MISSION REHEARSAL: ITS IMPACT ON DATA BASE TECHNOLOGY

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ABSTRACT

Mission rehearsal can be defined as the use of accurate, correlated data bases, generated or updated rapidly from a variety of sources, to simulate a mission exactly as it will be executed. While this operational definition of mission rehearsal is relatively straightforward, its implementation is not. Incomplete or incompatible data, as well as limitations in state-of-the-art data base processing and multi-sensor correlation, currently inhibit the implementation of mission rehearsal in its truest sense. The ability of data base tools and current processing techniques to comply with mission rehearsal requirements must be assessed. This paper discusses the definition of mission rehearsal, describes current data base processing techniques, and identifies the subset of mission rehearsal that reflects the current abilities and limitations in correlating visual-image and other sensor simulators. Strategies are proposed for closing the gap between current and desired capabilities.

INTRODUCTION: JUSTIFICATION OF MISSION REHEARSAL

Mission rehearsal is not a new concept to the military. For an example of practical mission rehearsal, consider the World War II B-29 air raids that were made on Japan. In each of these raids, a single bomb was dropped in preparation for the atomic bomb drops on Hiroshima and Nagasaki.

Several factors make the mounting of this type of practical mission rehearsal exercise forbiddingly dangerous and expensive. These include the potential risk of flying today's low-altitude, air-attack missions and encountering sophisticated and varied anti-air attack weapons systems, and the cost of today's air-to-air and air-to-ground weapons. However, familiarity with the terrain and with anti-attack threats along a mission's ingress and egress routes and at the target area improves the pilot's ability to navigate to and acquire a target, which in turn provides for a higher probability of survival and mission success.

Rehearsing an attack mission in a flight simulator combines negligible risk and minimal expense. A flight simulator whose hardware configuration is maintained at parity with the evolution of aircraft and weapons systems needs only an accurate *Simulator Data Base* (SDB)* which contains the mission routes and targets at sufficient resolution to provide the necessary navigation, target acquisition, and threat recognition cues. However, traditional SDB development does not adequately address these needs.

Traditional operational flight trainer (OFT) and weapons tactical trainer (WTT) flight simulator contracts include visual and/or sensor data bases for specific, limited locations of the earth. These data bases are prepared and supplied by either the simulator contractor or the image-generator subcontractor. These data bases are image-generator specific; i.e., they have to be re-created not only for each different manufacturer's machine, but possibly for each different product a manufacturer produces. Furthermore, these data bases provide cues for general training exercises over large areas, but typically do not provide coverage of the specific area of the earth, or the degree of resolution, required by a real mission.

Thus, successful mission rehearsal and mission planning become an issue of rapid SDB development or update, which is the focus of this paper.

DESCRIPTION OF MISSION SIMULATION

SDBs are affected by, or affect, four mission-associated functions:

- Mission training
- Mission planning
- Mission rehearsal
- Mission debriefing

Mission Training

Mission training maintains air-crew currency in performing typical mission-related tasks such as navigation, target acquisition, threat avoidance, weapons systems control, etc. The goal is not to train for a specific mission, but rather to maintain general skills. This training can be done at least in part in simulators, using data bases developed for specific missions. At a minimum, the quality of the mission training data base should be similar to that of a typical mission rehearsal data base.

* The term Simulator Data Base (SDB) is used in this paper to describe the data base(s) required by visual, radar, infrared, and other simulated sensor subsystems that make up a flight simulator. See Figure 1.

Mission Planning

Mission planning determines the route over which the mission will be flown, the type and quantity of aircraft and weapons or reconnaissance equipment to be used, and the support (such as electronic countermeasures and refueling aircraft) that is required. The route and possible alternates are influenced by the following conditions:

- The type of terrain to be overflown
- The number and positions of anti-air threats and detectors
- The number and positions of primary and secondary targets and targets of convenience
- The performance parameters of the aircraft
- Political considerations

The inevitable conclusion is that the mission plan determines the content of the SDB, and viewing the data base influences the mission plan; therefore, both must be developed in concert. Mission planning results in briefing agendas, briefing materials, ground crew instructions, ordnance specifications, and contingency and rescue plans.

