REUSABLE SOFTWARE - TOWARD RECONFIGURABLE TRAINER SYSTEMS

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ABSTRACT

As the degree of sophistication of military equipment has increased, there has been a corresponding increase in the complexity of trainers, not only for the equipment, but also for the inter and intra service environments in which such military equipment will be used. The most explosive area has been computer software. Trainers and training systems have become a software-intense product. However, for a number of reasons, the perception of training systems users and training systems manufacturers alike is that each new training requirement is unique to such an extent that the required software must be newly developed each time. What are the causes of that perception, and is that perception accurate? Could software modules which perform specific functions be transportable among several training system families? Will the training system manufacturer who first proposes reusable software be in a position of favor for successive training system contracts? This paper not only addresses these questions, but also speculates on some inroads which are being made in transportable training system software and examines the opportunities which this approach presents. One of the most significant of these is making training systems themselves able to be configured in multiple ways.

INTRODUCTION

Reusable software is needed to reduce the cost and risk of trainer development. The software development cost of a typical trainer may be as much as four to five times that of the hardware cost for a single system [1]. The millions of dollars of software development costs for a large trainer are applicable only to the one or several units of that particular training device. The cost savings alone justify an extensive effort to reuse the software products generated on similar trainers.

Further, the cost of the software development alone does not include the costs that result from schedule delays in developing the software and in correcting deficiencies once the software is delivered. Software development is practically synonymous with schedule delay, and sofware bugs are a major cause of complaint by the users of training devices [2]. The cost of delays in the training schedule caused by late delivery of the trainer may be more significant than the cost of the software development. Correction of software malfunctions after the trainer is delivered can result in many hours of downtime. Cost of this downtime has been estimated to be $100 to $400 per hour for different categories of flight trainers [3].

Reuse of software in trainers offers a solution to the high cost of software development and an improvement in software reliability. In addition, the development of standard software will reduce the development time for a new trainer and lead to a simplification in trainer operation. The simplification will result from continuous improvement of the instructor and student interfaces to provide "user friendly" operation and from the common interfaces for each trainer that will reduce familiarization time required for each new system.

The key to the savings that can be achieved is the development of standard data bases, mathematical models and software modules that can be used for many trainers. This paper describes the trainer data base and mathematical modeling requirements that might be standardized, some of the DoD initiatives to develop such standard data bases and mathematical models, and further steps required to achieve the goal of reusable software.

CANDIDATES FOR STANDARDIZATION

The three primary candidates for standardization to achieve reusable software are (1) data bases, (2) mathematical models, and (3) instructor interfaces. The heart of the simulation is the mathematical model that computes the environment and the vehicle dynamics. This computation is supported by a data base that provides the parameters needed by the mathematical model. This combination provides the simulation which can accept student inputs to model the situation and provide realistic cues to the trainee about what is occurring.

The instructor manages the training problem and monitors student performance through communication with the computer. In early trainers, the instructor initiated the problem and monitored student performance through outputs such as repeaters of aircraft instruments and over-the-shoulder interaction with the student. Newer systems put a much greater burden on the instructor in monitoring the performance of more students and providing additional inputs to the training problem. This greater burden on the instructor has been made possible by providing the instructor with computer assistance in the tasks to be performed.

The key to reusable software is the separation of functions into separate software modules. A significant change from some of the earlier trainer systems is the separation of the mathematical model from the data used to implement the model. Thus, for example, the vehicle dynamics are modeled by the equations of motion which are independent of the vehicle performance. The mathematical model is related to the specific vehicle being simulated by a data base which contains both the vehicle characteristics and the environmental characteristics.

Development of the instructor interface requires the same sort of modularization. The instructor functions that are trainer specific must be separated from the procedures. For example, an instructor might be given a menu of possible options. The selection of options would be a general program that provides a table of possible actions and allows the instructor to select one of the options. The options themselves would be provided in the form of a data table that is tailored for each application.

