DRLMS TECHNOLOGY - A CRITICAL ASSESSMENT OF THE STATE-OF-THE-ART

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ABSTRACT

It was 20 years ago that the training community stopped to make an assessment of radar simulation fidelity and effectiveness. An evaluation of analog systems, which had served well for many years, identified that many of the inherent limitations could be overcome if modern digital technology were applied. Project 1183 and the acquisition of digital radar landmass simulation (DRLMS) systems for the Navy A-6E Weapon System Trainer and Air Force Undergraduate Navigation Training System helped make the transition from analog to digital radar training systems a reality. During the last 10 years, radar simulation technology has been significantly impacted with the introduction of training requirements for high resolution synthetic aperture radar (SAR) systems. Now, in 1991, we are again at a time appropriate to reevaluate the progress we have made and the effectiveness of today's DRLMS systems. The objective of this paper will be to provide a brief history of radar simulation, make an assessment of the successes as well as specific problems and issues associated with the simulation of high resolution radar systems, identify an approach based on video processing of optical sources that could lead to satisfying many current and future radar simulation requirements, and introduce alternative approaches for specifying the performance of future DRLMS systems based on a more rigorous assessment of training needs and the benefits that might be anticipated.

INTRODUCTION

Digital Radar Landmass Simulation (DRLMS) has come a long way during its 20 year life. Some bold decisions were needed and made along the way that brought us to where we are today with highly realistic radar displays capable of supporting many types of training. However, limitations do exist that cannot be economically overcome by just advancing technology again. Some tough decisions need to be made that will optimize the tradeoff to be made resulting in operational training needs being met utilizing all the relevant technology available and within a reasonable cost.

HISTORY

Project 1183

In the early 1970's, ground mapping radar simulation technology took a significant step with the use of digital processing of data to create the simulated radar video. These simulations utilized the same source data as the analog systems except in a digitized form. In 1973 a major step was taken by starting an R&D program, Project 1183, that employed new concepts in both database and processing technology.[1] This program addressed the following limitations of the existing F-111 simulator:

- Inadequate breakups of cultural features
- Lack of height data for cultural features
- Costly and lengthy process to make even minor updates to the transparency and database
- Unusable display on the attack radar on the short range scales
- Unrealistic simulation of the terrain following radar system
- Maintenance problems due to the complex analog servo mechanism and analog signal processor.
- Inability to consistently reset the simulation to precise geographic positions and obtain precise repetition of the simulation over a previously flown ground track.
- Point features aligned in the cardinal direction instead of their true orientation.

Project 1183 and the Navy's A-6E DRLMS program, which started a little later, demonstrated that all these limitations could be eliminated or significantly improved.[2]

Radar Data Base Evolution

One of the key reasons for the very significant improvement in ground mapping radar simulation was the completely new approach to the source database. The Defense Mapping Agency (DMA) produced a multi-level/multi-resolution digital database that described both terrain elevation and the features that sat on top of the terrain. These features were described using physical characteristics (material type, feature identification, definitive outline of feature, etc.). Because these database descriptions were generic, the DMA product could support any radar simulation through the development of a transformation program.[3] This was the foundation of this new concept defined by ASD and was essential to the development of an economical approach to digital radar landmass simulation. In the late 1970's many new simulator programs adopted this proven concept, and the need for extremely large quantities of digital data from DMA was identified. During the middle and late 1970's DMA established multinational agreements to produce data. This increased the production capacity for digital data and resulted in a further expansion of the database support concept for radar simulation with the British and German Tornado simulators.