Mission Rehearsal

Mission rehearsal involves preparing the various air crews for their parts in a specific mission. The mission may be flown and reflown in the simulator using the SDB produced from the mission plan. The goal is to optimize the air crew's ability to:

- Navigate to the target while avoiding threats or detection
- Acquire the target
- Arm weapons systems or operate reconnaissance sensors
- Lock on target
- Escape

During mission rehearsal, potential flaws in the mission plan may be discovered and adjustments made. These adjustments may involve cycling back to the mission planning stage for major or minor mission plan revisions, including SDB revision.

Mission Debriefing

Mission debriefing follows an executed mission. The success or failure of the mission, as well as the specific problems encountered or observations made by the air crew, are discussed. Adjustments to strategy, tactics, or training may be developed accordingly. The simulator and the mission rehearsal SDB give the crew the opportunity to better visualize the debriefing discussion. Imagery* acquired during and after the mission may be used to update the SDB if the mission is to be flown again, or if the SDB is to be used for mission training.

* The term imagery as used in this paper includes image data from such sources as electro-optical sensors, photographs, maps, DMA, and other sensor data, such as radar, which can be displayed visually on CRTs or other devices.

SDB PRODUCTION

This section discusses the goal of SDB production, the process model used to produce SDBs, the data sources used for SDB production, the methods used for storing imagery in the Imagery Library prior to SDB production, the image processing techniques required to produce SDBs, the mission planning imagery support process, and the process used to transform the Correlated Data Base (CDB)** imagery into SDBs.

The Goal

Mission rehearsal requires rapid SDB development or update of specific areas of the earth, with emphasis on the cues required for navigation, target acquisition, and threat recognition. While rapid SDB creation and modification is essential (it can be shown that complete SDBs can be produced overnight), it is expected the SDBs will actually be produced in an incremental fashion and in three phases:

- Maintenance of unenhanced, relatively low-resolution SDBs
- Mission planning enhancement
- Mission execution

Unenhanced SDBs corresponding to political hot spots are created and maintained on a routine schedule. The SDBs are then enhanced along mission routes and in target areas as part of mission planning, with final enhancement occurring just before mission execution. Multiple SDBs may easily be produced and maintained when there are diverse mission, routing, and target options.

Either the unenhanced SDB, or the first mission planning enhancements to it, will enable reconnaissance missions to be adequately simulated. The information from the reconnaissance mission, and from whatever other sources are available, may be used to further enhance the SDB. The SDB can be manipulated correspondingly as the mission plan evolves, as more precise data is acquired for fixed targets and threats, and as the location of mobile targets changes. Depending on both the amount of processing required on imagery data and the complexity of changes to the SDB, the mission planning enhancements may require a few hours to a few days time to complete. Assuming the mission planning has progressed without complications, the final SDB enhancement should require a couple of hours at most after mission "go" is given. This means that the final simulation, using the latest reconnaissance, could be completed immediately before mission execution.

The Process Model

The block diagram in Figure 1 represents the model for the SDB production process.

** The term Correlated Data Base (CDB) refers to a computer data base that contains all of the imagery and associated data that is required to create a specific SDB. See Reference (2).

