Development of a Personal Computer Simulation-Based Multimedia Ship Control Training Program

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To improve the cost-effectiveness of training, the Navy is implementing personal computer (PC) based, interactive multimedia courses such as the Submarine Ship Control Training Program. Developed at the Applied Physics Laboratory, this program is a multimedia and simulation-based training tool that teaches the principles of submarine ship handling for various classes of U.S. submarines. As a PC-based program, it allows students to conduct independent and self-paced training on laptop PCs while aboard ship and on long-duration deployments. One feature of the program provides multimedia lessons in theory, techniques, and procedures related to driving a submarine while submerged. The program's most significant feature, however, is a high-fidelity, 6-degree-of-freedom, interactive, real-time ship control simulation (built by the Laboratory originally for analysis applications) in which students can practice driving a "virtual" submarine while responding to problem scenarios. This training tool has been in the Fleet since early 1997 and has been well received by submarine crews. This article discusses the evolution of the Submarine Ship Control Training Program, from its origin as an analytical simulation to its development as a multimedia PC-based training tool.
(Keywords: Computer-based training, Interactive courseware, Multimedia, Simulation, Submarine ship control.)

BACKGROUND

Training in the Navy is being aggressively targeted for improvement in its cost-effectiveness as the military continues to downsize. In the submarine force, effective training has been accomplished using expensive, full-scale mock-ups of shipboard systems that simulate various watch stations. Operating costs for these simulators, however, are very high because of the full-time commitment of expensive instructors and electrical power. To enhance the training effectiveness of these simulators, the Navy is supplementing current curriculums with low-cost IBM-compatible (Wintel) personal computer (PC) based training packages called "interactive courseware" (ICW).[1] Along with multimedia and simulation-based content, these packages are

designed to monitor a student's progress, give examinations, and keep score. When the student has mastered a laptop-based course, he will gain more value and spend less time using the costly simulators. Even laptop PCs are now powerful enough to run complex simulations in real time. The convenience and portability of laptops provide added benefits to training effectiveness because students can use them virtually anywhere, particularly aboard ship during off-watch study hours.

For more than 30 years, APL's Strategic Systems Department (SSD) has developed and used computer simulations as part of its test and evaluation of the Navy's Fleet Ballistic Missile weapon systems. One of these simulations predicts a submarine's motion using hydrodynamic, environmental, and ship control subsystem models. This "ship control" simulation is an analysis tool by which engineers can assess the effect of an equipment problem or unusual condition on a submarine's ability to control depth and course. Beginning in 1995, recognizing the Navy's trend toward PC-based training, and using the experience gained through the ship control simulation, a team of engineers and programmers from SSD spent over a year adapting the simulation to create the Submarine Ship Control Training Program (SCTP). The program provides instruction in submarine ship control (the art of driving submarines) and is now in widespread use throughout the Fleet. For a brief tutorial on the important aspects of ship control, see the insert entitled Submarine Ship Control Fundamentals.

SCTP was developed under the sponsorship of the Submarine On Board Training (SOBT) Division of Commander, Submarine Group Two, which is responsible for the management and configuration control of ICW products developed for the Fleet. They also provide the laptop PCs on which the ICW is used. SOBT defines a rigid software development cycle, including quality control, final delivery, and maintenance support phases. Adherence to military standards[2] for ICW is also a requisite. SOBT standardizes the format of its ICW by requiring two main educational components: knowledge-based lessons and drill-and-practice free

SUBMARINE SHIP CONTROL FUNDAMENTALS

While submerged, a submarine is mainly controlled by two sets of wing-like structures called planes (see Fig. A). These planes can pivot about an axis lateral to the ship and, when deflected in the oncoming flow of water, they produce an upward or downward hydrodynamic force on the submarine. The planes near the forward end of the ship are used to control depth and are called either fairwater or bow planes, depending upon their location. The planes near the stern control pitch and are called stern planes. The planes operate most effectively when the ship is in a condition called neutral buoyancy. This condition exists when the ship's weight is equal to its buoyancy, and when there is no pitching moment induced by an uneven distribution of weight along the ship's length.