Standardization Of Requirements

In the late 1970's, when several new Air Force simulator procurements were being planned that included DRLMS systems, a small group of Air Force engineers was tasked to produce a generic set of DRLMS requirements. The resulting document was the product of much soul searching and incorporated the lessons learned from all previous DRLMS developments and products from the three DRLMS vendors at the time.[4] This document was provided to these vendors for comment. The results of these activities were:

- A quantitative requirement that defined the DRLMS processing and memory capacities based on a DMA data density curve and feature location accuracy.
- A quantitative requirement that defined the fidelity of terrain reconstruction techniques based on the roughness of the terrain and the range scale selected for display.
- Identification of specific radar effects significant to training.
- A requirement to provide specific test features to aid in the test and evaluation of the display as well as a diagnostic tool.
- The requirement to provide a means to make simple modifications to the DRLMS database to support the insertion of mission specific features and/or the correction of minor database errors.

As DRLMS technology matured along with the DMA database production methods, some new concerns came into prominence including digital processing of radar signals in the airborne radars, the cost of producing the DMA digital database in the resolution levels and in the quantity desired by the operational commands, and the need to determine how much fidelity is enough to satisfy operational training requirements. Newly defined requirements for high resolution radar simulation were based on engineering analyses of operator performance rather than as a result of controlled research using operational scenarios. However, because of the large apparent increase in feature content on the high resolution radar display, issues associated with source data bases again became critical.

Transition To Synthetic Aperture Radar Requirements

By the late 70's, synthetic aperture radar (SAR) systems were being developed in the laboratories that could produce extremely high resolution displays. Samples of Forward Looking Multi-Mode Radar (FLAMR) data, an advanced development program, were provided to simulator developers and DMA to assess how this type of radar would impact DRLMS technology. The initial consensus from industry was that the database would need improvement but that processing technology was basically adequate even with the need to simulate SAR unique effects. One of the first programs to address the requirements associated with high resolution radar simulation was the F-16 DRLMS system development program which featured a doppler beam sharpened mode.

The Analytic Sciences Corporation (TASC), under contract to the Air Force, Aeronautical Systems Division (ASD), accomplished an analysis in 1983 to illustrate the characteristics of SAR imagery which should be incorporated into a

DRLMS system and to then evaluate the suitability of existing DRLMS technology for simulating these characteristics.[5] This analysis was soon followed in 1984 by a similar study by Link Flight Simulation Division, under contract to the Navy, Naval Training Equipment Center (NTEC), to explore the implications of Doppler beam sharpened radar and synthetic aperture radar in training requirements.[6]

Conclusions reached by both analyses were similar in nature. First, it was noted that although the state-of-the-art in digital technology was adequate to support SAR simulation, existing DRLMS systems would require significant redesign to successfully meet training requirements. Second, a series of specific radar effects was identified as being uniquely characteristic of a SAR map. SAR unique effects identified by both reports included scintillation, motion compensation errors, moving targets, range/range-rate mapping distortions, feature layover, azimuth/range sidelobe overloading, and range foreshortening. However, of potentially greatest significance, both reports identified the need for a more detailed, higher resolution source data base as a basic necessity for realistic SAR simulation. The Link report specifically identified the need for a simulation data base equivalent in terms of feature content and resolution to DMA's Level X prototype data base.

These additional phenomena and the lack of operational experience with SAR systems increased the dilemma of how much simulation fidelity was needed to satisfactorily train radar operators. Up to this point, the primary performance requirements were based on engineering analyses of the ability of a radar operator to finely tune his scope and lay cursors on an aim point. This analytical determination of requirements was satisfactory, but begged the issue of experimentally derived data to demonstrate whether this approach resulted in over specification or under specification of performance requirements. The Air Force laboratories were challenged with the difficult problem of determining how accurate feature location had to be maintained, to what fidelity feature shapes had to be maintained given all the information available to an aircrew. Digital processing of radar video further compounded this issue and added some additional questions due to characteristics of the processor.

It was apparent that the content of the source data base had to be addressed. It also became obvious that the cost of database production was becoming extremely large. One of the first efforts to address this problem was to enhance the existing database artificially. The feasibility was demonstrated in 1978 and again in the early 1980s by generating synthetic features in large DMA database homogeneous features (residential areas, factory complexes).[7] This was done without any additional descriptors required in the DMA database. From the outset it was realized that this approach could not be applied to key radar significant features, but was viable for large non-radar significant homogeneous features. Still, there were skeptics among the user community and some database purists.