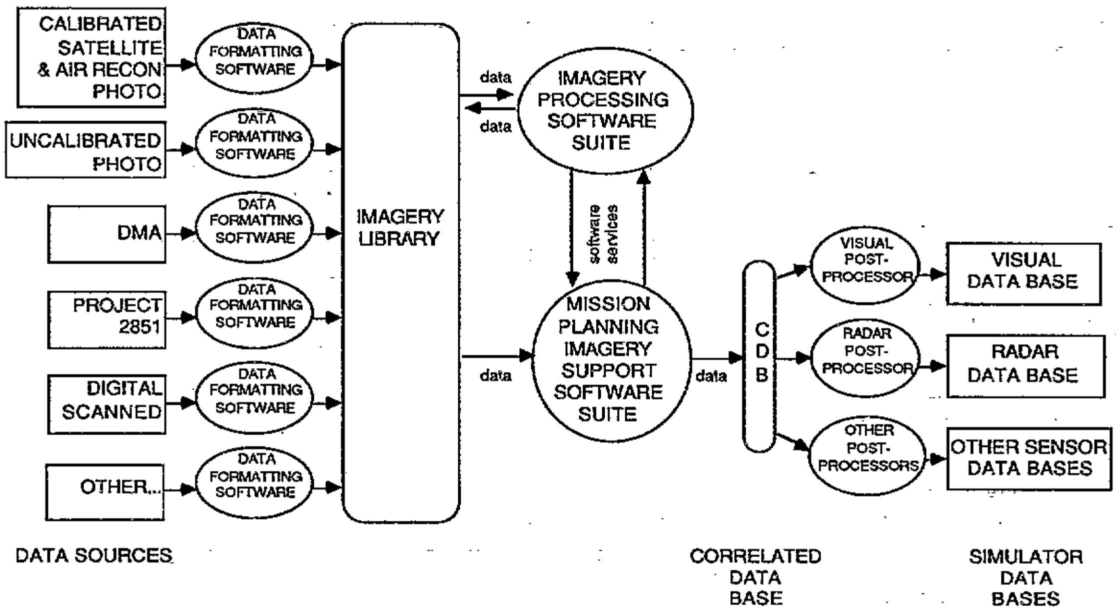

Figure 1. SDB Production Model

Figure 1 shows the SDB production process from original data sources, through imagery processing and mission planning, to a correlated data base, and finally to simulator data bases for mission rehearsal.

The data received from the various sources is stored in the Imagery Library. The data may be stored in the form in which it is received or it may be modified in some way by data-specific formatting or processing routines. An example of such processing is data compression for very large data sets.

Once stored into the Imagery Library, the data may be extracted and processed by the image processing software and then restored to the Imagery Library. An example is routine photo interpretation—the interpreters would have at their disposal various feature-recognition, detail-enhancement, and image-comparison software routines.

The production of the CDB from the Imagery Library follows a natural flow through the mission planning software. As the mission is planned, the image data in the Imagery Library is displayed and can be accepted or rejected for use in the CDB. The functions in the image-processing software are accessible directly from the mission-planning software so that the user need not exit the planning software to modify imagery using the image-processing software.

The mission-planning software generates parameterized instructions that control the SDB post-processing software. The mission-planning software can generate display views from the Imagery Library, the CDB, and the SDB. The software can also project imagery from the Imagery Library onto the CDB or SDB to preview its effect prior to committing it to updating the CDB and SDB.

Data Sources

The imagery for producing mission rehearsal SDBs is available from a multitude of sources, including:

- Photographic and electronic imagery from various satellites, and from air and ground reconnaissance
- DMA Digital Terrain Elevation Data (DTED) and Digital Feature Analysis Data (DFAD)
- Data in Project 2851 format

In addition, maps and charts can be electronically scanned and automatically interpreted, and engineering drawings and even sketches of features can be electronically scanned and prepared for computer usage. Data from human, electronic, signal, and communications intelligence gathering which can be visualized can be converted to imagery if a computer-aided design (CAD) system is used by an operator skilled at interpreting intelligence information.

The data from all of the above sources differs in resolution and spectral frequency. For example, SPOT satellite data is available in 10-meter panchromatic and 20-meter multispectral resolution. Satellite data may need geometric correction and orthogonalization, and digital terrain model (DTM)* data may be extracted from stereo pairs of satellite data images. The scale of aerial reconnaissance electro-optical data is a function of the instrumentation and the flight path. DMA DTED is

* The term Digital Terrain Model (DTM) is defined as a set of terrain elevation samples in digital format referenced to a known datum.

available in one- or three-arc-second resolutions. The resolution of photos, maps, charts, and other data sources that are electronically scanned is determined by the scale of the source material and the resolution of the scanner used.