A major objective of ship control is to achieve the neutral buoyancy condition, particularly when the ship must operate slowly. At slow speeds the planes are ineffective because they cannot produce much hydrodynamic force. Weight and buoyancy can vary appreciably throughout the course of a submerged operation. For example, a ship's weight is affected by seawater ingestion (for use in making fresh water) or by waste expulsion. Buoyancy is affected by seawater density, which can change radically because of temperature gradients at various depths or salinity variations near river inlets. To achieve neutral buoyancy, submarines are designed with the capability to adjust their overall and fore/aft weight. The system that permits this adjustment is called the trim system and incorporates variable ballast tanks throughout the ship's interior, as shown in Fig. B. The tanks near the ship's center, called auxiliary tanks, are used to adjust the ship's overall weight and can be pumped to or ingested from the sea. The tanks located at the extreme fore/aft ends of the ship, called trim tanks, are used to adjust the ship's fore/aft weight and can be pumped from one to the other. Most submarines in the Fleet use this configuration of planes and tanks to control submerged depth.
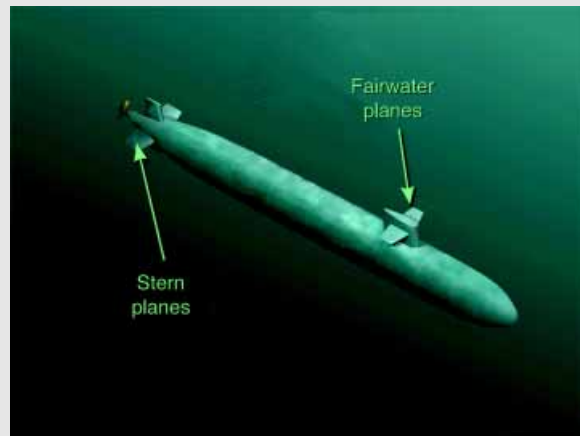
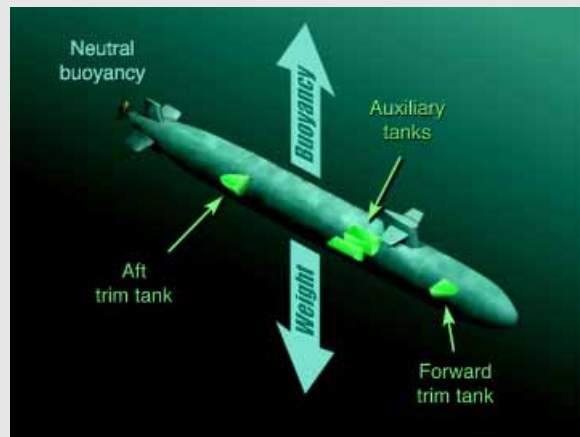**Figure A.** Typical locations of submarine control surfaces.

Figure B. Variable ballast tanks used to adjust a submarine's weight to achieve "neutral buoyancy."

play. The knowledge-based component is intended to instill a fundamental understanding of the subject matter, including theory and basic principles. The drill-and-practice component provides a means by which the student can put the fundamentals to practice. A comprehensive development guide[3] published by SOBT details all current ICW requirements.

KNOWLEDGE-BASED LESSONS AND EXAMINATIONS

The knowledge-based lessons and examinations in SCTP give students the background they need to gain a basic understanding of the systems and principles related to driving a submarine. What they learn in this portion of SCTP can be applied directly to the exercises they will perform when entering SCTP's drill-and-practice simulator. The lessons are presented in a multimedia format with viewgraphs containing audible narration, text, graphics, animations, video clips, interactive exercises, and quizzes. Figure 1 shows a typical page from these lessons. Compared with classical teaching tools (e.g., chalkboard, viewgraph transparencies, and textbooks), these presentations clearly improve student retention because of their illustrative and captivating nature. They cover major ship control topic areas including

- Duties of the ship control party members
- Principles of buoyancy and compensation
- Definition, recognition, and computation of the ship's trim conditions
- Trim/main ballast system equipment and operation

- Hovering and missile compensation systems' equipment and operation
- Periscope depth operations
- Control surface and flooding casualty procedures

In the end, student retention of the material is thoroughly tested by the knowledge-based examination—a multiple choice test that revisits the information and exercises covered in the lessons. A small team of engineers, programmers, audio/video technicians, and artists developed this knowledge-based portion of SCTP in about a year.

Training Content Development

One of the objectives of SCTP was to expand the knowledge-based content of a SOBT legacy course[4] used for training the Diving Officer of the Watch (the submarine crewman responsible for reaching and maintaining a ship's depth) so that other vital members of the ship control crew could be trained. Subject-matter experts within SSD served as valuable resources in developing this training content. Engineers and former Navy technicians on SSD's staff have first-hand knowledge of ship control equipment and its operation from their submarine patrol analysis along with Demonstration and Shakedown Operation experience. These experts used a host of up-to-date Navy technical manuals and procedural guides to develop a thorough collection of lessons for SCTP.

The development of the knowledge-based lessons first involved developing a "draft" ICW through storyboarding, which included writing the narration script and laying out the text, graphics, animation, and video clips for each lesson page. The storyboards were assembled using multimedia editing software described later in this article. They were submitted via CD-ROM to the sponsor and to designated submarine training commands for review and comment. The storyboards had provisions for the reviewers to type in comments on each page and save them to a floppy disk. The comments were later consolidated for inclusion in the final lessons.
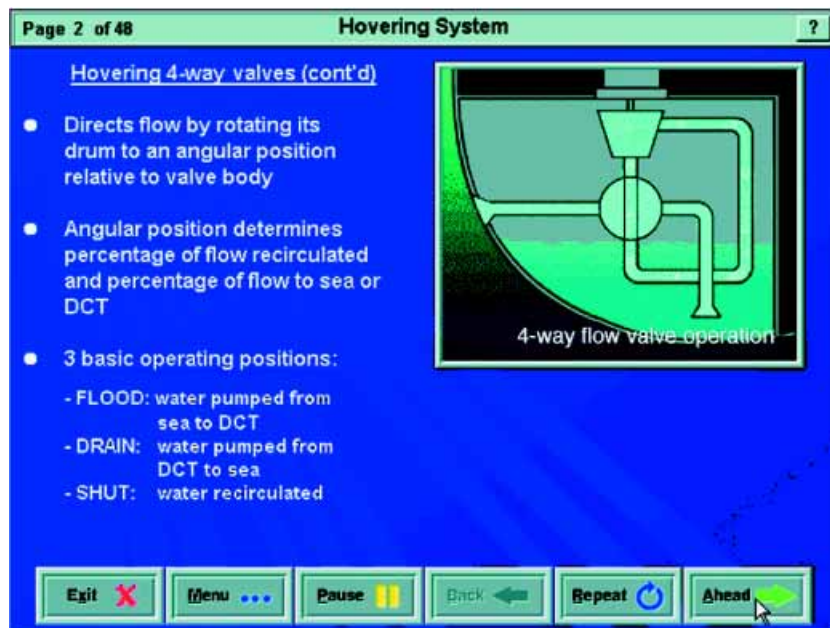
Multimedia Content Development and Production

