F. JENNINGS WILLEY

SHIPBOARD ADVANCED TACTICAL DISPLAYS

Shipboard tactical displays are designed to appear on well-understood and durable electronic display equipment. The displays can only support the evolving mission to the extent anticipated by the hardware designers when the equipment was originally developed. In the next decade, the Navy will break the pattern of dependency on hard-wired hardware by introducing more flexible electronic devices. In the meantime, APL is demonstrating how advances in tactical display equipment can serve the Navy. We are developing tactical display techniques that will use the coming technology and are demonstrating ways to show data that are independent of the display equipment.

DIRECT VIEWING OF REAL-TIME DATA

Little improvement occurred in tactical displays until the last few decades. Granted, scratching in the dirt with a stick gave way to moving pins in a map and writing backward on Plexiglas plotting boards, but those displays only reported hearsay—what someone wrote in a message or called in on a telephone.

When cathode ray tubes (CRTs) became practical, we could display voltage against voltage. When the electronic oscilloscope, with an internal time base, was invented, we could display short-lived repeatable events as voltage versus time. By the beginning of World War II, radio engineers were displaying received radio echoes versus range and calling it radio detection and ranging (radar). Done underwater with sound, it was called sonar.

The early oscilloscopes, or "A" scan displays, showed signal strength, or Doppler shift, in the vertical direction and time, which equated to range, horizontally. They soon evolved into plan position indicators. Plan position indicators are scopes that draw lines from center to edge, timed to match the round-trip propagation time of signals from emitter to echo source. The trace rotates around the CRT's center in synchronization with the rotation of a directional receiver. The CRT's beam current is modulated by signal strength to produce alterations in brightness. The display is in real time and map-like; radius equals range, bearing equals bearing, and brightness equals echo strength. Versions of this scheme were developed to meet the demands of trackers, height finders, and other specific uses, but the principle was the same: a real-time display of data on a two-dimensional surface in relation to a real physical place.

HARD-WIRED COMPUTERIZATION

As the work load on display users increased (and radar operators were dominant among the users of dynamic electronic displays), analog computers were introduced to predict track position and intercept points. To get more data on the screen, engineers began to use the time between the end of the plan position indicator's instrumented range and the start of the next range scan to draw circles and lines pertaining to tracking problems. Demand

for data display continued to increase, and designers invented more and more exciting schemes. Some diverted the electron beam to a stencil-like mask and extruded it into the shape of alphanumeric characters, which they refocused onto the screen. In other designs, a second set of drivers and deflection coil windings was introduced so that preselectable small beam movements could be made to draw characters on the screen.

Thousands of tactical display sets were made that work like data plotters, loading groups of location, beam on, and beam off data words into modest-size display list memories. The memory is read repeatedly into the CRT deflection system through digital-to-analog converters that change location data words to screen coordinates. The limits of the display's complexity are the length of the display list, the speed of the deflection system, and the amount of display flicker the user can tolerate. Some systems give the data precedence over the radar signal when the trade-off among radar, data, and flicker is made. Equipment of this type is on every Navy ship.

Nonflickering equipment that had memory in the CRT screen was also developed but typically had no internal display list and was refreshed (erased and redrawn) from a host computer at the user's command. Those devices were used in many applications, usually in an engineering computer room or for computer-aided design. They were relatively costly and were proprietary with one vendor. The bistable storage tubes gave way to raster scanning display equipment.

RASTER SCANNING DISPLAY EQUIPMENT

The only competing technology of importance was television. The television picture is a raster composed of hundreds of horizontal lines that are drawn across the screen, starting in the upper left corner of the CRT. The picture is continuously redrawn on a fixed schedule that is standardized and broadcast with the television signal. Millions of television sets are made each year, and raster technology has developed a support infrastructure that is both deep and broad; that is, we understand it and it is inexpensive.

