Radar performance analysis system: A software package of learning simulations for electronic laboratories

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ABSTRACT

The purpose of this paper is to present design/development and implementation of the automated end-to-end functional radar simulation software package: Radar Performance Analysis System (RPAS). This study demonstrates its usefulness as an educational tool. The review of literature supports the use of technology in a variety of learning environments. In addition, this study suggests that RPAS can be extended to solve problems of dynamic systems.

INDEX TERMS

Education, MATLAB, Radar, Simulation

I. INTRODUCTION

Literature shows that the radar system design and application follows the paradigm that focuses on rigorous mathematical derivations. However, few books provide software simulation tools. Because radar system technology has evolved tremendously during the last decade, a need has been created for a software tool that focuses on the fundamental principles of radar and rigorous mathematical derivations. This software tool should be able to accommodate various users and inputs to analyze radar performance under different conditions. To address the need for a software simulation tool for radar and other applications, RPAS was developed during the summer fellowship program under the direction of Ru-Ying Roger Lee at the Naval Air Warfare Center in Patuxent River, Maryland.

Presently, computer simulation is used extensively in developing complex systems, including radar performance systems and other signal processing environments [1]. In order to analyze the performance of radar at a system level the basic radar principles must be used to model their performance with the top-level parameters characterizing the radar design. Computer simulation is the most practical method of supporting system analysis due to the complex system interactions between radars and parameters relating to the environment [2]. However, radar simulations, like most real-time signal processing tasks, require significant quantities of data. The data set contains a collection of different signals. As a result organization of the data implies some constraints on the way the data is processed by different functions [3].

The existing PC-based software, although lower in cost, falls short of meeting the high powered simulation requirements needed to test complex radar equations [4]. Several potential software-based enhancement solutions were studied along with the trade off considerations to meet the complex modeling requirements of the radar system technology. The Electronic Workbench is a popular circuit capture and simulation system that is frequently used for educational training [5]. However, the Electronics Workbench lacks the ability of simulating model equations. Because of these limitations, it was decided to use MATLAB (Matrix Laboratory), a special purpose computer program optimized to perform engineering and scientific calculation, in the implementation of RPAS.

MATLAB is particularly useful for RPAS because it can reduce overhead and speed up development. It provides abundant mathematical and engineering functions and comprehensive graphics routines. This is useful for the development of scientific and engineering systems [6]. In addition, MATLAB also offers graphical user interface (GUI) tools that allow the designer/developer to use MAT-

LAB in an application development environment. This research indicates that MATLAB is an excellent choice for the development of RPAS.

Since MATLAB does not contain radar function library database. The Radar function library database was designed/developed in RPAS for six different categories: Radar Equation, Radar Detection, Radar Search, Radar Measurement, Environment and Mitigation Techniques, and Radar Countermeasures and Counter-Countermeasures. Finally, a seventh category called Others was added to the system. This category mainly included the topics of simulation associated with the Electronics Engineering Technology courseware. The category Others was added to demonstrate the ease of creating and simulating applications with RPAS.

Section II of this paper documents the RPAS system design, section III describes RPAS special features and capabilities, and section IV shows how to use RPAS for simulation of models in Electronics Engineering Technology.

II. SYSTEM DESIGN AND RADAR SIMULATION

A. System Design

RPAS is designed as an open architecture system which results in a generic analysis and evaluation tool. RPAS is a static system; it analyzes and evaluates the radar performance at the system level. Figure 1 shows the information flow among various components in RPAS. For easy maintenance and expansion of the simulation program, a modular approach was adopted for the implementation.

Several push buttons such as *Figure*, *Result*, *Clear*, and *Cancel* were created by using the GUIDE (Graphical User Interface Development Environment) facility of MATLAB [7]. In the block diagram, shaded rectangles are menu/submenu. Shaded ellipses are the switches, and the underlined names are the software modules. The modules ending with CB are callback functions. For instance, the *ResultCB* is invoked when the *Result* button is pressed. The *ResultCB* function, in turn, invokes the *GenResult* function. The *GenResult* retrieves a specific function from the Radar Library. The retrieved function, derived from menu/submenu, uses parameter inputs and selected data units stored in Global Data by *ParInputCB* and *SelectBoxCB* to compute results. Solid lines represent control flow, dotted lines represent data flow, and dot-dash lines indicate how the GUI is enabled.