In keeping with their mission to promulgate engaging training tools to the Fleet, SOBT requires that a large amount of audio/visual content be included in knowledge-based lessons. SCTP complies with

Figure 1. Typical SCTP knowledge-based lesson page, which shows text, animation, and navigation buttons (DCT = depth control tank).

this requirement by incorporating audible narration, color graphics, animation, and video clips. The action in the animation and videos was painstakingly synchronized with the narration to ensure a clear presentation and thus good comprehension of the training material.

The narration was recorded onto tape in the Laboratory's audio studio by a professional announcer and then digitized onto computer disk. The digitized audio was then edited and segmented into individual disk files, each of which corresponded to a lesson page. To conserve space on SCTP's delivery medium (i.e., a 650-MB CD-ROM), a 4-to-1 compression process was performed on each audio file using Microsoft's Adaptive Delta Pulse Code Modulation (ADPCM) algorithm.[5] The algorithm routine compacted, with acceptable degradation in clarity and signal-to-noise ratio, the original high-quality 16-bit, 44-kHz files.

SCTP displays animated graphics where appropriate to promote retention of the theory and technical material. Macromedia Director, a frame-by-frame two-dimensional (2-D) animation tool, was used in conjunction with 2-D and 3-D computer graphics applications such as Adobe Photoshop and Alias Wavefront to depict complex systems in operation or to show proper use of controls on the ship's instrument panels. Animations were saved to disk in the Windows audio/video interleave format for later editing and sound dubbing. In their raw (uncompressed) form, 24-bit color animations running at 15 frames per second and only as large as 320 × 240 pixels consumed over 200 MB of space per animated minute. Raw animation files were thus stored on several 1-GB removable disks.

In some SCTP lessons, live action video in the submarine's control room is shown to illustrate normal and emergency procedures. Videography was performed aboard ships in port, and scenes of submerged operation were staged in a simulated fashion using actual personnel. Two Sony Hi-8 camcorders with image stabilization, low-light capability, and high-fidelity audio were used to record the scenes. Video scenes were converted to digital files on a PC's hard disk using a Creative Labs VideoBlaster RT300 capture card. This hardware can continuously digitize 320 × 240-sized 16-bit color video at 30 frames per second simultaneously with 16-bit stereo audio sampled at 44 kHz. The raw captured files consumed well over 300 MB of disk space per video minute and were stored in bulk on 1-GB removable disks for later editing.

Animations and videos were finalized using Adobe Premiere, an industry-standard digital audio/video editing/compression application for the PC. The prerecorded audio narration was synchronized with the visual action and mixed with the audio of the live shipboard scenes. To ensure smooth playback on a laptop and to conserve disk space, edited animations and videos were compressed from Premiere using standard Windows-based compression protocols such as Microsoft Video 1, Intel Indeo, or Radius Cinepak. A 5-to-1 compression ratio was commonly achieved. The audio track was also compressed 4-to-1 using the Microsoft ADPCM routine.

Authoring

Icon Author from Asymetrix, Inc., is a preeminent multimedia authoring tool for the PC, and is required by SOBT for developing the multimedia lesson segments and the overall run-time structure of all their ICW products. This requirement ensures that SOBT standards for menu structures, page-by-page navigation schemes, and student progress monitoring are met. Because Icon Author can be embedded with databases and other executable programs, it was made to be the overall shell within which all SCTP modules (for example, presentation lessons, drill and practice, and examination) are installed and run. Figure 2 shows the hierarchy of SCTP's run-time structure.