288

The difficulty in adapting raster systems to data display lay in rescheduling the data so that they would appear on the television wire at the right time. A conversion method was needed to change data from their natural format (a string of data words) to the television format (a string of dots). Film used by the television industry for data conversion was too slow. Storage tubes and rotating disk memories had as many disadvantages as advantages, and, since digital memory was made by stringing ferrite doughnuts on wires, a picture made of a million pixels (picture elements) was impractical. A fast and inexpensive memory material was needed before raster displays could be used as a universal data display medium. We waited for silicon memory to get cheaper.

Keyboard send-and-receive devices were the first to exploit the low cost of television technology. With only 80 characters per line of text and 24 lines per screen, only 2000 bytes of memory are needed to support a screen full of alphanumeric data. The all-electronic device competed with the Teletype for computer input and output almost as soon as the first semiconductor memories became available.

Data display was now a matter of having a television monitor and a fistful of semiconductors—a substantial fistful, of course, to do full-color graphics on 8- or 16-bit maps of a million pixels each. It took another 10 years to raise the video bandwidth from 3.5 to more than 100 MHz. Now, more than half a century after the invention of television, the primary interface to the silicon revolution is a stepped-up television set.

COMPUTER GRAPHICS

A short visit in 1987 to the Special Interest Group for Computer Graphics trade show and symposium revealed that "display" is now an industry. Every aspect of the technology—printers, plotters, imagers, animators, large screens, small screens, computers, processors, computer programs, textbooks, and advertising space in display-specific trade papers—is for sale. CRT displays are no longer just for radar operators. Computer graphics has created pictures of things that never were, has shown us the inside of our heads, and has taken us on a flight over the surface of a Uranian moon that most of us did not know existed. If it helps people visualize so many things, surely we can make better tactical use of it than coloring the bad guys red. Or can we?

In July 1987, APL took aboard USS *Ticonderoga* and USS *Yorktown* an experiment (the Command Support at-Sea Experiment, Fig. 1) to demonstrate and evaluate modern display concepts in a real tactical combat information center. At the beginning of the experiment, I was asked by a computer graphics specialist why we were bothering to take such low-level graphics aboard ships when "everybody" was already doing the exciting things mentioned above. I asked the critic how many full-color large-screen displays he thought were already out there in the Fleet. He thought that every modern warship must already have one or more. To set the record straight, the number of full-color display systems in the Fleet, or at least in the surface Navy we work with, that are connected

Figure 1—The large-screen color display for the Command Support at-Sea Experiment, installed in USS *Yorktown*.

to the combat system and are involved in real-time tactical situations is none; there are plans to change that figure in the future.

This is not to say that color graphic displays are not on ships. Commercial desktop computers are everywhere, and some are connected to elements of the combat system. Some are connected to television projectors and give the impression that Star Trek is already with us. Whether this is real or illusion depends very much on how you feel about the words "real time" and "tactical" in the previous paragraphs. One definition, "If it doesn't put rounds on target, it's not a weapon," is probably a useful concept. It separates the planning tools from the combat system. The Aegis display system has FIRE ASAP and HOLD FIRE buttons; it is a part of combat. Aegis Baseline 4 ships (DDG-51, scheduled for commissioning in 1990, and CG-65, scheduled for delivery to the Navy in January 1990) are expected to use an Advanced Graphics System,[1] developed by APL for color selection, color fill, and object priority evaluation.

ADVANCED GRAPHICS

In spite of this plan, advanced color graphics are still not yet part of the Navy's standard display set, the AN/UYQ-21 system of components. Support components for color graphics have been developed but are now available only as advanced or engineering development models. The products to be used on those future Aegis display systems are not, at the time of this writing, under contract. Other programs (non-Aegis) are also attempting to get more modern display sets integrated into combat. Navy personnel, both in and out of uniform, who see color graphics everywhere, and the vendors of display equipment (which they always call "displays") pressure the Navy to buy color equipment. Others wonder what the color will be used for and how it will improve performance, especially when it is used to enhance the appeal of the hardware and not the combat system performance.

Once again, technologists have well-developed equipment and support programs, but few developed plans.