The data from different sources is not necessarily consistent; due to construction, destruction, or the movement of features, data collected at some time in the past may differ in content from data collected more recently. Inconsistencies in the data can be caused by the time of day or season of the year, as well as by differences between sensor types or between calibration in the same types of sensors.

The data available from these different sources is also likely to be stored in different computer storage formats. Useful detail would be lost if high-resolution data were reformatted to a standard appropriate for lower-resolution data; and storage capacity would be wasted if all data were stored in the high-resolution format. For example, a specific feature's footprint available in 10-meter (or higher) resolution imagery is much more useful for feature identification than is the generic building description available in DMA DFAD data.

Imagery Library

The various imagery discussed above is collected and stored in the Imagery Library by data formatting software. The Imagery Library's design must provide efficient storage and access to the imagery. As the data formatting software stores each image, several pieces of information must be added and indexed to facilitate access. This information includes the following:

- The location, in latitude and longitude, that the image represents
- The image content, such as terrain type and key features
- The image type, such as electro-optical, photograph, scanned map, or rendition of DMA data
- The type of processing the image has received
- The date and time that the data was acquired

Additional valuable information may also be stored; examples are geologic and demographic descriptions of the area shown in the imagery, and indicators of the confidence level of the data's accuracy. The data formatting software may also include data compression algorithms to reduce the amount of storage space to be occupied.

Various Imagery Library maintenance routines add and delete images, print image catalogs, search images for specific content, etc. Storing all possible useful images on-line would overwhelm even the most modern high-capacity storage devices; a typical 60-km square, 10-meter resolution, SPOT-satellite panchromatic image consumes some 50 megabytes of uncompressed data. Therefore, an efficient image-archiving function must be available for storing images off-line (on magnetic tape, for example).

Imagery Processing

The imagery generally requires processing before it is used to produce the SDB. The types of processing required include the following:

- Image enhancement to add or improve color, sharpness, and contrast
- Histogram equalization to provide even contrast between mosaicked images
- Image warping to orthogonalize an oblique view of an image, correct perspective distortion, etc.
- 3D feature recognition
- 3D feature geometry extraction
- 3D feature surface-texture extraction
- Correlation of 3D feature footprint to DMA DFAD description
- Terrain and 3D surface-material determination
- Image overlay for comparing or combining
- Digital terrain model extraction
- Surface-feature, Geo-Specific* texture extraction
- Topographic-shading, Geo-Specific texture extraction
- Hard-copy output of image(s)

Once the imagery is processed by any of the above techniques, it may then be included in a CDB for mission rehearsal use.

Mission-Planning Imagery Support

The imagery support of mission planning is the obvious place to begin the SDB conversion process. This process can be summarized in the following steps.

1. The mission planner specifies a gaming area, which includes the staging area and the target(s).

2. The mission-planning support programs extract from the Imagery Library a catalog of all on-line and off-line imagery that pertains to the area in question.

3. The locations of threats and detectors are verified.

4. Overhead views of all or part of the gaming area are displayed so that the mission planner can choose ingress and egress routes that optimize the avoidance of threats and detectors.

5. Specific areas are magnified and displayed either from overhead or in perspective from any viewing angle.

6. Appropriate parts of the ingress and egress routes and target areas are enhanced with higher-resolution terrain or 3D feature detail to provide navigation and target acquisition cues for the rehearsal.

When a specific area is to be enhanced, a catalog listing of all imagery pertinent to that area is displayed so that the best, most efficient enhancement can be made. The image-processing routines can be used

* The term *Geo-Specific* refers to the use of terrain-specific, map-correlatable texture maps that have high fidelity to real-world terrain. See Reference (1).

directly from within the mission planning software to provide whatever image-modification services might be required. Various forms of enhancement may be tried and viewed before the image, or part thereof, is committed to the CDB and SDB.