Using the Icon Author application, logic was assembled in an icon-based flowchart paradigm, as shown in Fig. 3. The flow and interactivity of the SCTP application were developed by assigning properties to each icon. Lesson modules were assembled using Icon Author's "Smart Object" editor, which brings
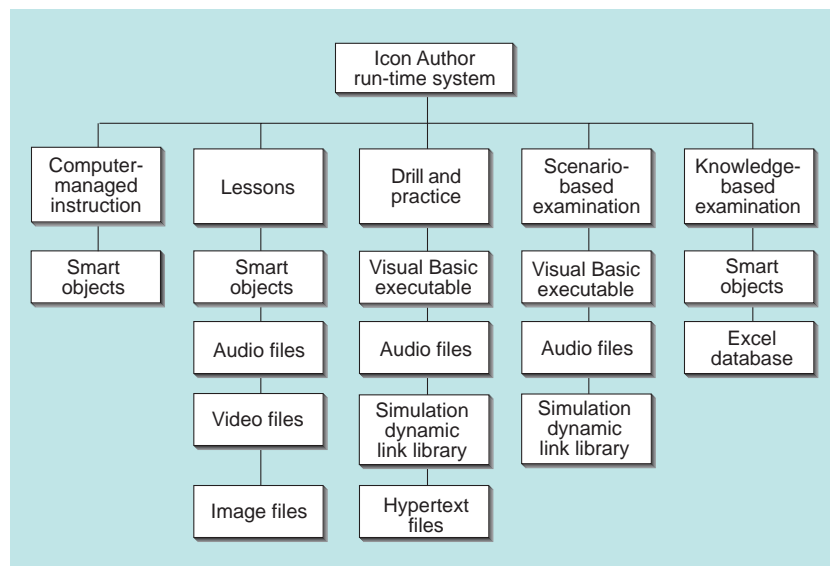

Figure 2. Hierarchy of SCTP run-time modules showing how all aspects of the program run under the control of an Icon Author shell.
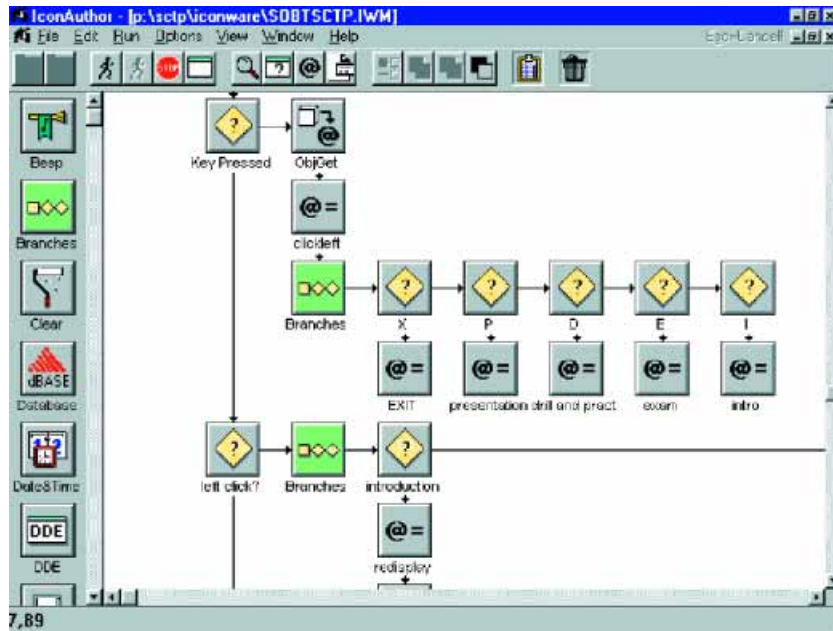
Figure 3. An example of the Icon Author development interface showing how the flowcharting paradigm is used to create a code in SCTP's knowledge-based lessons.

multiple times; however, the answer order will be different for all questions and there will be some new questions on each successive attempt. Each time the examination is initiated, the software randomly selects 50 questions from a database of 125.

The knowledge-based examination was programmed in Icon Author using its open database functions. The questions and answers are stored in a flat dBase IV formatted file. As the student goes through an examination, Icon Author's random number function randomly selects a question and randomly arranges each question's answer list before presenting it on screen.

together multimedia elements (e.g., still pictures, sound files, video clips, and animation) and interactive elements (e.g., database links, text, push buttons, tables, and list boxes). The appearance and behavior of these elements were controlled by changing their associated properties via Icon Author code.

SOBT requires that interactive courseware automatically track the student's progress through the lessons. Computer-Managed Instruction (CMI) is a system developed by SOBT in Icon Author for recording student information and generating various progress reports. At the start of the course, a CMI function runs a student sign-in procedure. A "student disk" must be in the floppy drive. Individual student information, including the number of courses started, the begin and end dates of each lesson, and examination scores, is recorded on this disk. Instructors may browse the disk to monitor student progress. CMI also contains a bookmarking feature that remembers which pages were completed in each lesson by a student. CMI also implements a feedback mechanism for students to provide critiques of each page.

Knowledge-Based Examination Development

Associated with the knowledge-based lessons in SCTP is an examination that students can take after completing their study. This interactive test contains 50 multiple-choice questions based on the concepts, theory, and exercises covered in the knowledge-based lessons. Each question has four selectable answers. The student must correctly answer 75% of the questions to pass. If the student fails, he can retake the examination

DRILL-AND-PRACTICE AND SCENARIO EXAMINATION SIMULATOR DEVELOPMENT

Overview

The drill-and-practice free play element of SCTP contains a submarine ship control simulation in which students exercise the knowledge they gained in the lessons by practicing at-depth control and reacting to submarine equipment/operational problems. This simulator portion of SCTP was developed in parallel with the knowledge-based portion and was about a 1.5-year effort of a small team of engineers, programmers, and technicians. The simulator incorporates the sophisticated computer models of submarine hydrodynamic and ship control systems developed for test and evaluation in SSD. Figure 4 shows the main drill-and-practice interface that provides a ship control station mock-up at the bottom-right of the screen, a view of the submarine's pitch attitude at the top-right, and a gauge panel on the left that provides an overview of the submarine's depth control and course-keeping status.