As a defense industry, we do not yet fully understand how to use this technology to improve the lot of combatants. Like any other "fusion center," the combat information center can be swamped with information, and new technologies cause still more data to be added. APL has been studying this problem, under the sponsorship of the Aegis Ship Building Project, to develop displays that help the combat information center watch officer understand his tactical situation. The Aegis display system, with its four large-screen displays, is an outgrowth of this work, as are the Advanced Graphics System display and the Command Support at-Sea Experiment.

With the Advanced Graphics System, APL developed a relative-value color system.[2] The relative value (importance) of objects in the display was evaluated against the relative ability of the system to display them. D. W. Nesbitt[3] wrote a computer program, the Color Display Control System, into which were put all of the assumed relative values. The output was a set of colors for tactical tracks and points, areas, and backgrounds. (Each "color" is a set of three numbers, from 1 to 256, that represent the brightness of the red, green, and blue components of each pixel displayed in that color.)

In the Advanced Graphics System display, middle-ground filled areas are dark and semitransparent where they overlap. Background areas, land masses, and seas are very dark, and track symbols are very bright.

AUTOMATIC IDENTIFICATION

The Automatic Identification System, also an APL product, has a display associated with its doctrine processor. The code and the programmers were taken from the Command Support at-Sea Experiment and modified to meet the program need and will no doubt be moved back at some phase. It also has a relative-value color system for its display but needs the Color Display Control System to pick its colors. It has a limited repertoire of displayable items so the number of colors needed is not very large. The Color Display Control System program produces the colors, value-driven as in the Advanced Graphics System display and the Command Support at-Sea Experiment, and controls the use of hardware resources, but its color values are fixed variables. The ocean is a dark blue to match user expectations; land masses are dark milk chocolate. Middle-ground colors are nameless (Fig. 2). A constraint on the Color Display Control System was to include enough red, green, and blue in every color so that the failure of one video driver element would not cause loss of data in the display. This results in impure, or grayed, colors.

Automatic Identification is the first automated doctrine system of its kind, a decision system that implements antiair warfare doctrine (an Operational Order). It identifies locally held tracks (air tracks from the ship's own radar and tracker system) and passes them, with their identification, to the ship's combat system. Its display system facilitates entry of the two-dimensional areas associated with complex statements of flight kinematics, IFF (Identification, Friend or Foe), and a very short history. To direct the functions of Automatic Identification, the
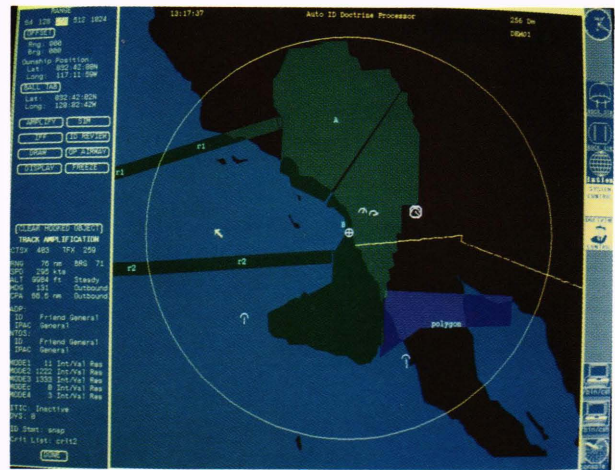

Figure 2—The normally unmanned display of the Automatic Identification System, installed in USS *Forrestal*, assists officers in implementing identification doctrine.

Tactical Action Officer or AntiAir Warfare Officer uses the display system to draw with a mouse, enter data from a keyboard, or select areas stored in memory. The system knows countries by name and commercial high-altitude airways by their international nomenclature. So that the officer can visualize what he is doing, graphic elements that are parts of different activities are shown in different colors, as established by the Advanced Graphics System.

Once the Automatic Identification System is operational, it is not a manned watch station. It continues to display air tracks held by own-ship's radar, lands and seas, airways, and the specified areas related to antiair warfare doctrine. The lands and seas are brown and blue, respectively, the tracks are white, and the air routes are a light blue. The doctrine is green, one of several colors specified by the Color Display Control System as having enough contrast to be easily seen but not so much brightness that it masks other related display data.

