain measurements. To accomplish this, correlation definition and measurement methods are needed for simulation users, simulator databases, and simulated displays. To date, most testing of simulation correlation has involved end-users.

CORRELATION DEFINITION: INTERACTIVE TESTING

Sensor and visual simulation applications may require different sensor and visual simulation characteristics to achieve the desired training effects or mission rehearsal realism. Based on the requirements common to the applications just surveyed⁵⁻¹³, there are two ways to define user-specified, interactive operational correlation between aircraft sensor simulations A and B.

The first can be stated in terms of what the user simply observes on multiple displays. This type of correlation is inherently visual, non-quantitative, and subjective. Content and Environmental Correlations are examples of this type of correlation:

Content Correlation - Sensor/visual A and B simulations are content-correlated if user-significant objects are observable in both A and B simulations, to the extent achieved in the actual aircraft.

Environmental Correlation - Sensor/visual A and B simulations are environmentally correlated if weather effects (visibility, fog, clouds, and haze) do not conflict in the A and B simulations.

These types of correlation definitions require the user to identify "user-significant" objects in the simulated subsystems. The "user-significant" objects include terrain features, cultural features, targets, navigation checkpoints, and threats. When objects are stationary with respect to the ground, not all of them need to be observed, only the "significant" ones. Furthermore, because of the human visual system's sensitivity to motion and change, all moving objects are "user-significant", since these objects must match in dynamics.

Correlation can also be defined in terms of the degree of correspondence between imaging functions and non-imaging measurements. For example, correlation testing can measure the degree of correspondence, or differences, between values obtained from two simulated subsystems. Typical values are range and azimuth of a target or a navigation checkpoint, target size and orientation (aspect), and obstacle range, azimuth, and height. In practice, in this type of testing, the user first obtains differences between measurements from

two simulated subsystems and then classifies them as acceptable or non-acceptable, based on the resolutions of the actual aircraft subsystems, as is done for Location and Dynamics Correlations:

Location Correlation - Sensor/visual A and B simulations are location-correlated if the geographic longitude, latitude, and elevation of user-significant objects (e.g., terrain features, cultural features, targets, navigational checkpoints, threats) observed in simulation A match those in simulation B, to the extent achieved in the actual aircraft.

Dynamics Correlation - Sensor/visual A and B simulations are dynamically correlated if the position, speed, direction of travel, and rate of change of orientation of all moving objects (targets and non-targets) observed in simulation A match those in simulation B, to the extent achieved in the actual aircraft.

While quantitative, such interactive testing presents problems when it is performed over large gaming areas:

1. Testing the entire gaming area can be very time-consuming and costly.
2. Not testing the entire gaming area causes some significant objects and features to be skipped, and these may not correlate well in the final displays.
3. While saving time, testing by observation without measurements becomes qualitative and extremely subjective.
4. Even if testing involves gathering measurements, the results are in terms of acceptable or not-acceptable differences and do not provide any degree or range of correlation.