Building the CDB

The CDB is built from the imagery that the mission-planning process selects from the Imagery Library. The mission-planning software must consider all the *selected data sources* and resolve any conflicting information which could result in reduced correlation. Any unresolvable conflicts are flagged for user intervention. A watchdog program monitors the complexity of the CDB so that the simulator's image generator is not overloaded. The program provides overload warnings and suggests load-reduction compromises based on the type of overload it anticipates.

The production of the CDB is not a linear process; it is a circular, iterative process. The CDB is produced from the best data available in the Imagery Library. When the mission is first rehearsed, flaws may be revealed that require modification of the mission plan, which means deletions from and/or additions to the CDB. The CDB does not have to be rebuilt from scratch for each modification.

The mission plan may require that one or more reconnaissance missions be flown to obtain additional, more up-to-date, or more detailed imagery. Certainly, before the reconnaissance mission is executed, it can be simulated using the SDB. The imagery updates resulting from reconnaissance can easily be processed into the Imagery Library, then into the CDB, and finally into the SDB.

Transformation from CDB to SDB

Proper correlation between the simulated sensors is *guaranteed because* each sensor's *SDB* post-processing software accesses the original image source data in the CDB. The processing software is simulation-device-specific, which ensures optimal use of the available data in creating each sensor's SDB. To ensure that a minimal amount of processing is required to update the SDB from an updated CDB as the mission plan is finalized, the post-processing software must be able to make additions to and deletions from each SDB without requiring time-consuming total recompilations.

The ease of modification of the SDB provides a heretofore unused simulation potential—the use of synthetically enhanced cues. A threat or detector, and/or its volume of coverage, can initially be colored in high-contrast so it may be more readily picked out of its surroundings; then, it can be changed to its normal coloring as the mission crew becomes accustomed to its location. Complex target areas and navigational waypoints may be treated in the same way. While the use of synthetically enhanced cues in an OFT is normally considered negative training, in mission rehearsal these cues enhance an accomplished pilot's ability to quickly identify a specific point of interest.

THE SOFTWARE USER INTERFACE

The typical user of mission-rehearsal software could have as little as a high-school education with up to six months training in his specialty.(3) In order for this typical user to effectively operate the software that manipulates imagery and produces the SDB, the software must be written with a high degree of user friendliness. This requires a rapid-response graphics workstation with a windowed user environment and some kind of pointing device such as a mouse, digitizing tablet, or trackball (or a combination of the three).

A context-sensitive help system must also be included; the help system must be both referential and tutorial in nature. It is not enough to explain how a function or command works and what parameters it requires; hints must also be given about what typical values those parameters might be given and what results can be expected from the use of those particular values.

Error recovery must be eloquent and tutorial. Typical computerese, numerical error codes are totally inappropriate. Each error must be intercepted and a message explaining the error condition, in English, must be displayed. The message should be as concise as possible, and a more complete description of the error, with suggested error recovery procedures, should be available at the push of a function key or some similar stimulus.

The image-rendering software must be able to compute both overhead and perspective views of the imagery. Zoom-in and zoom-out display capability, as well as the capability to overlay images for comparison, must be convenient and fast.

OVERVIEW OF CURRENT CAPABILITIES

Using DMA DTED and DFAD, the terrain and features of an SDB the size of a geounit* can currently be produced in a four-hour time frame.(2) *Features can be* added or changed in as little as a few minutes. The tool system that does this has been used successfully on large OFT SDB projects, showing that terrain skin can be produced quickly, with generic features placed according to the DFAD description.

We have observed that OFT SDBs typically do not contain sufficient cues for mission rehearsal. OFT training provides appropriate cues to train the student in basic flight and aircraft-system operation skills but, because the armed services do not have the required computing power and have not established the departments of highly skilled data base designers, OFT SDBs have traditionally been part of image-generator contracts. To achieve maximum flexibility of simulation *flight plans, these SDBs* tend to be compromises—they provide large area coverage with scene content averaged over the total area. The areas covered are usually domestic so that the student, when he progresses to actual flight, will find the terrain and features familiar because of his simulation training.