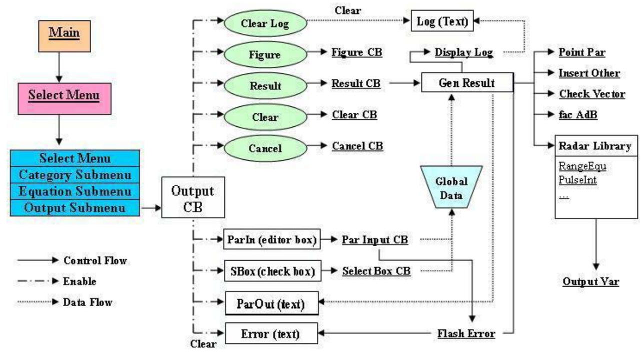

Figure 1. RPAS/function block diagram

B. Radar Simulation

This section describes the features of RPAS. For example, the basic form of the radar range equation gives the ratio of signal power from the target to the background noise power at the radar receiver; this includes both noise received from the external environment and noise added in the radar [8]. The following classical Radar Range equation was used to demonstrate the simulation using RPAS.

$$S/N = (Pp\ \tau\ Gt\ \sigma\ Ar)/[(4\pi)^2\ R^4 k\ Ts\ L] \qquad (1)$$

where

S/N = radar signal-to-noise ratio (factor)
Pp = radar transmitted peak RF power (watts)
τ = radar pulse duration in seconds
Gt = radar transmit antenna gain (factor)
σ = target radar cross-section area (square meters)
Ar = radar receive antenna effective aperture area (square meters)
R = range from the radar to the target (meters)
Ts = radar system noise temperature (kelvin)
L = radar system losses (factor)
k = Boltzmann's constant (1.38e-23 joule/kelvin)

A simple simulation of radar was undertaken with the antenna transmitting 1kW of peak power with a duration of 1msec at a frequency of 3 GHz. The receiver has a gain of 32dB, the effective aperture area is 14 square feet, the target cross section is 92.903 square meters, the loss factor is 10, and the effective noise temperature is 800K. Signal-to-noise ratio was computed at a range of 20, 40, and 100 nautical miles.

This simplified example provides a parameterizable radar system, where the geometry of the antenna and other parameters can easily be changed.

The following special features and capabilities will be discussed in the next section:

- The database design to achieve a generic system.
- Selection of the output parameter of an equation.
- User input with Unit selections.
- Compute and show output.
- Execution records/history in the LOG area.

III. RPAS SPECIAL FEATURES AND CAPABILITIES

A. Database to Achieve a Generic System

The RPAS system is designed to be application independent. Radar function library was developed to solve generic problems. The text of pull-down menus for *Category, Equation, Output selections, Mathematical Expression of Equation, Input Parameters* and *Unit Selections* are all read in from a master database file. The system is a generic system not only for the radar application but also for general application. Selecting another master file, the system can become an "electronics engineering," a "civil engineering," or a "mechanical engineering" performance analysis system. In the current RPAS system, all equations for radar applications are implemented into a package called the "Radar Library." This approach presents a simple and concise way to define a function in a manner equivalent to functional languages using higher-order function.

B. Selection of Output Parameter of an Equation

The RPAS groups all radar equations into six categories: Radar Equation, Radar Detection, Radar Search, Radar Measurement, Environment and Mitigation Techniques, and Countermeasures. The user selects a particular equation via the SELECT ->CATEGORY -> EQUATION pull-down menus. For example, the above radar range equation is obtained from the selection of SELECT -> RadarEquation ->RangeEq equation as shown in Figure 2. Equation (1) is a Radar Range Equation having S/N as output and the other parameter as inputs. When the user has selected this equation with this output, as shown in Figure 2, the system provides the mathematical expression and prompts the user for input as shown in Figure 3. The system also provides the user with the capabilities of using the same Radar Range Equation but selecting another output parameter, such as R, the range. In this case the system should provide the mathematical expression of the Radar Range Equation with R as output and again prompt the user for the input parameters. Likewise, other parameters in the Radar Range Equation can be selected as output. If it is known that some parameters, for example Ts, will never be an output, one can disable the output selection of this particular parameter as shown in Figure 2. Furthermore, it should be noted in Figure 2 that the allowable parameters for output are S/N, pulse width, and range. Also, the switch *cancel*, shown in Figure 3, can be used for canceling the previous selection and selecting a new equation and output.