By clicking on the appropriate section of the mock-up, students can access ship control instrument panels. Figure 5 illustrates the view of the trim system panel that emerges in the foreground when the user clicks the "trim" section of the mock-up. Indications and switches on the panels were replicated to provide as much realism as possible. Students must be able to interact with the PC screen like they would interact with an actual ship's instrument panels so that, when confronted with

Figure 4. Main SCTP drill-and-practice interface screen providing a summary of the submarine's ship control status and access to ship control console panels. (By clicking on the abbreviated icons on the mock-up of the ship control console, the panels are brought to the foreground.)

Figure 5. An example of the SCTP replica of a ship's trim system panel on which all indications and switches are active and can be controlled via mouse clicks.

In drill and practice, students can select from a menu of up to 18 exercises, which include scenarios such as proceeding to periscope depth or flooding. Students can modify the default values for the scenario's parameters. Figure 6 shows a dialog box that allows the student to change the submarine's initial depth, speed, and trim. Other modifiable parameters are the ocean's sound velocity profile (a measure of seawater density), the ship's initial heading, and the location and rate of flooding. While running a scenario, the program provides audio cues that inform the student of casualty occurrences. Students can then practice taking the actions they learned about in the knowledge-based lessons. If necessary, they can view the ship's standard operating procedures using the online documentation hypertext system built into the program. This system was created by scanning pertinent, up-to-date procedural documentation using Calera WordScan Plus optical character recognition software, and building the resulting text into Windows "help" files. Students use this online system under advisement because no mechanism exists for ensuring that the embedded documentation is periodically updated with procedural changes. Options for addressing this problem are being considered for future upgrades to SCTP.

Other miscellaneous features of the simulator interface include the time compression and replay capabilities. Students can speed up simulation action by up to 3 times faster than real time. The increased speed does not affect the accuracy of the simulation. Replay allows the student to rerun a simulation while simultaneously observing the inputs made on each panel. This feature enables an instructor to review and critique the student's actions.

Associated with drill and practice is a scenario-based examination that tests a student's ability to control depth in the simulator while reacting to a randomly selected scenario. Student performance in the scenario

real submarine panels, they will have immediate familiarity because of their practice on the PC.

Since a submarine's ship control station is manned by several people, drill and practice can simulate various watch-station points of view. This system focuses the scenario on a particular set of panels while actions on the other panels are performed automatically in the background by the simulation.

Figure 6. An example of the parameter initialization dialog box providing capability to vary initial conditions and events of an SCTP exercise.

is assessed against the ideal responses. In reacting to the scenario, a student must follow standard procedural guidance to gain scoring points. If commanded to achieve a new ordered depth, a student must expeditiously bring the ship to the new depth to receive points. To pass the examination, the student must obtain 50 out of 100 points.

When either the drill-and-practice or the scenario-based examination component of SCTP is running, two separate modules are in execution. One module contains the submarine hydrodynamics, submarine subsystems, and the sea environment models that are in the form of a dynamic link library. The other module is the graphical user interface that provides the interactive submarine panel replicas and all parameter dialog boxes. This module is an executable (a PC file in a form that the computer can directly run) compiled from Visual Basic source code. The library is compiled from C++ and is accessed by the executable.

Origin and Engineering Description of the 6-Degree-of-Freedom Model

The simulation contained in SCTP is a PC-based version of a mainframe-computer–based ship control simulation that has been developed over the past 30 years.[6] As part of SSD's Fleet Ballistic Missile (FBM) evaluations, a 1-degree-of-freedom (DOF) digital ship simulation was developed in the late 1960s. This simulation was used to model ship control of a Polaris submarine during the launch of Polaris A3 SLBMs. The models contained in the Polaris simulation were fairly primitive, but provisions for simulating hydrodynamic, hovering, sea, and launch forces were all present. The 1-DOF designation signifies that submarine motion is modeled only in the vertical direction. Despite these limitations, the simulation was used successfully to model the effects of ship subsystem equipment faults on

the capability of Polaris submarines to hover while launching missiles.

Over the years, the simulation models were refined, and in the late 1970s a full 6-DOF simulation was developed.[7] Besides modeling the submarine motion in the vertical (or heave) direction, the new simulation modeled ship's motion in the surge (fore/aft), sway (port/starboard), roll, pitch, and yaw directions. The evolution to a full 6-DOF model meant that any type of ship control maneuver or external force (such as the roll effects of sea action) could be simulated.