DATA BASES

Trainers use data to represent the external environment, the characteristics of the vehicles and operational equipment or weapons systems being simulated, and information needed to evaluate student performance. One of the early developments of a data base for use in training was the compilation of topographic and cultural features of land masses developed by the Defense Mapping Agency. More recently, several Navy laboratories have cooperated in the development of a data base of the characteristics of acoustic targets.

DEFENSE MAPPING AGENCY DATA BASES

The Defense Mapping Agency (DMA) is the primary source of topographic and cultural data needed for training. Prior to the computer revolution, these data were provided in the form of maps which were used by the contractor for a trainer system to provide a computer data base. In the early 1970s, DMA generated data by digitizing existing maps to provide elevation values for land mass and the location and type of cultural features included on the maps. These data were used in early radar trainers.

The need for a more complete data base than that provided by the digitized maps was recognized. DMA was given the task of developing a data base that contains cultural data to a resolution down to 50 feet in some areas. This data base was used to support the F-111 flight trainer.

The need for a data base to support visual system, high-resolution radar and IR systems has led to reformatting of the data base and a new effort to provide the data needed to support these systems. A standard simulation data base (SSDB) is being developed as a joint services effort. Because of high resolution requirements brought on by the evaluation of computers in the training simulation community, the original DMA data base was not sufficient and needed enhancement. This enhancement was implemented through photographic methods, land survey data gathering and other methods. Thus, a set of generic data bases to be used in support of new simulators is being developed. These include: radar, visual, IR, etc., and the result has been to make each data base a dynamic entity, each version or generation more complete in detail than its predecessor, without repetition of the front-end development work. With these additions, these data bases should meet the training needs through the 1990's .

ACOUSTIC DATA BASES

Until recently, the need for acoustic data bases was satisfied by having the contractor for each trainer development obtain the data necessary to meet the requirements of that trainer. Three different types of data are required for simulation of acoustic sensors: (1) specification of the ocean environment, (2) specification of the target characteristics, and (3) specification of the operational characteristics of operational acoustic processors and sensors. The initiatives to meet these needs are described below.

OCEAN ENVIRONMENT. Specification of the ocean environment is a requirement for prediction of operational sonar capability. Data bases on the ocean characteristics are available from the Fleet Numerical Oceanographic Center (FNOC) and are included as part of the Sonar In-Situ Mode Assessment System (SIMAS) and the Integrated Command Anti-Submarine Warfare Prediction System (ICAPS). The incorporation of these data bases into the training system is part of the standard ocean modeling effort described in the next section.

TARGET CHARACTERISTICS. Simulation of the acoustic signals generated from a target vehicle depends upon a data base providing the characteristics of all acoustic noise sources and their relation to mode of operation and target speed. The common Navy need for a standard data base for targets has led to a joint effort by Navy activities requiring such data on a continuing basis to develop the Common Acoustic Target Model Data Base (CATMDB). This data base, as a common source, is intended to support Navy needs in acoustic target simulation modeling for training device and operational equipment research, development, test, evalution, and long term testing/training scenario applications. The Naval Training Equipment Center, Naval Underwater System Center-New London Laboratory, the Naval Surface Weapon Center-White Oak Laboratory, the Naval Air Test Center, and the Naval Intelligence Support Center have been principal participants in the data base content/format development. The CATMDB describes those acoustic intelligence (ACINT) parameters considered to be necessary for developing useful Anti-Submarine Warfare (ASW) simulator/stimulator targets. The data base format allows storage of many parameters (all of which may not be available for a given target).

OPERATIONAL EQUIPMENT CHARACTERISTICS. The characteristics of each acoustic processor and sensor are needed for realistic simulation in a training system. Information, such as the directional response of hydrophones or sonar arrays, the signal processing algorithms used in the sonar sets, and the display characteristics are essentials that must be available to the training system contractor. Creation of a general data base to solve this problem is one of the proposed R&D efforts at the Naval Training Equipment Center (NAVTRAEQUIPCEN).