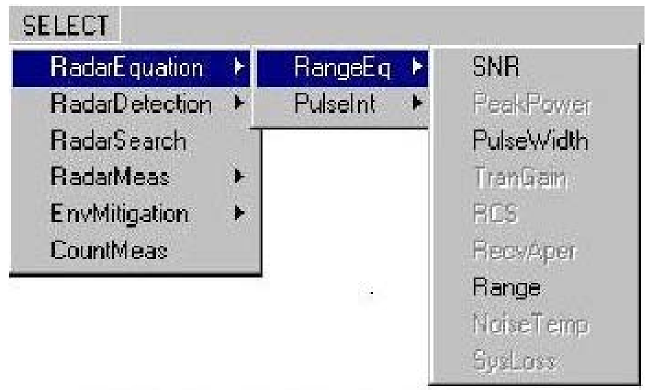

Figure 2. SELECT -> RadarEquation ->RangeEq

C. User Input with Unit Selections

System response to user selection of equation and output parameter is shown in Figure 3. The user enters data to the prompted input parameters. The valid inputs are: (a) single value x; (b) a sequence of values separated by commas (,) as x,y,z; (c) beginning and ending values with step value 1 as x:z; and (d) beginning, step, and ending value as x:y:z. If the input is other invalid data, the system will flash an error of "illegal input at nth input" in the "system error box" at the left bottom corner of the screen. Also shown in Figure 3, the system provides the user with the capability of selecting various commonly used units for inputs and output, and once a unit is selected, the other units of the same parameter will be automatically unselected. A user can also start with a clean "sheet of input" by clicking the *Clear* switch and then entering the new set of data.

D. Compute and Show

The user can click the *result* switch for numerical output or the *figure* switch for a plot after the inputs and data unit selections are entered, If one input is a vector, then a click of the *result* switch will yield a vector result, and a click of the *figure* switch will plot a two-dimensional figure of input vector vs. output vector. If two input vectors are entered, then these two will form a mesh, and a click of the *result* switch will yield a two-dimensional output. A click of the *figure* switch will yield a three-dimensional plot with the two inputs vector as x – and y-axes and output as a z-surface. When a three-dimensional plot is displayed, the user can further leverage the MATLAB figure utility to manipulate the figure such as 3-D rotation. Figure 4 shows the three-dimensional figure after the *figure* switch is clicked and a rotation is applied to the figure.

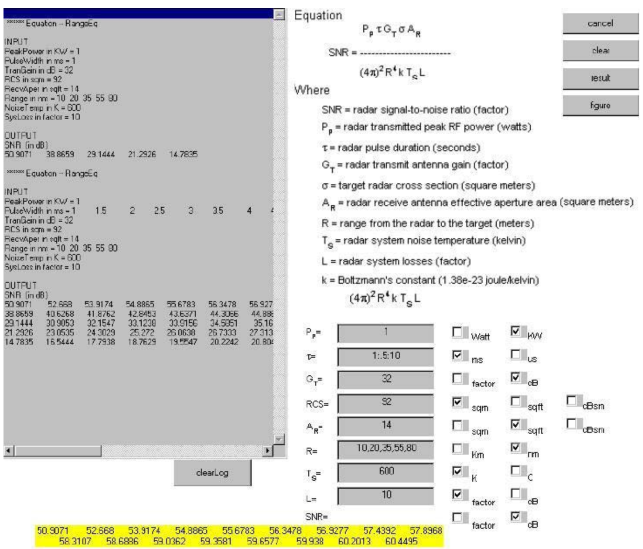

Figure 3. Execution of the Range Equation

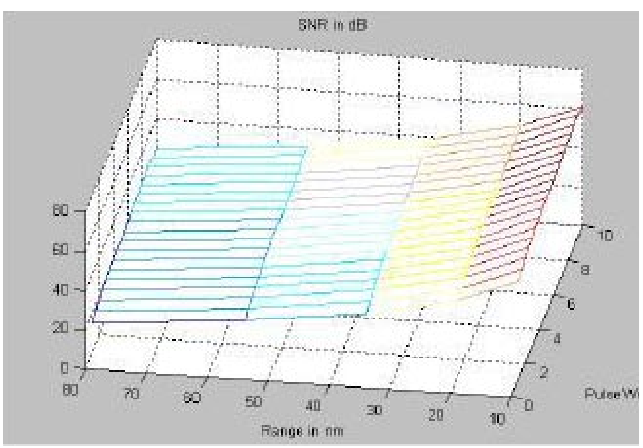

Figure 4. 3D plot of the Radar Range Equation

E. Execution records/history in the LOG area

Upon the execution of the range equation, the input and the output will be displayed in the LOG area on the left side of the screen, as shown in Figure 3, for review or to print out a hardcopy. The LOG text will be concatenated from one run to the next run. A *clearLog* switch is also available to clear the text in the LOG area.

IV. OTHERS CATEGORY

MATLAB is a dynamic software program for solving problems in engineering courses. The use of MATLAB provides a unified approach for engineering students to learn one problem— solving software package. The RPAS software package developed in MATLAB can be fully integrated into any course with little effort and can provide a viable method for solving problems in engineering and technology curriculum. The following example of an RC circuit analysis is presented to show the flexibility of RPAS.