In addition to the refinement of this 6-DOF model, new models were created for each new generation of FBM submarine (Polaris, Poseidon, and Trident SS-BNs). The latest version of the mainframe simulation is used to assess the impact of equipment failures and sea effects on the capability of the Trident submarine to remain at a stable depth while launching missiles. This assessment is used to calculate the overall weapon system readiness. The simulation was validated using empirical at-sea ship control data. As an independent evaluator of the FBM Program, SSD maintains a continuously updated database of at-sea ship control data. These data originate from the performance of various operational and readiness tests, and are used to continually validate and improve the ship control simulation.

Conversion from the Mainframe Environment

To provide a simulation that could drive the PC-based SCTP simulator, the mainframe simulation was converted to run on the required minimum delivery platform (486DX4 100-MHz laptop PC with 16 MB of memory). Additionally, the platform was restricted to Microsoft Windows 3.1 as its operating system. These factors and the need to run the simulation in real time strongly influenced the conversion path. Other considerations included long-term plans to migrate the simulation to a 32-bit Windows operating environment to support the Navy's migration toward Microsoft Windows NT.

The best solution for meeting all these requirements and to leverage this work in support of future needs was to recode the simulation using object-oriented methodologies and compile the simulation as a dynamic link library. The mainframe simulation was coded using the Advanced Continuous Simulation Language,[8] which is a FORTRAN-based simulation language designed principally to support analysis tasks. This language requires significant overhead and processing capability to execute and was not designed to be run in real time or on a PC with just 16 MB of memory. It was also not designed to be interactive (i.e., receive user-generated inputs during simulation execution).

The models needed to support the SCTP simulator were recoded using C++. Special consideration was

given to designing the code to optimize memory and speed of execution, as well as to modularize its components.

Subsystems Models

The current SCTP simulator contains models that simulate the operation of the ship control subsystems and the effect of external forces acting on the submarine. Ship control subsystem models include, for example, the propulsion, trim, and control surface systems. Hovering and missile compensation system models are also included for the Trident class of submarines. The external force models include hydrodynamics, sea effects, and weapons launch forces. The interaction of the various models with the user interface displays and controls is shown in Fig. 7.

To model the submarine propulsion system, equations were derived to describe (1) the propeller's angular velocity as a function of propulsion commands and the submarine's forward speed, and (2) propulsion forces as a function of submarine and propeller speeds. These functions were empirically measured during numerous sea trial[9]

Figure 7. Interconnection of the SCTP simulator models with the user interface. User inputs on the control panels directly affect subsystem models that in turn affect the hydrodynamics model. All subsystem models receive ship's depth parameter from the hydrodynamics model.

evolutions when the submarine was first deployed, and measurements were used to validate the propulsion models.

The trim subsystem is a manual system used to maintain the submarine at a neutral overall and neutral fore/aft ballast condition.[10] The neutral ballast condition is maintained by an operator pumping ballast between several trim and auxiliary tanks. In modeling the trim subsystem, equations were derived from the trim pump flow rate versus differential pressure and pump motor speed curves. Bernoulli equations modeled valve and pipe losses, and the ideal gas law was applied to model flow rates as a function of tank pressures. The changes in forces on the ship due to water transfer among tanks are passed to the hydrodynamic model.

The control surface subsystem includes the operation of the fairwater and stern planes to maintain depth and pitch (see the boxed insert) and the operation of the rudder to maintain course. In the SCTP simulator, control surface operation is modeled as an automated man-in-the-loop control system (i.e., "autopilot"). The control system's response is selected to model a control surface operator's (i.e., "planesman's") reaction to an ordered depth or course change. Two types of planesmen are modeled in the simulation: proficient and inexperienced. The inexperienced planesman tends to
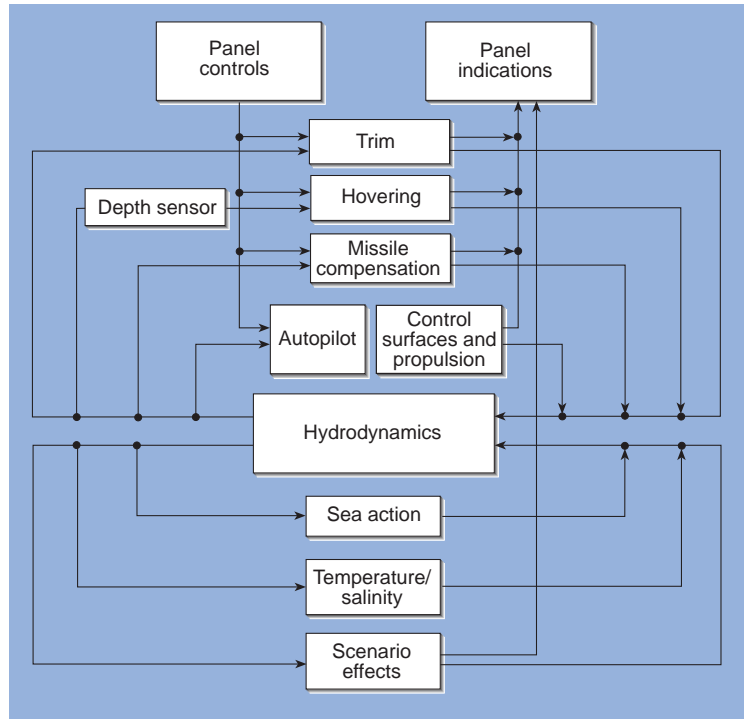
take longer to acquire the change and to excessively overshoot the ordered depth/course change.