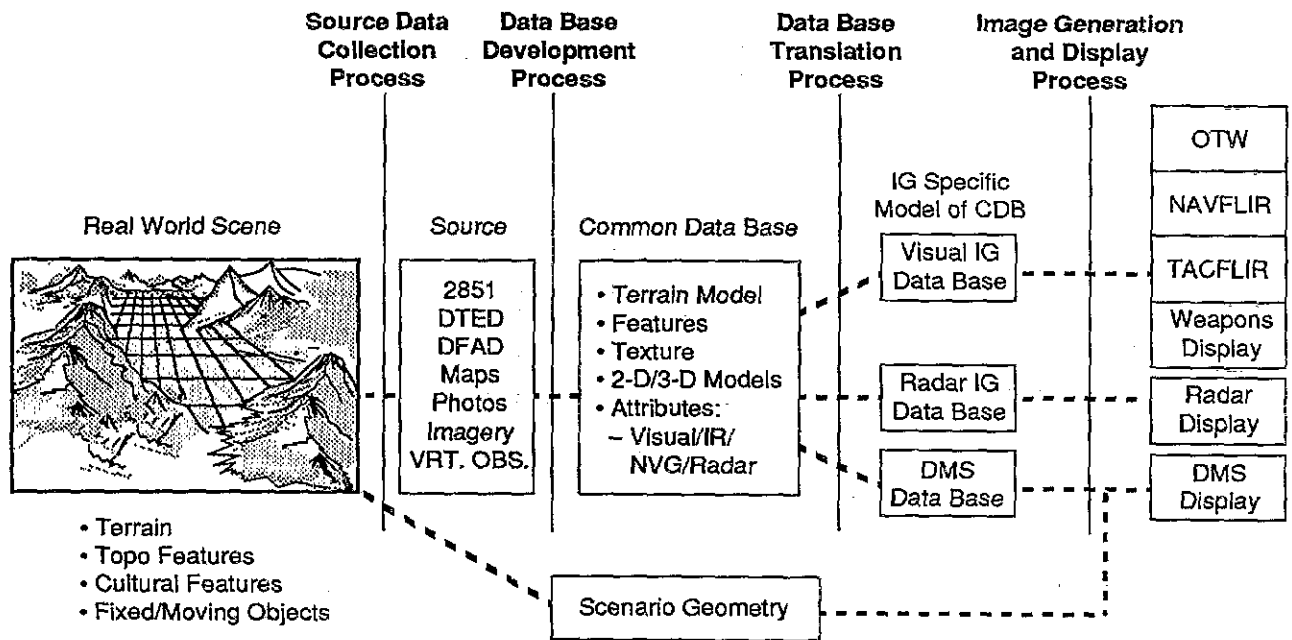
When user testing is done on an integrated simulation system, as is always the case, this testing detects correlation errors at a very late stage in the development of the system. At this stage, error correction can be very costly and may delay the delivery of the trainer. Although some amount of user testing must always be done, it should be introduced at earlier stages of the development and should be supplemented by faster, automated methods which will also ensure adequate

CORRELATION DEFINITION: AUTOMATED TESTING

Figure 1 illustrates the traditional Computer Image Generation (CIG) and sensor source-to-simulated-image transformation processes. 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 Image Generators or Sensor Simulations. Each run-time database is then processed by the CIG to produce an image or input to the users (students and/or instructors).

DATABASE CORRELATION

Sensor and visual databases provide the basis for 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 certain CIG requirements, such as surface polygonalization or object culling, affect database construction and generation, such "tailoring" effects will be measured via database-to-database correlation.



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Figure 1. Correlation Error Sources

Correlation can be defined and measured at several points in the transformation processes. Comparisons of the input data indicate the maximum possible correlation. Even if no processing step degrades object orientation, size, shape, or location, the correlation of the outputs can be no better than the correlation of the inputs. Objects and views presented on the displays, at the other end of the transformation chain, are the ultimate indicators of the correlation. The displays present all data-transformation and image-generator effects and artifacts, desired or not, to the user.

For databases, correlation refers to the degree of correspondence among data types and their contents needed by image generators. If we use the Project 2851 data types¹², correlation should be measured on digital terrain elevation data, cultural features and models, and texture. In addition, if required by the simulation, correlation of the data types with a digital (moving) map is needed to estimate the real-world rendering accuracy. Proposed database correlation definitions for each of the data types are:

Terrain Elevation Correlation - A statistical distribution of terrain elevation differences between two databases.

Cultural Correlation - A percentage of zero differences in cultural pixels between two databases.

Texture Correlation - A statistical distribution of differences between the boundaries of texture patterns from two databases.

Although comparing databases cannot provide insurance against errors introduced by subsequent processing and transformations, it is fairly easily implemented, and can detect errors at a very early stage in simulation database development, when the errors can be easily and inexpensively corrected.

DISPLAY CORRELATION

As indicated by the correlation survey⁵⁻¹³, the displays are the ultimate indicators of correlation actually attained, because they include all image generator effects and artifacts, wanted or not, to the user. For displays, both imaging and non-imaging, correlation can refer to the degree of correspondence among measurements observed from the displays, such as range and azimuth of a target or a navigation checkpoint, target size and orientation (aspect), obstacle range, azimuth, and height. Although a high degree of this type of correlation can exist and permit accurate navigation and targeting, the images on the displays may appear stylized and of low fidelity. As long as accurate measurements are derivable from the displays and correspond to each other, correlation can be said to exist.

