ENERGY LEVEL MODELING: A NEW APPROACH TO REAL-TIME ECM RADAR THREAT SIMULATION

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ABSTRACT

Effects level modeling in radar simulation has been the traditional approach for satisfying Electronic Countermeasure (ECM) training requirements. A new Radar Environment Simulator (RES), developed for a U. S. Navy F-14A Weapon Systems Trainer, utilizes design principles which go beyond the traditional. The jammer models in the RES are based on detailed modeling of real-world transmitted and received energy levels ("energy level modeling"). This design approach is used instead of simply attempting to duplicate visual effects ("effects level modeling"). While either of these methods can provide an accurate simulation under normal operating conditions, the energy level model has significant advantages when ECM is introduced into the scenario. The result is a trainer that is more realistic in its response to a large set of radar operator actions and threat variables.

Energy level modeling can be applied to the simulation of systems designed for the detection, acquisition, and tracking of various targets. This design principle enables the software to emulate all radar system behavior without anticipating each unique scenario. In addition, non-standard radar operator inputs to an actual radar system interface are processed real-time using a detailed radar model allowing realism never before possible. Consequently, the goal of preparing a trainee for a wide variety of ECM threats and threat signatures is achieved to an extent not feasible through traditional effects level simulation.

ABOUT THE AUTHORS

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INTRODUCTION

Most aircraft, ships, and missile systems in the military inventory utilize radar as one of the primary sensors in the performance of their mission. Simulators and trainers based on these systems employ radar simulation for training in the operation of these increasingly complex radars. *Effects level modeling is the predominant method* that has been employed in radar simulation. This traditional method involves designing simulation algorithms based on resultant effects rather than the underlying processes.

A new approach was used when developing a radar environment simulator for the U.S. Navy's 2F112 F-14A Weapon System Trainer at NAS Miramar. This approach, termed "energy level modeling", allows for a more intuitive design, a simpler integration, and expanded trainer capability. The merits of this method will be discussed in terms of ease of development and suitability for training. The focus will be on energy level modeling algorithms used for simulation of electronic countermeasures (ECM), or "jamming".

HISTORICAL DESIGN APPROACH

There are two basic approaches to the problem of providing a radar simulation. One is an effects level model where the emphasis is on providing the correct display appearance. The second uses energy level modeling to track the emission of microwave energy, its interaction with the environment, energy captured by the antenna, and hardware-induced modifications to the resulting signals. Under normal conditions, either approach can provide an accurate simulation of the radar.

Historically, effects level modeling has been chosen for sensor simulation of ECM. Until recently, this simplistic approach was all that could be implemented for reasonable cost in a real-time system. Although simulations were developed using energy level principles, these systems did not have real-time capability and were not designed with training in mind.

Hardware Platform Selection

While not directly related to the design methodology, another distinction can be drawn between two historical approaches. In the past, *the substantial processing necessary for real-time* radar simulation dictated designs utilizing specialized analog hardware or custom digital processors. However, with the increasing availability of low cost, high speed processors, a software design can now be implemented. The approach chosen for the F-14A trainer upgrade was to use commercial, off the shelf (COTS) digital processors. This allowed for the radar simulation algorithms to be purely software-based, allowing maximum flexibility. For reasons of cost, implementing a software design on low maintenance COTS equipment is preferable to designing and maintaining simulator-unique hardware.

Effects Level Simulation

Effects level design concentrates on devising an algorithm which presents the appropriate display to the operator. The algorithm is primarily concerned with the appearance of a system capability or artifact and is generally very efficient. This approach can provide an accurate simulation of a radar during its standard modes of operation. The requirements analysis and system engineering is done empirically. For instance, the detection ranges of different types of targets are determined by performing a limited (and hopefully representative) set of experiments using the sensor device to be simulated. The resulting "rules" are encoded in the hardware or software which implements the model. Different aspects of the radar being simulated can be modeled and modified in isolation as the system is developed and integrated. Changing the characteristics of one artifact will have no effect on another artifact. This makes adjustment of environmental effects (like reducing atmospheric attenuation) a difficult proposition.