It was suggested to industry that they apply the texture schemes used in visual simulation to radar simulation. Some of the initial texture patterns were very artificial; however, they matured rapidly. This sharing of development history helped to bring the visual and radar simulation communities even closer. This approach was successfully used on the F-16 DRLMS and subsequently on the F-15E, B-1B, and B-2.

ASSESSMENT OF CURRENT CAPABILITY

DRLMS System Performance

The simulation industry has made tremendous strides developing the state-of-the-art in DRLMS technology over the last 20 years. The quality of simulated imagery, particularly for real beam systems, has improved to the point where target analysis and radar predictions can be accomplished with the support of a DRLMS system. Problems associated with quantization effects (e.g., number of reflectance codes, number of video output levels, antenna beam implementation, etc.) from various stages of the digital processing and data storage observable on the radar display have largely been overcome. Fundamental radar effects such as terrain shadowing, aspect geometry, and directionality effects are well understood and effectively modeled in most DRLMS products. Creativity by DRLMS vendors such as GE, Link, Boeing, Loral, Harris, and Merit Technology have resulted in innovative ways of providing enhancements (i.e., texture, artificial feature implementation, and multi-level data base merging) to the simulated image that result in improved fidelity. Technology growth has had a significant impact on improving system reliability, maintainability, and availability while at the same time reducing both development and life-cycle costs.

DMA Data Base Concept

A major contributor to the successful evolution of DRLMS systems has been the application of the multi-level DMA digital database.[8] Standard DMA digital products developed to support radar simulation have included Levels 1 and 2 DFAD. Both products were originally intended to be used as source data for real beam radar simulation - Level 1 for large area coverage for general navigation and Level 2 for increased detail surrounding radar fix points (RFPs) and offset aimpoints (OAPs).

The database transformation concept has proven successful and has permitted a single source database (DMA) to be tailored to a specific radar simulation. DMA is currently supporting radar data base transformation programs for the A-6E, E-2C, EA-6B, B-52, B-1B, C-130, EF-111A, and F-16 WSTs.[9] An inherent capability associated with the implementation of digital systems that has been exploited by DRLMS vendors is the data base update capability that permits the end user to easily make simple modifications to the radar database through the use of an update console.

Although problems associated with the use of DMA data were initially identified (e.g., digitizing anomalies, differences in how DMA analysts interpreted and encoded source data, areas with sparse or missing data, etc.), the overall quality and availability of the DMA products has steadily improved. Further improvements can be expected as DMA progresses with the implementation of their Digital Production System scheduled for completion in 1992. This new system, referred to as DPS MARK 90, will provide an all-digital production system for increased throughput, greater product flexibility, and improved responsiveness.

High Resolution Radar Simulation Data Bases

A fundamental aspect of DRLMS system requirements and design approaches is that the DMA data, at whatever level available for a given application, is the ground truth representation for simulation purposes. The fidelity of the DRLMS ground truth image is, therefore, only as good as the DMA representation from both a feature portrayal and descriptive information perspective. Although a DRLMS vendor can provide enhancements to the simulated imagery to improve the qualitative realism, correlation to the Earth's surface will be no better than what is described in the data base product.

Analyses of high resolution SAR imagery for weapon systems such as the B-1B and F-15E indicated that the original DMA products Levels 1 and 2 would not suffice as the only source for generating simulated images. Based upon system resolution performance of better than 10 feet, specific data base limitations that were evident included a lack of continuous lines of communications, inadequate feature content and detail, and a general lack of adequate descriptive information.