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* A geounit is the area bounded by one degree of latitude by one degree of longitude.

On the other hand, the mission rehearsal SDB must provide the opportunity for the mission planners and pilots to verify optimal mission routing and for the pilots to become intimate with real-world navigation and target acquisition cues over hostile terrain. These cues must come from the real-world topography and scene complexity. Given that the requirements of the OFT *differ from those of mission rehearsal SDBs,* we have been investigating and developing methods for providing the needed cues. This effort has been part of our ongoing effort to improve simulation effectiveness.

Building on the data base development work presented at the 1987 I/ITSC conference (1) and on the continuing evolution of image-generator hardware, we were ready to capitalize on the recent commercialization of high-resolution, stereo-pair, satellite imagery. From this imagery, DTM data was extracted, topographic shading Geo-Specific texture was algorithmically derived, and the images were digitally warped into an orthogonal, non-perspective view for use as surface-feature, Geo-Specific texture. For areas of specific interest, where typical satellite imagery resolution was insufficient, air or ground photos were warped into place to provide the *required resolution.* See Figure 2.

After all of the imagery was properly contrast-equalized, mosaicked together, and edge-blended, the result was an SDB which included 3D terrain covered with seamless Geo-Specific texture from beginning to end.(4) This SDB represents the real-world complexity and specificity required to navigate and acquire targets in even the most complex enemy environments. See Figure 3.