The traditional effects level approach to ECM simulation provides only the visible display effects of a jammer without performing any detailed modeling of the energy responsible for these display effects. Modeling the brightness of a jammer on a radar display as a direct function of its distance is a simplified example of this approach. When ECM is modeled in an effects level simulation, it can become isolated from other models in the simulation such as targets and landmass. Often, the effect of radar operator actions is not fully taken into consideration.

The effects level design is based on the philosophy that for every environmental or operator action there is some related effect that may appear on the displayed output. An accurate but tedious extension of this approach would be to catalogue every possible combination of conditions and their corresponding outcomes. This endeavor would produce an exhaustive catalogue. Writing the simulation software, however, would call for little actual design. It would instead require a tedious data entry effort. Computer hardware to handle such a program in real-time would have to be generations beyond what is available today.

Since such an accurate simulation is not feasible in real-time, the effects level compromise is to simplify the "real world" cause and effect table down to a few of the most meaningful relationships. This provides a simulation that gives a reasonable approximation to reality, while attempting to provide the greatest fidelity in areas of interest to training. When a limited number of effects are simulated, the computer algorithm becomes quite efficient. This approach allows software models to be easily constructed once accurate information is collected about causal connections and training priorities. Testing is simplified because the limitations of the design can be identified from the beginning. These features are some of the reasons that effects level models became the standard in radar simulation.

On the other hand, there are several drawbacks to the effects level approach. Without access to direct experience in every complex training scenario, it may be more difficult to identify design requirements for an accurate implementation. If requirements are changed or clarified, additional engineering is required due to lack of design flexibility.

The impact on training is significant. A simulator designed with effects level principles tends to be more generic and less flexible. Training scenarios tend to be predictable. The system may be less responsive to a student's or instructor's input. As a consequence, the trainer tends to be less realistic in operation, and training goals are not fully realized.

ENERGY LEVEL MODELING - A DESIGN PERSPECTIVE

The alternative to effects level simulation is an approach called "energy level modeling". The goal of a faithful simulation with the correct effects is the same, but the solution is a bit more complicated. The focus is on understanding and modeling the underlying physical principles that bring about a sensor effect rather than on the effect itself.

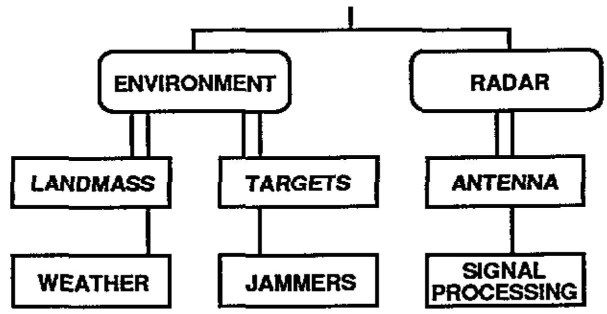

Figure 1 Object Hierarchy

In sensor simulation, the primary physical principle characterizing the model is energy level. This is true whether the sensor being modeled is designed to react to radar, infrared, light, or even sonic energy. The aim of energy level modeling is to determine the strength of a return on a display (or to send to another subsystem) by finding the amount of energy present at several significant points in the simulated environment. Although the name "energy level modeling" was chosen based on the principle of tracking energy intensity throughout a model, there are other characteristics of the signal besides energy intensity, such as wavelength, phase, coherence, spectrum, and pulse repetition frequency (PRF) that are tracked in the same manner.

Design Details

Although not inherent to the principle of energy level modeling, an object oriented design (OOD) strategy is recommended for implementation of a sensor simulation. Object oriented design allows for a logical breakdown of the components of a simulation. It allows for data encapsulation, while still providing a mechanism to share data between objects.

One example of an object oriented breakdown for a sensor simulation begins with the distinction between environment simulation and signal processing (see figure 1). Separate software routines simulate the real world outside the sensor and the processing of received energy inside the sensor. The environmental routines can be further broken down into objects that relate to landmass, weather, target, and jammer simulation.