A joint ASD/DMA data base requirements definition process was initiated in 1984 to specifically identify the content and format for a new product intended to support the simulation of high resolution radar systems. The outcome of this effort was a draft specification and prototype DFAD product referred to as Level X.[10] Level X data contained significantly more scene content and detail than any other existing DMA product and was met by much enthusiasm by the DoD training community. Level X data was evaluated by many DRLMS vendors and became the preferred solution for meeting the B-1B WST HRGM simulation requirements. However, after producing a limited number of Level X areas for the B-1B, DMA determined that the cost of turning Level X into a standard product would be prohibitively high and further efforts were discontinued.

Further high resolution data base requirements analyses conducted by ASD with the support of the Air Force Human Resources Laboratory (AFHRL) and Armstrong Aerospace Medical Research Laboratory (AAMRL) after the discontinuance of Level X resulted in the definition of two new products that could be more economically produced - Level 3C (compiled from 1:50,000 scale map source) and Level 2E (based on the existing Level 2 with more complete lines of communication representation).[11] Based on user requirements, specific RFP and OAP information can be provided in both Levels 3C and 2E. It is currently envisioned by DMA that DFAD Level 2E and Level 3C will remain the standard products to support high resolution radar simulation requirements for at least the coming decade.

The current assessment of Levels 2E and 3C is that for relatively isolated RFPs and OAPs, the basic information including the specific feature of interest and prominent surrounding features will be provided. However, the challenge of transforming these products into a DRLMS on-line data base capable of supporting high resolution radar simulation with a high degree of image fidelity will remain with the system developers. Information relative to the precise nature of feature detail, terrain characteristics, and foliage appearance will require the DRLMS system developer to infer as much as possible from the data base descriptors and apply artistic license to the degree desired in order to produce simulated imagery with similar attributes to that of the actual system.

High Resolution Radar Effects

The physics associated with fundamental radar effects such as terrain shadowing, aspect geometry, and directionality effects are well understood and effectively modeled by most DRLMS vendors. These radar effects provide the basic character of real beam imagery and can be justified from a training requirements perspective. Analyses conducted of high resolution systems have also provided a comprehensive definition of those characteristics unique to digital processing of doppler phase histories, and appropriate models have been implemented in existing systems. What is not clear, however, is the degree of fidelity afforded the simulated imagery by implementing a rigorous set of SAR algorithms and the cost from both a development and system complexity perspective. The bottom line is that the training utility of these simulated effects relative to the added system complexity and cost has not been well established.

ALTERNATIVE APPROACH

Recent efforts have resulted in significant improvements to the overall fidelity of the simulated high resolution imagery. However, each of these approaches is dependent upon information contained in the DMA DFAD product and associated enhancements resulting from DFAD feature descriptors (e.g., surface material, feature identification, etc.). Simulation results compared to an actual radar presentation are limited by the information contained in the DMA product.

This same problem was encountered when trying to utilize DMA DFAD products as the basis for visual data bases to support computer generated simulation imagery for visual systems. The real time application of different synthetic texture patterns based on DFAD feature descriptors has been successfully utilized with simulator visual systems for a number of years. However, of greater significance is the application of overhead imagery as a source for geographically specific photographic based texture. [12,13,14]

Science Applications International Corporation (SAIC) has developed and demonstrated a similar approach for radar simulation applications. Between January 1984 - January 1986, SAIC's Aeronautical System Operation in Dayton, Ohio completed the development of two B-1B Engineering Research Simulators (ERS) for the Armstrong Aerospace Medical Research Laboratory (AAMRL) and Strategic Air Command (SAC). The B-1B ERS is a real-time, man in the loop simulator designed to model and emulate the physical appearance and functional characteristics of the B-1B strategic bombers' flight and aft crewstations. Of prime concern to the B-1B Offensive System Operators (OSO) is a realistic simulation of the B-1B's High Resolution Ground Map (HRGM) synthetic aperture radar system.