CREATING NEW EXPECTATIONS

When we create new displays, we also create new expectations about how things should look. Sometimes others, needing guidance and standards, conclude more than was originally intended.

The first large screens for the Aegis display system were blue because the vendor, unable to make a black and white liquid crystal light valve that worked, did succeed in making a blue and yellow one. It was the only one he had so he delivered it. Now he makes good black and white light valves and has to put filters in them to make them look "the way they are supposed to look."

The Advanced Graphics System was developed for a command user, doing a command task, standing 6 feet from the screen, not for an operator sitting 18 inches from a CRT doing an entirely different task. Automatic Identification uses its display as an input device for creating antiair warfare doctrine; it is not a manned watch station. For example, antiair warfare doctrine is displayed in a pistachio-like green.

There are no scientific reasons for the choice of specific hues. Conforming to the color scheme developed by one activity might detract from the user's ability to find things in some other kind of display. Advanced Graphics, by virtue of the needs of our sponsor, was not intended to provide a universal solution to the use of color; it concentrated on the needs of a commander and was therefore a command solution. No doubt some of our reasoning and some of our ideas can be considered when evaluating the display needs of an individual watch station operator. A new set of values for operator-oriented rather than command-oriented tasks can be developed for the Color Display Control System, for instance, but the work may not be appropriate for individual operator needs.

HOLOGRAMS, STEREOSCOPES, AND PERSPECTIVE DISPLAYS

The preceding discussion deals with two-dimensional plan position indicator mapping of operating areas and objects of interest and the transition to color, but this is not a two-dimensional color world and our technology does not lack methods for making three-dimensional images. It is true that real-time tactical holographic displays have not yet been invented, but stereoscopic displays are easy to make. Stereoscopes are made by putting liquid crystal polarizers in front of CRTs that are displaying frame-sequential, right and left eye images.

Many schemes exist in the computer graphics industry for perspective rendering of computer-generated data on two-dimensional surfaces. The need for such displays has not been demonstrated. For short-range displays,[4] a perspective display presents a clear, understandable picture (Fig. 3), but in the conventional long-range-scan plan position indicator, it makes little sense to show height (or depth) scaled one-to-one with map distance. The battlefield may be 1000 miles across, the radar range 500 miles across, and the vertical component of a typical track no more than a few tens of miles. A more useful display might be range, bearing, and time-to-close, or threat value, or some other value plotted in the third dimension. Such a display would have an unfamiliar distortion, and its appearance would change dramatically with the point of view, but it might reveal something not previously anticipated.

GRAPHS, IMAGES, AND PICTURES

Many advances have been made in the presentation of graphs, images, and pictures. Since we do not know how they will develop and how they will become part of combat, we can only speculate on their future.

Passive electronic sensors (electronic support measures) can draw graphs and display the characteristics of the emitters they are listening to. They cannot put up a complete plan position indicator display because they do not know the range to the signal source. The signal does contain information about the source and emitter type. Identification is derived by machine and by man and display. Emitter type and bearing line belong in the combat display. Range information can be added to the display when
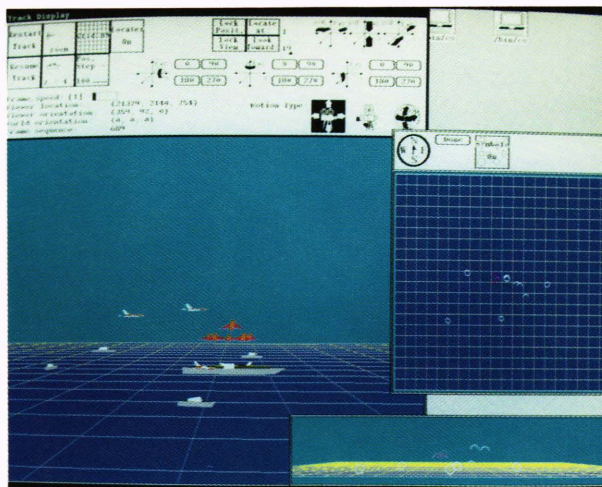

Figure 3—An experimental perspective display that shows (in various windows) pictographs and symbols in perspective and symbols in a two-dimensional plan position indicator plot.

multiple sensor inputs are linked, but it is difficult to imagine various resource managers relinquishing the bandwidth needed to link raw received data. A more coordinated link message containing emitter type and much more detailed information may be mandated.