Overview - In the case of a radar simulation, the first point at which energy is measured is at the radar transmitter. This is accomplished by performing a computation based on transmitter power, frequency, modes, and any simulated transmitter malfunctions. The effect of most operator actions is taken into account at this point. Next, the percentage of transmitted energy that arrives at the radar reflector is computed based on atmospheric and range attenuation and antenna gain pattern. Using the characteristics of each simulated environmental reflector, the energy returned toward the sensor is calculated. Finally, the amount of that energy is reduced by the return-trip atmospheric and range attenuation, and the receiver antenna gain is factored in. Once the intensity of radiation received in the waveguide is computed, it can be summed together with received intensities of similar character from other environmental reflectors. The appropriate signal processing computations may then be performed in order to determine whether the energy meets the required thresholds for display or detection. It is during this final step that other operator actions such as manual gain or threshold adjustment come into play.

Landmass - The terrain return is computed by sampling a local area map based on Digital Mapping Agency (DMA) data. This provides the altitude and reflectivity of a representative sample of points in the landmass database. At any given point, the return from a terrain patch is computed based on its reflectivity, distance, and angle of incidence. Because landmass is simulated as area clutter, the computed value for received power is attenuated in proportion to the cube of the range to the terrain reflector. The effect of the landmass blocking the line of sight to other environmental reflectors is also taken into account.

Weather - The weather return is computed based on the intensity of the weather cell and distance to the cell. Weather also has the effect of partially attenuating targets and landmass whose return must pass through the weather cell. Each portion a weather cell can also attenuate return from other portions behind it, so weather is simulated as volumetric clutter. The degree of this attenuation will vary based on weather intensity and (in the case of a radar sensor) transmitter frequency.

Targets - Target return is calculated from distance to the target, its radar cross section (RCS), and any atmospheric or weather-related attenuation. The received power is attenuated in proportion to the fourth power of the range to the target. This is done because, unlike landmass, the amount of reflecting target area does not vary with range. Objects which are smaller in size than the radar resolution are simulated as point targets. Larger targets can be combined with landmass or split into multiple point targets.

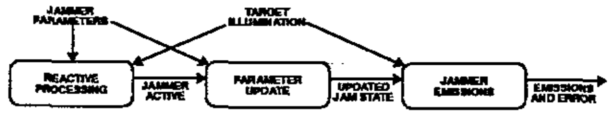

Figure 2 Jammer Data Flow Diagram

Jammers - When simulating the radar return of ECM, different strategies may need to be used based on the jammer type. Two examples are given here.

A simple noise jammer will emit high levels of radar energy regardless of the presence of other emitters. Model calculation for this threat begins at the jammer itself. Its effective power is attenuated by its own antenna gain. At this point the energy is treated as if it were a reflected radar return. Its one-way range attenuation and receiver antenna attenuation are calculated and applied to the energy generated.

A coherent repeating or transponding jammer echoes back an amplified or modulated version of any radar energy it may detect that falls within a certain frequency or power range. This type is handled in the same way as a target return. The difference is that the repeater gain is used instead of RCS to figure the turnaround differential at the target. In this way practical limits on total jammer power output can be simulated.

All jammer types can be simulated using a similar object structure. An example of a typical jammer object data flow is shown in Figure 2.

Signal Processing - In the signal processing routines, the return from each of the environmental objects is summed into one total return. Antenna gain is taken into account. Inputs from the sensor operator, like mode or channel switching, are factored in. Internal controls such as automatic gain control are applied.

Analysis

A limitation of this approach is that a greater investment in research and requirements analysis is required. This additional research is needed to identify sufficient underlying radar and ECM characteristics to provide an accurate energy level model. Feedback from experienced sensor operators remains an important part of the design process. An energy level model may also consume more processor time than a simple effects level model.