A capacitor is a storage device for electrical energy; the presence of an electrical charge on its plates produces an electric field between them. For example, consider a circuit where a battery of emf "E" is connected in series with a capacitor of capacitance "C" and resistor "R", such a circuit is termed as an RC circuit. When the voltage is applied to the RC circuit, a charging process takes place and the voltage across the capacitor assumes the form:

$$Vc = Vfinal + (Vinitial - Vfinal)^{e}[-t/RC] \qquad (2)$$

If the capacitor is initially uncharged, i.e., Vinitial = 0, and the input voltage corresponds to change in voltage from 0 to E, which implies that Vfinal = E, then the time variation of Vc(t) becomes:

$$Vc(t) = E(1^{-e}[-t/RC]) \qquad (3)$$

Problem: Find the three-dimensional plot for the transient behavior of Vc, when E = 40 volts, R = 8 k ohms, and C = 4, 6, and 8 uF.

In the analysis R is kept constant and the value of the capacitor is changed. Figure 5 shows the inputs and output after the execution of RC circuit. Figure 6 shows the effect of changing C on the charging phase. It shows that the larger the capacitance, the larger the time constant and the longer it takes to charge up to its final value [9].

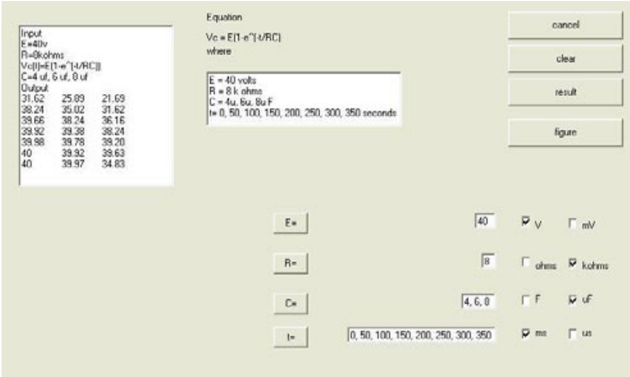

Figure 5. Execution of the RC circuit

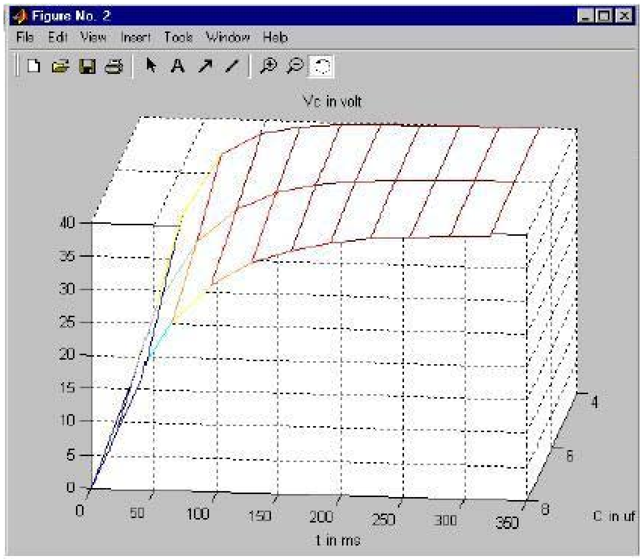

Figure 6. 3D plot of the RC circuit

V. FUTURE DIRECTIONS

Many different issues can be addressed as a result of RPAS effort. At present RPAS is a static software package that can be fully integrated into any course with minimal effort and can provide a robust method for solving engineering problems with a computer. Future research will expand RPAS into a dynamic system to analyze/evaluate the radar performance at an operational level in an environment where the radar equation, target geometry, terrain model, weather conditions, and jamming can change with time.

VI. REFERENCES

[1] Desodt, G., Miller, D., and Puzenat, D., "OSCAR, a simulation environment dedicated to the design and performance assessment of RADAR system," *International Conference on Radar*, Paris, 1994.

[2] Barton, D. K., *Modern Radar System Analysis,* Artech House Radar Library, 1988.

[3] Fransen, F. H. M., Balasa, F., Van Swaij, M. F. X. B., Cathoor, F. V. M., and De Man, H. J., "Modeling multidimensional data and control flow," *IEEE Trans on VLSI Systems*, pp. 319-327, 1993.

[4] Mahafza, Bassem R., "Radar system analysis and design using MATLAB," Chapman & Hall/CRC, 2000.

[5] Electronics Workbench. Available: http://www.electronicsworkbench.com

[6] Hanselman, D., and Littlefield, B., *Mastering MATLAB, A Comprehensive Tutorial and Reference*, 2001.

[7] Chapman, Stephen J., *MATLAB Programming for Engineers,* Brooks/Cole, 2002

[8] Curry, Richard, *Radar System Performance Modeling,* Artech House Radar Library, 2000.

[9] Boylestead, Robert L., *Introductory Circuit Analysis,* Prentice Hall, 2004.

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