The hydrodynamics model in the SCTP simulator contains both the dynamics model[11] (i.e., equations of motion) and the hydrocoefficients model (i.e., equations used to model the flow field around the submarine). Each of these models is implemented in the full 6-DOF, and together they simulate the motion of the submarine through the water. The dynamics model also includes variables to account for the internal and external forces produced by the other simulation models. For example, as the trim system is used, ballast is moved among tanks in the submarine. This change in the ballast condition is modeled as forces acting on the submarine at specific locations, which are added to the equations of motion.

The sea effects model represents the forces and motions induced by the action of a seaway.[12] Because of the intense computational nature of the mainframe sea effects model, the SCTP simulator uses a postprocessed model in which the force and moments calculated from several runs of the mainframe sea effects model are used. The sea forces and moments are parameterized in terms of the wave height (0 to 20 ft), heading relative to the incoming seaway, and submarine depth. The SCTP sea effects model selects the

proper set of forces and motions based on the selected sea state, the ship's heading, and the ship's depth. These time-varying forces are continuously input to the hydrodynamics model.

Scenario Modeling

The scenario effects model controls the execution of the scenario that is either selected by the student as a drill-and-practice exercise or selected at random by the scenario examination generator. On the basis of the scenario selected, an event-based logic engine inserts various events including depth/speed/course changes, equipment/operational problems, missile launches, and their associated audio commands. For example, in the "flooding" scenario, approximately 1 min into the simulation, the program audibly informs the student that flooding is occurring and then begins adding weight to the submarine at the affected location. If the flooding is in the engine room, the program simulates loss of ship's propulsion after several more minutes have elapsed.

When the simulator is executed in the scenario examination mode, an additional logic engine is used to grade the student on proper ship control techniques. The student is graded on a 100-point scale. The points are awarded on the basis of the proper conduct of standard operating and emergency ship control procedures, and on how well the student maintains control of the submarine. In the flooding scenario, 60 points are awarded if the student conducts the emergency action required by the flooding procedure. The other 40 points are awarded on the basis of how well the student's depth control performance matches the ideal. Ideal performance is based on the submarine's response to operator actions that are taken correctly and at the perfect time during a depth transient. At fixed times in the scenario, the student's depth is compared with the ideal depth, and scoring points are determined by how closely the depths agree. In the flooding scenario there are five such checks, and if the student's depth is within a defined depth band at the time of a check, 4 points are added to the score; however, if the student does better and is within half of that defined band, 8 points would be added. The total points awarded during these checks represents the student's depth control performance for the scenario.

User Interface Programming

Microsoft Visual Basic was chosen to develop the graphical user interface for SCTP's drill-and-practice/scenario examination components because of its excellent tool base for development in Windows, adequate CPU performance, and familiarity to programmers on the SCTP team. Visual Basic provides a programmer-friendly graphical development environment and supports the event-driven protocol of the Windows operating system. Unlike process-oriented programs where instructions are executed in a defined sequence, event-driven programs allow sets of instructions to be executed in response to random user actions such as choosing a menu item, clicking on an object, or moving the mouse.

The SCTP Visual Basic interface includes data structures containing all user-modifiable values. Each time a student flips a switch or enters an order, the corresponding value is set in the structure and then passed as a parameter to the simulation models in the dynamic link library. Although the library cycles through all model computations at a rate of 8 times per second, the Visual Basic executable calls the library and displays its computations only 2 times per second. This slower rate ensures that the laptop's CPU and associated graphics adapter can display the graphically demanding animated features in real time.

In the Visual Basic development environment, the user interface was created by placing "drawing controls" such as gauge and switch images, text boxes, and command buttons on a "form." Each panel on the ship control station was represented as a form. Adobe Photoshop was used to create an image of each panel and its associated instruments in their various operating states. For example, if a panel contained a simple ON/OFF toggle switch, two images of the switch (one in each of its positions) were drawn and stored in Visual Basic's "picture clip" control, an efficient mechanism for storing multiple pictures in an array. Then, an image control linked to this picture clip was placed at the toggle switch's location on the panel's form. Next, invisible controls with mouse-click properties were placed over the ON and OFF labels adjacent to the switch. Code was attached to these invisible controls so that when they were clicked on, they would update a variable that would cause the toggle switch's image control to change images to the appropriate ON or OFF position. The same variable also communicated the change to the simulation library.

CURRENT AND FUTURE DEVELOPMENTS

Surfaced Submarine Training Program

SOBT is currently providing funds to the Laboratory to develop a Surfaced Submarine Training Program (SSTP) that extends ship control training to evolutions involved in mooring and getting a submarine under way. An existing SOBT PC-based surfaced submarine training course is now in use by the Navy. The utility of this "legacy" course is decreasing because it runs in a DOS-only environment and it does not contain

multimedia elements or use a true simulation. SOBT has provided funds to the Laboratory to convert this legacy course from DOS to Windows, while adding engaging multimedia to the lessons as well as a true simulation capability to drill and practice. Students will be able to experience avoiding a collision with a pier.