NEW INITIATIVES

The work described above provides a basis for intelligent extension of the concept of a standard data base to the parameters needed for flight simulation. Flight simulation is a primary candidate for standardization of a mathematical model for simulation of aircraft dynamics and the data bases to support application of the general model to simulation of specific aircraft. Since flight simulators have more commonality than other types of trainers, the development of a general flight simulator offers more universal application at less risk than a similar development for any other trainer type.

MATHEMATICAL MODELS

The major progress in mathematical model standardization in trainers is the development of a standard ocean model (SOM) for anti-submarine warfare training described below [4]. The potential development of a standard mathematical model for flight simulators is based upon a hierarchical description of the major flight simulation functions and work being done to partition the flight system functions into modules for microcomputer implementation and to develop transportable modules for a wide range of trainers. This effort is supported by the use of MIL-STD-1644(TD) to document software developed for training devices. The ongoing work to standardize mathematical models and software modules is described below.

STANDARD OCEAN MODEL FOR ASW TRAINING

The customary method of acquiring ocean models for trainer applications has been to place the requirement on the trainer contractor, resulting in a new and different model in each trainer. This practice has undesirable consequences for ocean model life cycle costs. It leads to repetitive contractor design, development and integration efforts and results in increased trainer cost to the Navy. Software maintenance of multiple independent ocean models is unnecessarily complicated and costly. Configuration management of multiple models and control over individual model upgrades is complicated and difficult.

More important, the lack of commonality among models in different trainers results in differences in simulation results. In situations where two or more sonar operator trainers have been interconnected to provide team training, disagreement in propagation loss predicted by the different ocean models has resulted in conflicting detection ranges. In addition, the different models produce inconsistent results compared to the detection ranges estimated by the Navy briefing packages.

The Naval Training Equipment Center has initiated the development of the SOM in order to avoid the disadvantages of multiple ocean models. This provides a one-time model development, eliminating future duplication of contractor effort and producing a net savings in both development and life cycle support costs. Configuration management is simplified and centralized, resulting in greater control over model evolution and allowing an in-house ocean model baseline and testing capability. Designed and intended for use in all types of ASW training devices, the SOM uses standard Navy models to generate consistent, reproducible results. The SOM will be provided as Government Furnished Information (GFI) to trainer contractors. The first use of this model will be in Device 14A12, Surface ASW Training System.

FLIGHT EQUATIONS

The flight equations used in simulation are another potential area for standardization. There are two levels of standardization possible in this area. The first would be to limit the number of mathematical models to one for each class of aircraft. This could be accomplished by providing a standard model for the variables within the equations and having a data base provide appropriate coefficients and constants for simulation of a specific vehicle. A second and more ambitious but feasible approach is to have one model for all vehicles. Either of these approaches require the selection of a standard coordinate system (i.e., force axis, body axis, etc). Exactly the same techniques for standardization can apply to such things as cabin pressure, hydraulics, pneumatics, etc. In addition to the savings achieved by avoiding the development of a new model for each simulator, this approach allows the user and maintenance personnel to understand the mathematical model and thereby makes life cycle maintenance easier and less costly.

STANDARD SOFTWARE MODULES

The development of standard software modules for the mathematical models described above is one area in which standardization can be implemented. Another approach is to define a hierarchical structure for a simulator program and develop the hierarchy down to the module level. The program for a flight simulator offers a prime candidate for such an approach. The first level of the hierarchy for a flight simulator program is described in the next section.

MAJOR PROGRAM MODULES/FUNCTIONS FOR A FLIGHT SIMULATOR

The major program modules/functions for a flight simulator are described below.

FLIGHT

The flight modules perform the real time simulation of the aircraft aerodynamics. Using such information for inputs as engine thrust, control surface deflections, stores loading, and fuel loading, this module solves the six degree of freedom equations of motion for the aircraft. The primary outputs include the aircraft attitude (Euler) angles, attitude rates, and aircraft velocities and moments in inertia space as well as in the local air mass. In addition, the flight module performs simulation of both the primary and secondary flight control systems for the aerodynamic response of the control stick, rudder, trim switch, flaps and speed brakes.