The selected radar simulation approach featured a custom electronics module based on conventional DRLMS design which could provide real-time simulation of the B-1B's real beam radar mode. The High Resolution Ground Map (HRGM) mode simulation approach, however, was based on preprocessed fixpoint imagery generated off-line and stored on laser disk for data retrieval during training. While several data base sources (including high altitude photographs and actual SAR imagery) were originally evaluated, DFAD Level 1 was selected for production of the B-1B ERS's HRGM imagery because of coverage, cost, and schedule considerations. HRGM data bases are stored in a gridded format containing gray scales/reflectance values which represent the predesignated radar fix point (RFP) areas in two dimensions. Multiple data bases, each with a grid size corresponding to one of the available radar map resolutions, are developed for each RFP. Each data base map has a single set of geographic coordinates referenced at the map center that are used for display computations relative to the aircraft location. This approach captured some of the geographical content of the fixpoint area needed for procedural training; however, the resulting imagery was simplistic in appearance and did not contain the scene content observed with actual HRGM imagery.

In support of human engineering research for the Armstrong Aerospace Medical Research

Laboratory (AAMRL) and the B-1B SPO, SAIC was tasked to improve the fidelity of the B-1B ERS simulated HRGM imagery. After completing a review of alternative sources, it was found that United States Geological Survey (USGS) high altitude photographic data was available for most regions in the continental United States including SAC's Strategic Training Route Complex (STRC). Using this USGS photographic data as source material, and a variety of commercially available hardware and software products, a data base transformation process capable of supporting simulated HRGM images was developed.

The process developed to generate on-line HRGM data bases and provide real-time processing is illustrated in Figure 1 and includes the acquisition of source imagery, digitization, transformation of imagery and terrain elevation data into a video format for real-time processing, and storage on video disk. The transformation process requires that the data base photography be analyzed to determine radar unique feature characteristics which are subsequently assigned an appropriate gray scale/reflectance value. Particular attention is given to buildings and significant man made structures, land/water contrasts, no-show areas such as roads and runways, and vegetation. Surface texture is also added to enhance the overall image appearance. DMA Level 1 DTED is used as the terrain elevation source for computing occulting effects both within and to the selected map area. As part of the transformation process, a terrain elevation value is computed by interpolating between 3 arc second DMA Level 1 DTED values and storing each corresponding grid element in the feature map. Real-time data retrieval of the digitized radar imagery is accomplished on a scan by scan basis by the DRLMS. Each scan line contains approximately 400 range elements to approximate the required resolution. Grid cell gray scale values retrieved by individual scan lines are then mapped into the DRLMS display memory. Figure 2 illustrates a high altitude photo for a "typical" area of interest, and Figure 3 a simulated HRGM image produced using the described process.

In addition to the data obtained from USGS, source data was also obtained from LandSat (Thematic Mapper System). A significant advantage is that the LandSat data may be obtained in a digital format thereby eliminating one of the data base generation steps. However, the resolution of this data was less than that available from USGS and would result in a lower fidelity simulated image. SPOT imagery is another candidate data base source but was unavailable during the evaluation period.

The photobased approach provides a number of significant improvements for high resolution radar simulation that include enhanced image resolution and scene content that are highly representative of actual radar system imagery. The current process faithfully retains all characteristics of both the source imagery and the terrain elevation data. Information