Because surfaced submarine handling is more of a 3-D experience than submerged handling, SSTP's drill and practice uses a 3-D "virtual port" in its interface, rather than flat 2-D drawings, which were used for the instrument panels in SCTP. Thus, because Visual Basic cannot support 3-D virtual reality, the graphical front end is being developed instead in an application called Virtual Reality Toolkit from Superscape, Inc. On a Pentium-based PC, this application can display 3-D renderings of the submarine, pier, and tug boats in real time at a smooth rate of at least 15 frames per second. Students will be able to pan around the scene as if they were on the submarine's bridge, controlling the ship's motion using engine and rudder order panels, and commanding tug boat actions via dialog boxes. The submarine's response will be controlled by a surfaced version of the SCTP submerged 6-DOF simulation. Capability is being added to represent the forces on the submarine due to tug boats.

Virtual Instructor and Multi-User Network Play Capabilities

SOBT is continuing to support the development of advanced capabilities and upgrades to SCTP. Recently, a task was initiated to add an intelligent student/ICW interaction feature to the program. This capability is called the "virtual instructor" and will intelligently monitor student actions and ship control performance during the drill-and-practice scenario exercises. The virtual instructor will provide audible remedial comments when the student violates procedures in responding to casualties or in operating ship control panels. The instructor will also advise the student regarding the status of the ship's trim condition and will recommend actions if the student appears to be losing control. Programming this capability into SCTP has involved the application of artificial intelligence techniques, including development of expert systems.

Other advanced capabilities include a multi-user version of SCTP that would allow multiple students to conduct a simultaneous ship control simulation between participating ship control watch stations. This "networked" version could either be used among PCs linked in a multimedia classroom at the training centers or among laptops around a conference table aboard ship. Students could run practice exercises together and learn how to communicate effectively while polishing their operating skills on their respective control panels. Because this multi-user simulation is limited to ship

control station functions only, no mandate exists to implement a high-level architecture distributed simulation design. Such a design strategy may be brought to bear if this simulation is ever considered for implementation in an all-encompassing submarine systems trainer.

Voice Command

SOBT has expressed an interest in adding voice-command capability to SCTP. This capability would permit the simulation to respond to standard verbal ship-control–related communications, thus enhancing a student's feeling of total immersion in the actual environment. Some students of SCTP are training for managerial roles in ship control and do not operate any panels. Instead, they verbally command their subordinates to take actions on the panels. A voice-command feature in SCTP could accept, recognize, and reiterate such a student's command, and then call the simulation library with the appropriate inputs to the subsystem models.

The SCTP development team has been investigating commercial off-the-shelf voice recognition products for implementing a voice-command feature in the program. These products can operate in conjunction with Windows applications to add either dictation or voice-command capabilities, and generally require an hour-long learning session in which the software learns a person's unique voice. Although SOBT is considering asking the Laboratory to implement voice-command in SCTP, they regard the lengthy learning session requirement as a major drawback of the technology. Before committing funds to this feature in SCTP, SOBT would like to see voice recognition technology further mature and become more speaker independent.

CONCLUSIONS

As the military continues to cut costs in many of its branches, current assets must remain reliable and ready. Effective training helps to ensure the utmost in reliability and readiness of the Navy's submarine fleet; therefore, training must not be sacrificed despite cost-cutting measures. The Navy is addressing this problem by implementing cost-effective PC interactive multimedia training tools to enhance the effectiveness of traditional training centers. Multimedia is not only more interesting, but it is portable and more self-paced than conventional classroom/textbook training.

The SCTP developed at the Laboratory is a significant step forward in this new direction of Navy training. The result of a year and a half effort of a small team of engineers, programmers, technicians, and artists, SCTP is a low-cost PC multimedia and simulation-based training tool that instructs on the principles of

submarine ship handling. This article discussed the two educational components of SCTP and their development processes. The knowledge-based component was shown to contain multimedia presentations that provide basic theory and exercises on ship control principles in a captivating manner. The interactive 6-DOF ship control simulation included in SCTP's drill-and-practice component was also described, showing how it allows students to practice driving a virtual submarine and how it can include real-life equipment and operational problem scenarios. The simulation, originally developed in a mainframe environment for use during postpatrol performance analysis, was converted to C++ on the PC and linked to a graphical user interface through Microsoft Visual Basic. Drill and practice teaches students how to respond to training scenarios such as a flooding emergency.

The sponsor continues to support the Laboratory for development of advanced capabilities in PC-based ship control training. Currently, SCTP is being expanded to operate in a multi-user mode and to include intelligent student/courseware interaction called the virtual instructor. The SCTP development team is also applying its expertise to developing the SSTP, which incorporates knowledge-based and simulation-based components. The surfaced program's significant advancement over SCTP is the implementation of virtual reality, which will enhance the realism of training on a PC. Further advances are expected to be funded in the future, including the application of voice recognition technology to the simulators.

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