ENGINE

The engine module simulates the engine dynamics along with thrust forces, fuel consumption and engine startup and shutdown operations. Single engine and multiple engine failure can be provided by instructor inserted malfunctions.

MOTION SYSTEM

The motion system module provides the conversions of the appropriate body axis translational and rotational accelerations and angular rates from the flight module. The motion system servo command data are used to generate motion cues in consonance with pilot and flight control system inputs and resultant flight dynamic effects.

G-SEAT/G-SUIT

This module uses the present center of gravity location and the location of the pilot's seat in aircraft body coordinates to compute the translational accelerations at the pilot's station using the appropriate body axis translational and rotational accelerations and angular rates. The G-seat drive equations are designed to establish a linear relationship between air pressure delivered to the seat air cells and the accelerations acting on the aircraft. The lap drive equations provide signals for simultaneous belt movement which enhances negative acceleration cues. The G-suit drive equations establish suit pressure proportional to linear acceleration.

COMMUNICATION/NAVIGATION

The communication/navigation module performs the simulation of the VHF, TACAN, UHF and IFF systems which include the channel/frequency selection, in-tune, and in-range functions. Also, navigational functions of the air data computer and inertia navigation system (INS) are provided to the flight control system, propulsion system and other aircraft systems.

VISUAL

The visual system module computes the geometric relationship between the out-of-the-window scene and the aircraft's position; provides command data for the target, missile, and background projectors and the visual system; and provides data for the CRT displays.

ACCESSORY

This module consists of the following functions: (1) hydraulic system which simulates the hydraulic pressure indication for the flight controls and the associated caution displays and indicators. Dynamic simulation of the system pressure and demand capacity relationship can be included as well as instructor inserted malfunctions; (2) fuel system which simulates the fuel quantity indications, fuel available logic, normal fuel transfer, weight, and center of gravity for all fuel tanks for both normal and emergency operations; (3) electrical system which performs simulation of aircraft ac and dc electrical systems for both left and right engines. This simulation includes the cockpit indications and the control and logic for aircraft power distribution to other aircraft systems. Both normal and emergency situations should be simulated; (4) landing system which performs simulation of the cockpit indications for the landing gear, nosewheel steering, anti-skid, parking brake, launch bar and arresting hook system. Simulated malfunctions should be included; (5) instruments which perform the dynamic simulation of the various cockpit instruments such as the attitude indicator, airspeed, altimeter, rate-of-climb, magnetic compass, angle of attack, and radar altimeter; (6) fire detection/extinguish system which simulates the cockpit indications for warning lights and switches; (7) egress system which simulates cockpit indications for the canopy system and ejection seat, and freezes the training mode cycle on detection of an ejection; (8) environmental control system which simulates cockpit controls and indicators which control and relate the status of the cockpit air conditioning, temperature, and oxygen supply; (9) controls/indicators interface which provides the capability of transferring the analog/digital information to/from the trainee cockpit controls and indicators; and (10) aural tones/cues simulation which provides the audio system command data which are derived from the trainee control inputs and aerodynamics.

WEAPON SYSTEM MODULE

This module is comprised of the following functions: (1) weapon flight dynamics which simulate the aerodynamic characteristics, flight trajectory and scoring (hit/miss) parameters for several types of armament; (2) radar detection/tracking which performs the radar threshold calculations used to establish air target detections and maintain target tracking; (3) antenna simulation which simulates the antenna scan/track motion of the tactical sensor for the air-to-air radar mode. The resultant pointing angle is used by the radar detection/tracking module to determine target detection and maintain target tracking; and (4) ECM simulation which provides the ECM threat environment and detection capabilities.

AML PROGRAM TARGET MODULE

The AML target is a version of the NASA 1-9115 program which provides the simulation of a computer-controlled target while engaged in complex air-combat maneuvers with the trainee controlled aircraft. The program performs the decision logic plus the equations of motion for an instructor designated target.