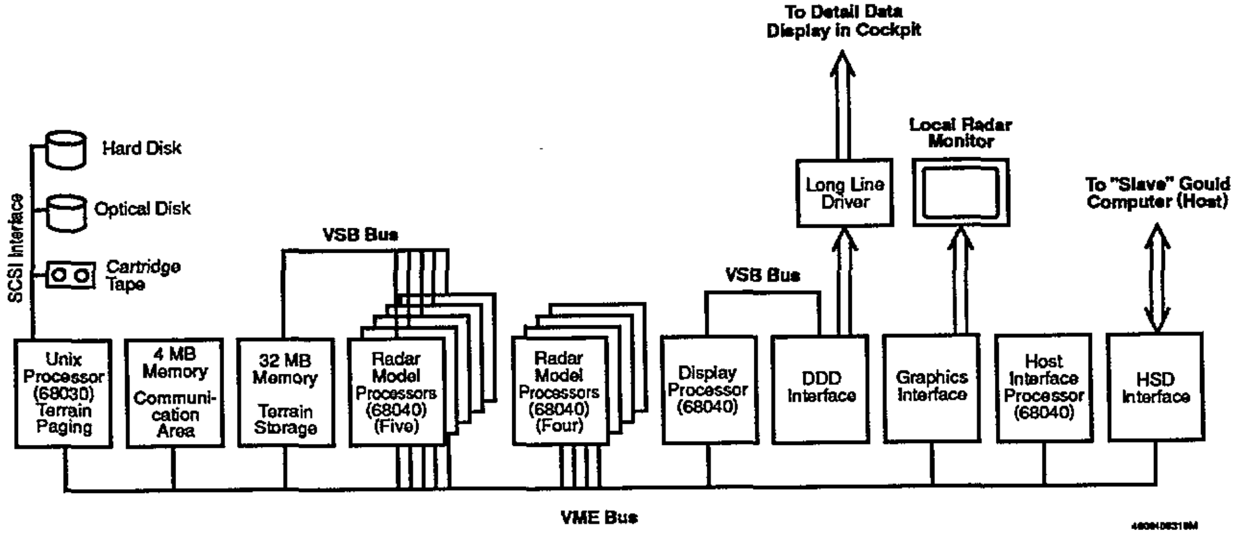

Figure 3 RES Processor Architecture

This extra investment during requirements identification provides a benefit during the design of the actual algorithms. This is a good example of allowing the computer to do the work rather than the programmer. With the proper radar equations encoded into the software, maintainability is improved. Enhancements can be implemented without additional research into the underlying radar equations.

ENERGY LEVEL MODELING - A TRAINING PERSPECTIVE

There are several benefits of simulator training utilizing a real-time energy level model instead of the simpler effects level model. The most predominant of these is the improved realism of the simulation afforded the student by providing an interface with the actual radar system software and control devices. This is preferable to using a software engineer's conception of radar displays, especially those affected by ECM, for two reasons. Pre-designed displays may not necessarily be correct for a given scenario, and planning for every possible scenario creates an inflexible training environment.

Realism is further enhanced by simulating the inconstant nature of energy waveform interactions emanating from two or more jamming sources. In the real world these waveform additions and cancellations would have to be interpreted by the radar system and displayed in a form consistent with running radar software. Depending on the various levels of the received energies, atmospheric attenuation, operator selected gains and a host of other variables, actual displays will be constantly changing. This phenomenon is not present at all in the effects level model. While the predictability of effects level modeling allows a specific scenario to be repeated unchanged until the desired response is elicited, the scenario itself is not a true simulation.

Another benefit realized by an energy level modeling solution is that a wider variety of potential effects are available for demonstration. By allowing the instructor to adjust ECM parameters such as sweep rate, frequency bandwidth and repetition rate to real or suspected values, an unlimited number of training scenarios can be presented with highly accurate displays. The energy level model is completely adaptable to future generations of jamming platforms with little additional software coding required.

Furthermore, all effects are interactive. The programmer does not have to design displays to fit all possible scenarios. All combinations of jammer energy are simply calculated, summed and passed to actual radar software for display. As a result, a wide variety of jamming platforms is available for display. This allows for the utmost in flexible training opportunities.