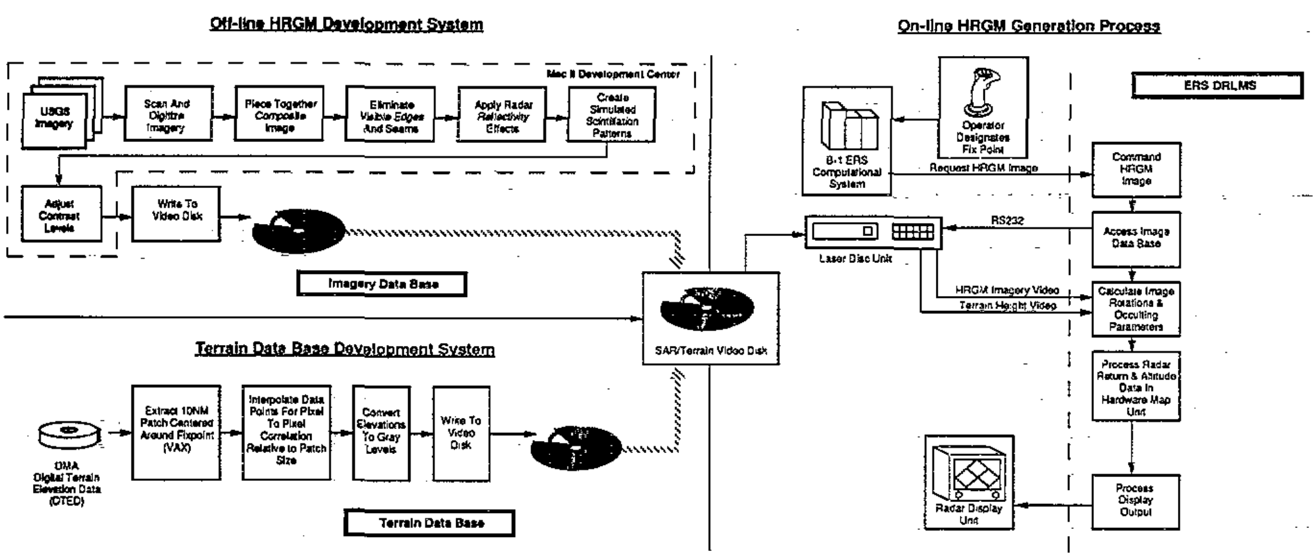

FIGURE 1 HRGM DATA BASE AND REAL-TIME PROCESSING

FIGURE 2 HIGH ALTITUDE PHOTOGRAPH OF AREA OF INTEREST

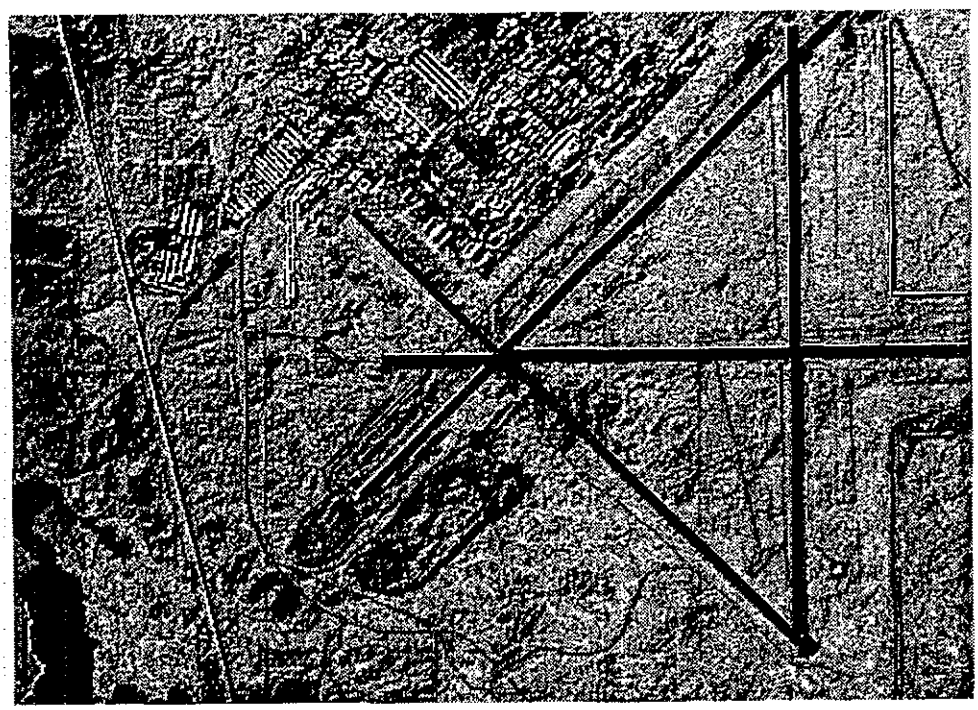

FIGURE 3 SIMULATED HRGM IMAGERY

collected from interviews with B-1B OSOs located at Ellsworth AFB who evaluated the simulated B-1B HRGM imagery indicated that it compared favorably to the actual aircraft radar system imagery. Although the transformation process and subsequent real time processing result in simulated image characteristics (e.g., feature intensities, terrain occulting, land/water contrast, etc.) that are representative of the actual aircraft radar system, further development in the areas of cultural occulting, the simulation of specific geometrical effects such as horizontal/vertical aspect, and implementation additional SAR unique characteristics needs to be accomplished.

CONCLUSION

As was related earlier, the principle limiting factor in large area, high fidelity DRLMS systems is the source data base. Given this fact, one needs to question the value of high fidelity modeling efforts of both the radar system and the phenomena due to geometry and physical laws if an adequate data base is not available. This is not to imply that high performance ground mapping radar simulation is not required but whether lower cost simulations with good performance will satisfy many training needs without some of the "special effects" due to doppler processing, seldom encountered geometry, extreme antenna pointing angle situations, or unusual operator use conditions. The following is suggested during the requirements definition phase of a program to determine the performance fidelity needed and the acquisition strategy to be followed.

The specific radar skills that need to be trained should be carefully evaluated to determine the most cost effective method of instruction. Careful consideration needs to be given to whether the objective of the DRLMS system is procedural in nature or whether advanced skills requiring target identification and radar scope interpretation (RSI) need to be trained. In the past, many Air Force radar navigators/weapon system operators have expressed the belief that the training benefits associated with radar simulation become less significant after a student has had several actual flights in the aircraft. On the other hand, the perishability of RSI skills also needs to be considered. If there are an insufficient number of aircraft training flights necessary to permit the needed skills to be retained, then ground based training must fill the void.