Based on the Specifications Survey, display correlation may be defined as follows:

Location Correlation: Displays A and B are correlated when significant objects are observed at the same range, azimuth, and altitude and of the same size and orientation (aspect) in both displays.

Dynamic Correlation: Displays A and B are dynamically correlated when moving objects are observed traveling at the same instantaneous speed and direction and the terrain background is observed moving in the same direction with respect to the ownship.

G-Cueing Correlation: A display is G-cueing-correlated when its intensity dims in response to the simulated acceleration forces of the ownship.

One caveat which applies to end-user testing also applies to display testing: it detects errors at a very late

stage in the development process, where error correction is very costly, and where error correction may delay the delivery of the trainer.

Automatic measurement of display correlation is difficult since the automation must replace the user, who currently observes the displays in coordination with the ownship simulation. An automatic comparison of two displayed images which will replace the user will require the grabbing (freezing) of selected image frames, followed by a complex multi-step image analysis to:

- 1) Detect, classify, and identify significant objects;
- 2) Compare the appearances (shape, size, and orientation) of the significant objects; and
- 3) Compare the locations of the significant objects by transforming the image locations into range/azimuth/elevation coordinates with respect to the ownship.

This analysis must also automatically take into account sensor-peculiar artifacts, intrinsic sensor resolution, display format, and sensing geometry based on the complete simulation scenario. The cost of automating this type of analysis may be too great for it to be practical at this time.

CORRELATION TESTING ALGORITHMS AND METRICS

As noted previously¹⁴, the visual and sensor databases offer the basis for the maximum static correlation attainable by ideal CIGs and simulators. Using only the databases, we can compute a maximum correlation "potential", excluding CIG particular processing effects and simulated display distortions.

Terrain Elevation Correlation - A statistical distribution of terrain elevation differences may be obtained by subtracting composite elevations of database A from database B (Figure 2) where composite elevation is defined as a sum, as applicable, of cultural texture (stereo-derived or generic), 3-D model, and feature (areal, linear, and point) heights with base terrain elevations (e.g., Defense Mapping Agency Digital Terrain Elevation Data) projected onto a reference resolution element grid. The elevation correlation, N_{dep} , is defined as the frequency of occurrence of the most represented difference, dep , over the reference grid (Figure 3). For example, by this definition, two databases are 100 percent (perfectly) elevation-correlated at zero elevation difference if the elevations in both databases are exactly the same. On the other hand, two databases are