Given that real-time operator action is factored into the equation as the scenario proceeds, the display effects resulting from operator input are realistic and instantaneous. This allows the instructor to reinforce proper decisions "on-the-spot" which equates to both a better understanding of ECM cause and effect concepts and a faster learning of correct procedures and techniques. Consequently, while effects level models afford limited training for a finite number of scenarios, the realism and flexibility offered by the energy level model allows a greater amount of quality training to be conducted.

APPLICATIONS

Energy level modeling is a relatively sophisticated approach to sensor simulation. Recent improvements in the power and cost of general purpose microprocessor-based computers make approaches such as this one possible. The suitability of energy level modeling to ECM simulation has been demonstrated by the F-14A Weapon Systems Trainer (WST) upgrade. Also, there are numerous other applications where this approach would be appropriate.

F-14A Weapon Systems Trainer

The main goal of the F-14A WST upgrade was to provide an accurate and maintainable ECM simulation at a reasonable cost. Rather than modify the existing obsolete radar simulation equipment, a new Radar Environment System (RES) was built. The choice of real-time computational hardware, a VME chassis with eleven 68040-based Motorola MVME-165 cards (see Figure 3), helped make the energy level model a success on this upgrade. These processors provided the power to make energy level computations using floating point arithmetic in real-time.

An extensive list of electronic countermeasures was provided on the new RES. Some of the ECM simulated were spot noise jammers, barrage noise jammers, velocity gate stealers, range gate stealers, false doppler target generators, repeater noise jammers, cross polarization jammers, swept amplitude modulators, and combinations thereof. In all, over thirty distinct jammers were simulated.

The RES simulated the functionality of the AWG-9 radar subsystem (see Figure 4).

Accordingly, it was required to interface with actual on-board computer (OBC) subsystem hardware and software by way of the host computer (see Figure 5). As a result, the ECM simulation was required to generate output that was realistic enough for identification by threat recognition algorithms in the OBC. An accurate presentation on the radar display was also a requirement. The energy level approach proved to be ideal for meeting these requirements, especially when simulating scenarios involving target screening and standoff jamming.

After the RES was successfully installed, an additional software upgrade was delivered. The schedule and cost of this modification would not have been possible without the flexibility of the energy level modeling design approach. Furthermore, such a change would have been prohibitive to make in the original analog hardware radar simulation system that was replaced by the RES.

Potential for Other Systems

Such an approach has many other potential applications. Any trainer or simulator that uses analog equipment or older digital equipment for its sensor simulation subsystem could be a candidate for such an update. Today's digital systems have the power to allow engineers flexibility in their software design. Designers can concentrate more on the radar models and spend less time worrying about software shortcuts (such as using integer arithmetic or assembly code) to satisfy real-time requirements.