Since high fidelity DRLMS systems with large, high fidelity data bases are expensive, alternatives to these systems as an integral part of full mission simulators or weapon system trainers need to be examined. Procedural training might be achieved using a lower performance DRLMS system that is fully integrated with the weapon system trainer. Requirements related to system processing performance (e.g., accuracy, data density, etc.) and radar effects fidelity for DRLMS systems supporting procedural training would need to be reassessed.

A limited number of high performance DRLMS part task systems might then be developed as part of the suite of training devices for the weapon system. These part task trainers could be devoted to training perishable skills that require high performance/high cost capabilities such as those associated with target identification, target prediction, and RSI. A high fidelity part task trainer would not require the complex interfaces with navigation or weapon delivery subsystems, nor would they require large, high fidelity source databases. Alternative DRLMS architectures or hybrid systems utilizing a photobased data base enhancement technique like that described earlier might be exploited to meet the part task trainer high fidelity simulation requirements. Revisions to existing DRLMS performance specifications would need to be addressed if the application of photo texturing techniques is to be considered.

Technology is available to support high fidelity real time ground mapping radar simulation. However, the database to support this level of fidelity is not available in sufficient quantities to meet operational training needs and the cost of producing such data is currently prohibitive. Enhancements are possible that contribute to realism and should contribute to training utility. But, some difficult decisions and smart choices must be made. In order to achieve the proper mix of radar training media suggested earlier, the end user and acquisition organization must conduct the appropriate trade studies. The specific tasks and a detailed analysis of how these tasks are accomplished must be accomplished in order to reach the most cost effective solution. Trade studies must also be accomplished to develop a more definitive understanding of mission rehearsal training requirements.

Performance compromises are often possible, but they must be made in the right areas. It is also essential that the contractor be completely aware of the results of these trade-offs so that the training philosophy is carried into the design implementation phase of the program. The entire team - end user, acquisition organization, and contractor - must seek to maximize performance for each new application by taking advantage of simple database enhancements, by developing alternative data base texture capabilities, and by selecting the appropriate mix of training devices (including simplified radar simulation systems) whenever the opportunity is presented.

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