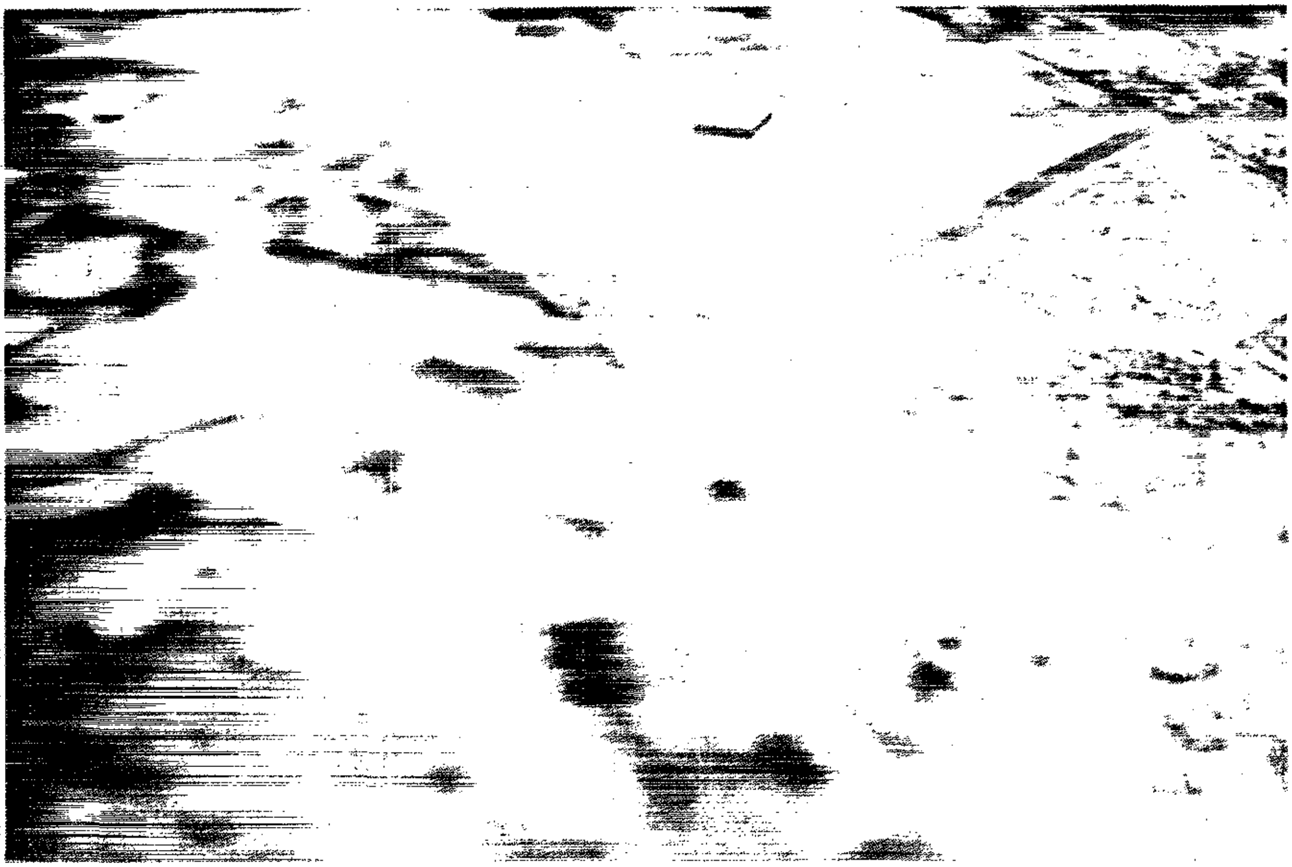
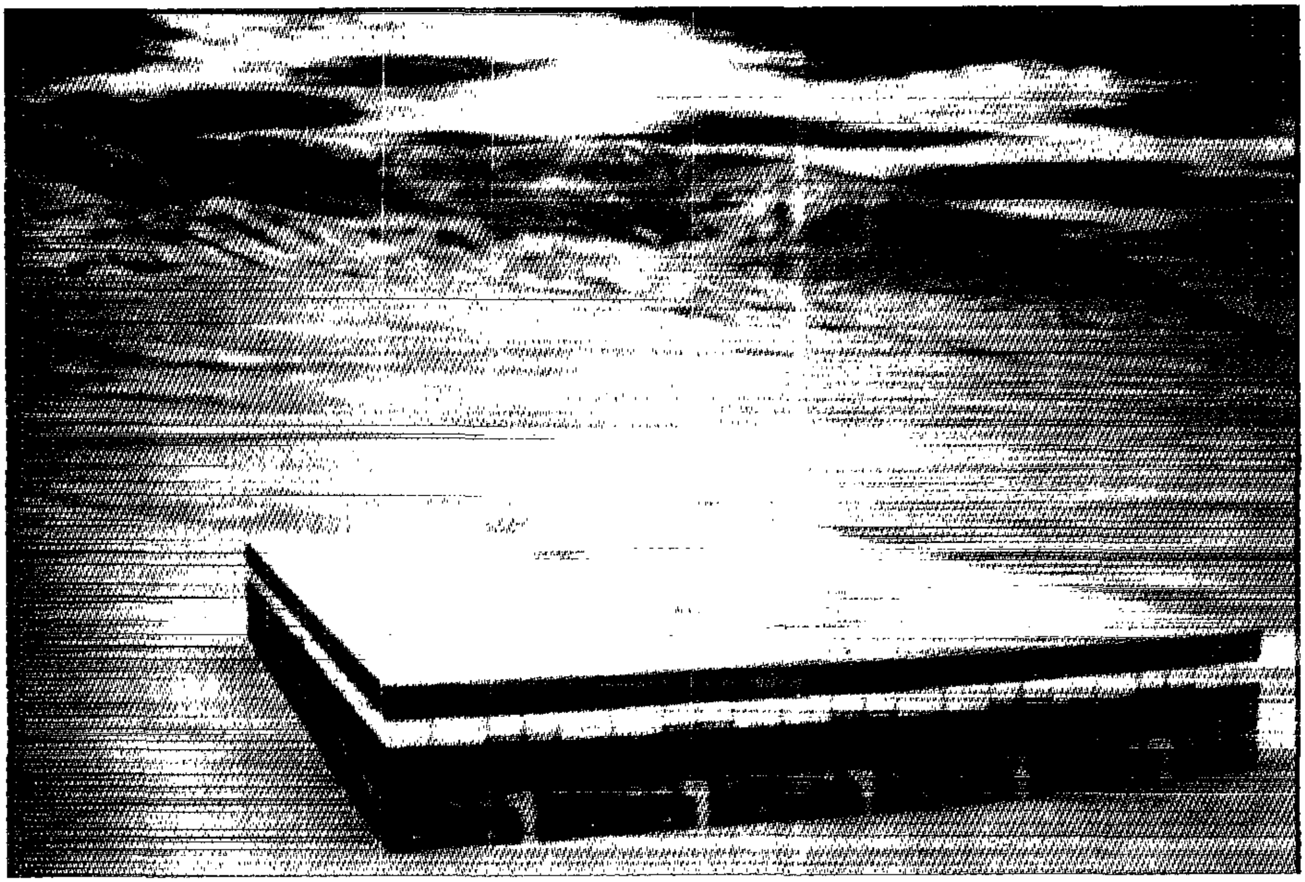