ADVANCED TRAINING MODULE

This module is comprised of the following functions: (1) instructor controls which perform the logic associated with the instructor station switches which are functional during the various simulation modes. This logic includes trainer management controls; (2) repeater displays which provide the display data selection and preparation associated with the displays of the trainee cockpit instruments; (3) instructor displays which provide the display data selection and preparation of the interactive display presentations for flight data, air combat situation, out-of-cockpit view, aircraft armament, weapon status, weapon scoring, approach area, ground approach, and procedure monitoring displays; (4) record/playback consisting of several routines which, during the training mode, gathers and stores simulation data, retrieves and replays the previously recorded mission; (5) procedure monitoring which provides the logic associated with the selection, activation, and trainee monitoring of the designated procedure used in both normal and emergency operations of the aircraft equipment; (6) malfunction module which performs the logic necessary for the instructor to select, insert, activate and de-activate simulated malfunctions which affect the simulated aircraft equipment operation and the associated cockpit displays and indicators; (7) parameter recording which performs the data collection, formation and output of the data previously specified by the instructor; and (8) instructor training/demonstration which provides the logic associated with replaying one of several predetermined scenarios which are resident on disk. The module presents all visual displays, aural and motion cues, instrument drives, and graphic displays as they appear at the trainee station and instructor station during the training mission.

OPERATING SYSTEM

This module consists of the following modules: (1) system monitor which provides the top level control capabilities common to the major simulation modes. This capability includes the handling of tapes and disc, I/O requests, interrupts, inter-processor communications and computer-operator interface; and (2) executive which performs the interrupt servicing, mode activation, intra-computer task scheduling, inter-computer task scheduling and system monitor interfacing for the various modes.

INSTRUCTOR INTERFACES

An alternative to developing standard modules for the flight simulator is to define a standard interface for the instructor portion of a trainer in a fashion that provides the common functions needed in a variety of trainers. The starting point for this work is the Advanced Training Module defined above. A generalization of this module to perform the functions common to a number of trainer classes will provide the hierarchy defining the software to be implemented.

DEVELOPMENT OF MODULAR SOFTWARE

This hierarchy must be expanded several more levels to get to a module structure that satisfies the modular design requirements for standard software modules that can be transported to a wide range of flight trainers and linked together to form the software for a specific trainer. The keys to the development of modular software that can be furnished to contractors as GFI are (1) partitioning the problem into appropriate levels of modularity for the application and (2) adequate documentation of the software.

MODULE DOCUMENTATION

MIL-STD-1644(TD) is the Military Standard for Trainer System Software Engineering Requirements. This standard, which is one of two approved software development standards within the DoD at this time, is based upon six years of development effort by the Naval Training Equipment Center, and has been coordinated with simulation industry manufacturers through the tri-service National Security Industrial Association (NSIA) Computer Working Group. This standard and its associated Data Item Descriptions specify a level of documentation for software development that supports the adoptions of standard modules. The combination of an enforced partitioning as specified by the hierarchical structure developed above and documentation to the requirements of MIL-STD-1644(TD) will produce a first step toward reusable software.

SOFTWARE PARTITIONING

The Naval Training Equipment Center is currently pursuing a research task that goes a step further in the development of reusable software. This research will derive standard software design parameters and the necessary levels of modularity and will demonstrate the concept feasibility. This research will develop tools and techniques to identify common functional elements in a training device program and develop standard design rules to produce software modules. Standard modules will be generated to demonstrate the universality of the design rules, and these modules will be tested to confirm the results.

APPLICATION TO MICROCOMPUTERS

A major benefit of the partitioning of software into reusable modules is the application to microcomputers. Use of multiple microprocessors to replace the minicomputers in a simulator offers savings in hardware cost over the use of larger computers. Summer and Wyndle [5] estimate the cost of a microprocessor Operational Flight Trainer (OFT) to be approximately one-half the cost of an OFT implemented with minicomputers. Their analysis of life cycle costs show a similar savings in software and maintenance costs.