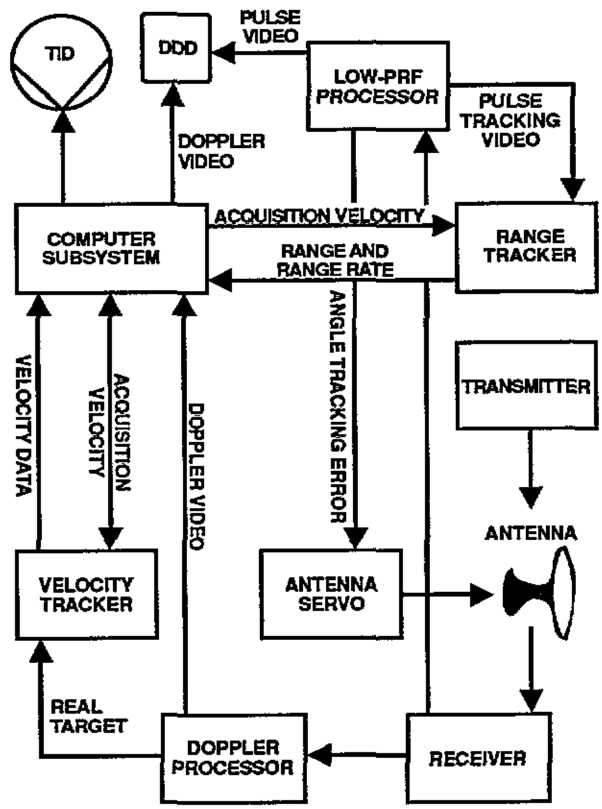

Figure 4 AWG-9 Radar Subsystem

This approach also makes sense for any system where improved fidelity or realism is crucial to the training objective. If the simulation host processor is sufficiently fast and has enough spare capacity, an energy level sensor model could be added in software with no hardware modifications at all. The improvements in microprocessor technology have made feasible new software design approaches that were not possible even five years ago.

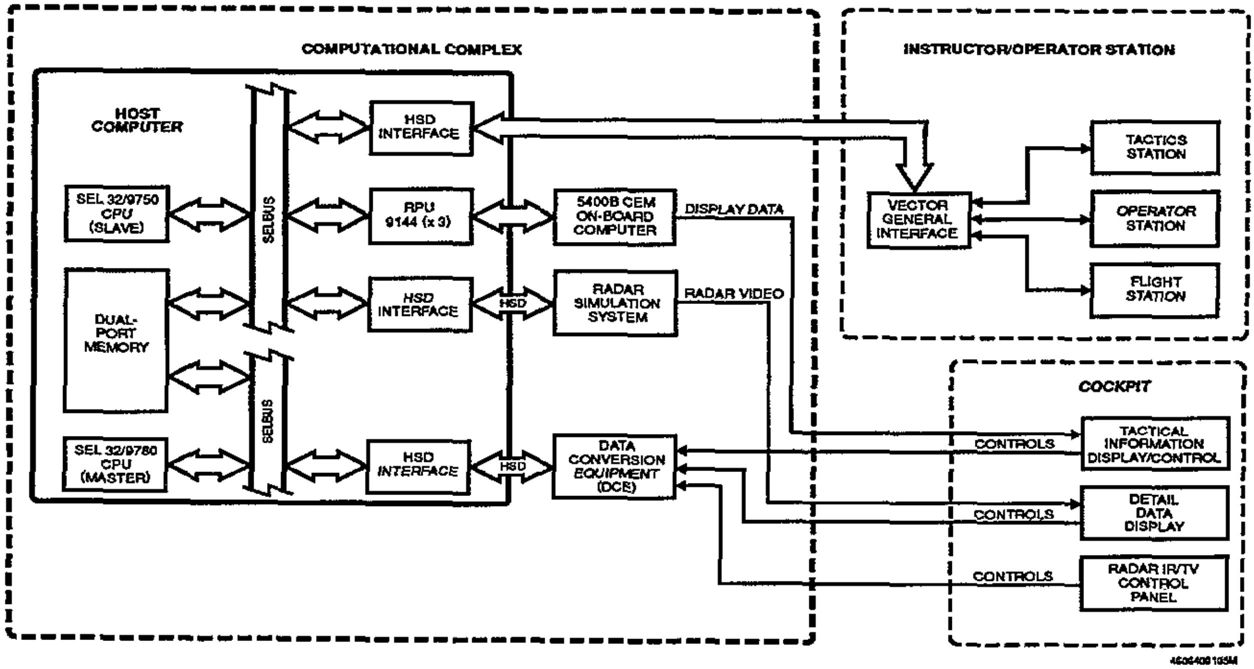

Figure 5 Trainer Diagram

CONCLUSION

The software design approach called energy level modeling, made possible by recent advances in hardware technology, has many benefits from both a design and training standpoint. Reliability, flexibility, and fidelity are all enhanced. It is hoped that others will be able to apply these principles to a wide range of real-time applications. As computational power increases, software design solutions must continue to evolve to exploit the potential of machines providing greater speed and capacity. The principles that underlie energy level modeling should inspire continual methodology improvements as hardware capability grows.