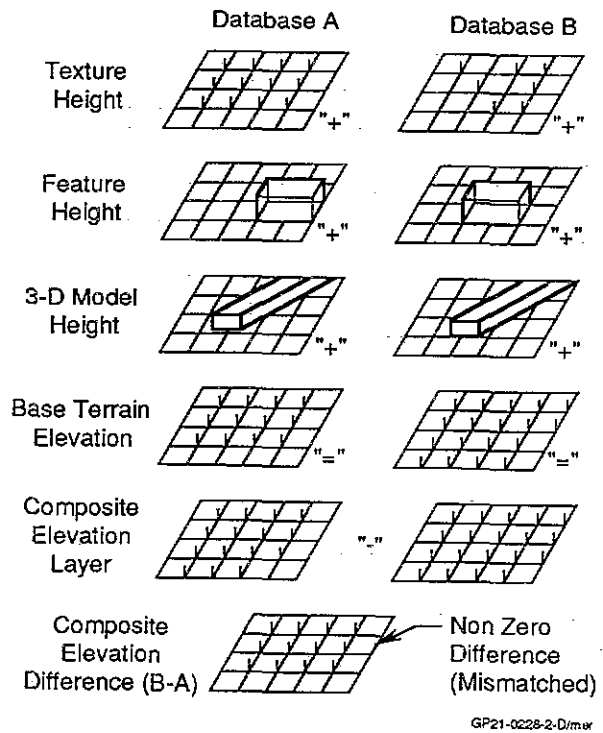


Figure 2. Elevation Correlation Layer Generation

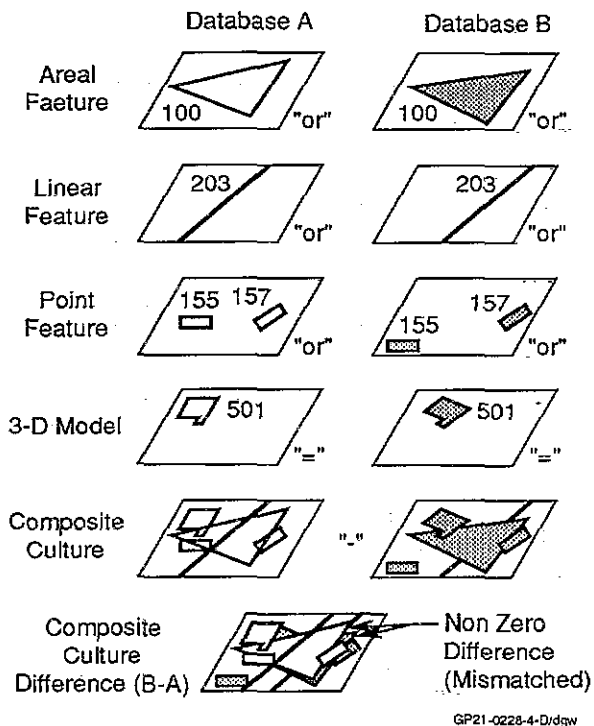
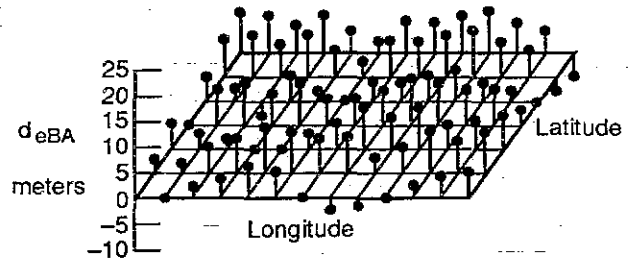
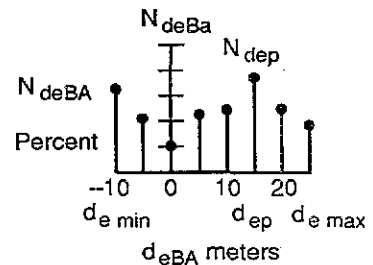


Figure 4. Cultural Correlation Layer Generation

Composite Elevation Difference Layer (d_{eBA} Meters)



Elevation Differences Histogram (N_{deBA} Percent)



Elevation Correlation = N_{dep} percent at d_{ep} meters

Note: Two data bases are perfectly correlated if $N_{dep} = 100\%$ at $d_{ep} = 0$.
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Figure 3. Elevation Correlation Definition From Elevation Differences Histogram

50-percent elevation-correlated at 5-meter difference when half of the elevations differences are less than or equal to 5 meters.

Cultural Correlation - Cultural differences may be computed by subtracting composite cultural identification (CID) code pixels of database A from database B (Figure 4). The correlation will then be the percentage of zero differences in cultural pixels between the two databases. The cultural pixels are determined by projecting areal, linear, and point features and 3-D models onto a reference resolution element grid. The cultural correlation, N_{dcp} , is defined as the frequency of occurrence of zero CID code differences over the reference grid. With this definition, two databases are 100 percent culture-correlated if the culture pixels resulting from both databases are exactly the same. On the other hand, two databases are 50 percent culture-correlated when half of all culture grid pixels are the same.