Indeed, the multiple microcomputer network provides a number of advantages over other approaches. However, these advantages are outweighted by its one disadvantage--such a system has not yet been developed. The development cost and high risk are a result of problems that must be solved in order to use multiple microcomputers effectively. The basic architecture of the multiple-microcomputer system concept is to take advantage of the inherent parallelism that exists in many applications. To do this successfully depends upon three major criteria:

- Successful partitioning of the problem into disjointed tasks.
- Provisions for some form of centralized control by an operation.
- Developing a run-time structure which provides for the passing of system parameters between tasks and/or processors while preserving precedence.

NAVTRAEQUIPCEN has conducted an active research program in this area since 1974 [6,7]. Implementation problems which have been solved include:

- The development and demonstration of a control algorithm for "N" microcomputers and embodied in hardware, firmware and software. This control algorithm is identical in each microcomputer and functions as an applications task manager (ATM) for distributed control.
- The development and demonstration of a distributed cache concept whereby the address space of a shared (common) memory is distributed among each applications processor. Data and parameters to be passed to various processors from other processors are broadcast globally on the system data bus but are read locally in each processor in a parallel manner. This significantly reduces the system data bus bandwidth requirements and the likelihood of bus contention.
- The processing frame scheduling (unique to real-time sampled data processing) is carried out by the control processor. Groups of microcomputers are scheduled according to the processing required in a given frame time. All interprocessor communications are controlled by the ATM which is stored in a Programmable Read-Only Memory (PROM).

The partitioning of the problem is being addressed in the research task to implement a demonstration model of such a system. The development of reusable software modules will provide a basis for partitioning the problem for microcomputer applications.

SUMMARY AND CONCLUSIONS

The development of reusable software modules is an effective solution to the high cost of software development. The data bases being developed by DMA for describing topographical and cultural features and by a Navy effort for describing acoustic targets offer a substantial cost savings over the contractor development of a new data base for each new trainer. In addition, the common data base approach offers uniform training which is not available when multiple data bases are used for similar training requirements.

The tools necessary for development of reusable software modules are being developed. Current trainer development is being done under a specification that requires the contractor to provide sufficient information to make a program reusable. A research task is investigating the partitioning problem to provide a rational method of partitioning the problem to provide commonality in the modules for similar application. The result will be a practical implementation of reusable modules that will make trainer development less costly and reduce the schedule slippage common to trainer development.

REFERENCES

1. Wagner, K. E., D. E. Daniel and Lang, A. L., "Total System Documentation: Interactive Graphics to the Rescue," Proceedings of the National Aerospace and Electronics Conference (NAECON), Dayton, OH, May 1983, pp. 822-829.

2. Daniel, D. E., "Software Productivity Improvement Through Discipline, User Education, and Automation," Proceedings of the Summer Computer Simulation Conference, Vancouver, BC, July 1983.

3. Healy, L. D., Wyndle, G. A. and Baker, B., Computer Architecture Study for the VTXTS Simulators. Orlando, FL, April 1982, Report No. NAVTRAEQUIPCEN IH-336.

4. Healy, L. D., Curran, W. J., Woolsey, R. W. and Day, R., "Standard Ocean Model for ASW Training," Submitted for Publication.

5. Summer, C. F. and Wyndle, G. A., An Analysis of Microcomputer Technology for Application to Real-Time Trainers. Orlando, FL, July 1979, Report No. NAVTRAEQUIPCEN IH-313.

6. Pettus, R. O., Bonnell, R. D., Huhns, M. N., Stephens, L. M. and Wierzba, G. M., Multiple Microcomputer Control Algorithm. Orlando, FL, Septemer 1979, Report No. NAVTRAEQUIPCEN-78-C-0157-1.

7. Pettus, R. O., Huhns, M. N., Stephens, L. M. and Trask, M. O., Multiple Microcomputer Control Algorithm Feasibility Breadboard. Orlando, FL, August 1981, Report No. NAVTRAEQUIPCEN-79-C-0096-1.

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