Figure 2

Figure 2 is an example of texture blended from different data sources. In this case, an aerial reconnaissance photo taken at 40,000 feet was blended with 10-meter, SPOT-satellite-derived data. The resolution at specific points of interest is vastly increased by this method, enabling the pilot to make positive area and feature identification at simulated altitudes much lower than the SPOT data alone would allow. Note the precise alignment of roads across the blend boundary. (Although the boundary was left obvious here, further processing can effectively eliminate it.) [Source imagery ©CNES 1988 SPOT Image Corp.]



PHOTOGRAPHED DIRECTLY FROM A REAL-TIME CT6 SYSTEM EVANS & SUTHERLAND

Figure 3

Figure 3 demonstrates 3D feature extraction from source imagery, which is another facet of Evans & Sutherland's ongoing, simulation-improvement effort. In this figure, the building's geometry and surface texture were derived semi-automatically from a series of scanned photographs. [Source imagery ©CNES 1988 SPOT Image Corp.]

To further improve scene realism, the SDB can be populated with 3D features extracted from imagery taken from a Feature Model Library. While a given simulator may not provide the polygonal budget to fully populate the SDB with such features, specific areas of interest such as navigational waypoints and the target's surroundings can certainly be enhanced to ensure rapid, accurate identification. Correlation of Geo-Specific surface-feature texture, aerial reconnaissance imagery, and DMA data will ensure accurate rendition of the target in its proper context.

Based on current data base production capabilities, prognosis for mission rehearsal is good. The use of overhead imagery and DTM to produce an accurate, 3D terrain skin textured with Geo-Specific texture goes a long way towards providing the real-world scene accuracy and complexity required for viable mission rehearsal capability. The 3D feature extraction adds to this capability.

FUTURE DEVELOPMENTS

While the individual software tools previously described can produce viable mission rehearsal SDBs, the user interface that allows for a smooth flow of data from source imagery into the Imagery Library, to CDB, and to SDB must be improved. Therefore, these tools are now being consolidated into a consistent, user-friendly environment. When this is accomplished, the function of SDB production will be removed from the realm of the expert data base designer and put into the hands of the mission planning team. This team will then be able to produce viable simulation while concentrating on mission planning and rehearsal instead of on the esoterica of data base design.

The image-manipulation tools must be designed so that new image-processing algorithms, or routines to handle imagery of finer resolution from new or improved sources, can easily be added. Existing tools and techniques would not need to be disturbed by these additions. The consistent user interface would also minimize the training necessary to implement new methods or imagery.

CONCLUSION

Viable mission rehearsal can be accomplished with currently available simulation software and hardware. We already have the capability to produce a set of well correlated SDBs for visual, infrared, and radar sensor simulators in a time frame consistent with mission preparation. These SDBs contain the required cues to successfully simulate navigating to a target, delivering ordnance, and escaping.

Improving software tool user interfaces will reduce the training required for effective use of these tools. Increasing the sophistication of imagery processing will improve the ultimate quality of the SDBs. Automating the optimization of the SDB to take the fullest advantage of the specific simulator in use is also important. Projects for accomplishing these tasks are under way.

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