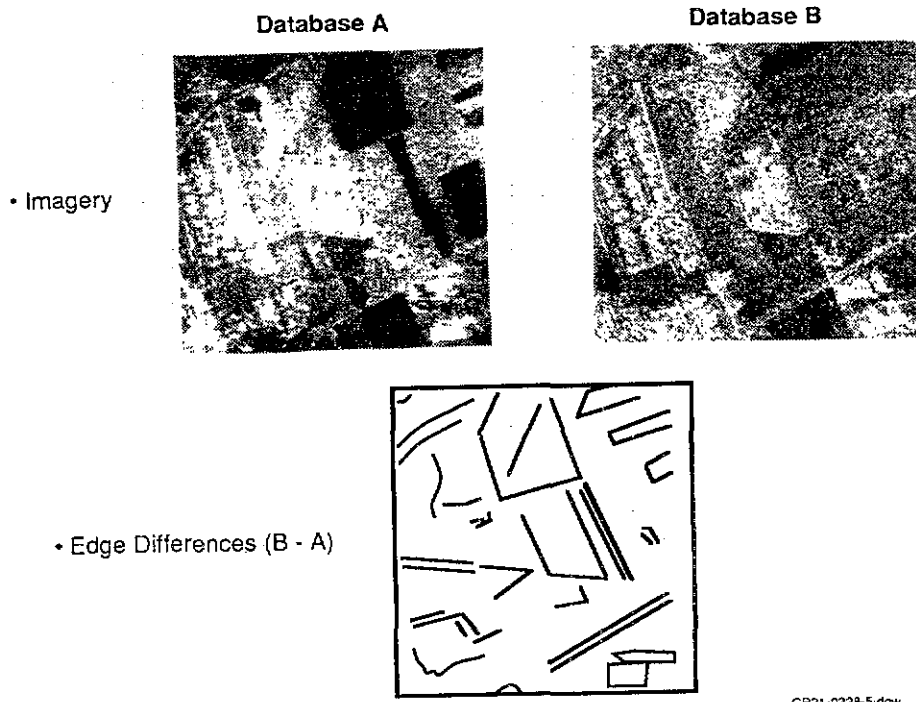


Figure 5. Textural Data Base Edge Differences

Texture Correlation - Texture differences are computed by subtracting boundary pixels of database A from the corresponding pixels of database B where the boundaries are detected by applying texture edge enhancement operators and thresholding the result into a binary image (Figure 5). The texture correlation, N_{dtp} , is the frequency of occurrence of zero edge pixel differences over the texture images. With this definition, two databases are 100 percent texture-correlated if the corresponding texture edge pixels resulting from both databases are exactly the same. On the other hand, two databases are 50 percent texture-correlated when half of all texture edge pixels are the same.

SUMMARY AND CONCLUSIONS

This paper is an initial attempt to define correlation and its measurement in the context of image and signal simulation for training and mission rehearsal applications. Existing documents, discussions with MDTs database experts, and theoretical considerations have been used to develop the definitions and metrics.

While qualitatively correct, the correlation definitions found in the correlation Specifications Survey⁵⁻¹³ are too general and do not quantitatively specify how to evaluate correlation in finished databases and working

simulation devices. Therefore, this study has proposed specific correlation definitions and statistical metrics for simulation system users, database evaluators, and viewers of the image displays which are generated.

Defining correlation in content, location, and dynamics can be seen as a common requirement for display users and database evaluators. However, display users can manually perform only qualitative correlation assessment over selected portions of gaming areas. On the other hand, the suggested database correlation definitions and statistical metrics can be used to automatically evaluate maximum achievable correlation over an entire gaming area and identify locations where insufficient correlation may be a problem. To determine total the simulation system correlation, a combination of automated database correlation with interactively observed display correlation over selected portions of the gaming area is suggested.

The correlation definition concepts, metrics and software developed under this study will be used to perform database correlation measurements on data from Project 2851. A long-term plan is to compare these measurements with qualitative display correlation observed in sensor and visual imagery produced by image generators which use Project 2851 databases.

The authors would appreciate feedback from simulation users and suppliers on the suggested definitions of correlation and its testing. Please contact the authors at McDonnell Douglas Training Systems, 12301 Missouri Bottom Road, Mailcode 2882055, Hazelwood, Missouri 63042, or call at (314)895-9141.

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