Although electronic support measures identification may be done quickly and reliably by machine alone, with no need for the display, the display and the display subsystem will probably stay in combat to give the user a measure of confidence and for the analysis of new signals. Augmenting these displays with color and three-dimensional plotting may be useful for identifying emitters, but the displays are analysts' tools and off-line processes and not usually part of the tactical picture.

Beyond the passive and active electronic and acoustic systems of today, we can imagine real-time imaging. Spaceborne and airborne sensors can transmit real pictures to battle group system operators. Those pictures already contain information buried within information. To get the most out of them, the graphics industry has built elaborate postprocessors that slide a usable dynamic range window through the detailed brightness content of the original picture. They also can add color to enhance changes that are not otherwise apparent. Some processors can fly the operator through terrain derived from a stereoscopic pair of overflight images.

These tools, like the electronic support measures example, are more like analysts' tools and would have no place in combat except that the final analyst, the man responsible for the ship, is in combat.

OUR EXPECTATIONS

We propose for the post-Aegis period a display suite, not unlike that now found on an Aegis cruiser, except that the four large screens will be variable-scan-rate, high-resolution, full-color television sets rather than the two-level, monochrome, 1000-line sets now in use. The displays will be under the control of a display operator, as today, but his console will have additional compo-

nents for video source selection and display windowing. To this display console we would feed the outputs of the off-line planning aids, the low-light-level masthead television, the weather satellite postprocessed image, the passive sensor displays, all other available image displays, and the combat plan position indicator picture. Devices that do not naturally produce raster scan images can be scan-converted by equipment like the Advanced Video Processor that is already in procurement. Because radar operators do their job and the analysts theirs, these functions may go unused until someone says, "Captain (or Tactical Action Officer), you should see this." Then the display operator would bring up a new picture on one of the display screens that calls on additional system resources.

The graphics enthusiast may not see this as an optimistic forecast. If he has invented some clever new device to make information more understandable, he would like to move it into the field quickly, but equipment to be fielded must have proven combat worth because it is costly, and it must be durable—so durable that display equipment being installed aboard ships today will be used by operators who have not yet been born.

The tactician of tomorrow is waiting for the designer of today to create a system that will help him understand his environment so that he can fight a better fight and live another day.

REFERENCES

[1] F. J. Willey and D. W. Nesbitt, "Advanced Graphics for Command Displays," *Nav. Eng. J.* **98**, 130–137 (1986).
[2] *Command Support at-Sea Experiment, Phase I, Description and Recommendations*, JHU/APL FS-88-031 (1988).
[3] D. W Nesbitt and F. J. Willey, "Real Time Color Display Control System," in *Society for Information Display International Symposium Digest of Technical Papers*, Vol. XVIII, New Orleans, pp. 326–329 (1987).
[4] J. S. Lindberg, *Three-Dimensional Tracking Display Demonstration on the Sun 3/260*, JHU/APL F2C-5-232 (1987).

THE AUTHOR

F. JENNINGS WILLEY is the supervisor of the Command Support Systems Section of APL's Anti-Air Warfare Systems Engineering Group. He has represented APL on the Navy's Display Working Group and at working group and design reviews for the Navy Standard Display System, AN/UYQ-21. For the past two years he has been involved in the design, development, and at-sea experimental phases of the command support at-sea experiment and of AutoID. He is a physicist from the University of Maryland and has been with APL for nine years. Before joining APL, he worked for the Bendix Communications Division's ground radar systems groups. Mr. Willey's experience with radar systems and radar displays began in 1954, when he worked as a radar maintenance man while serving as an enlisted man in the Air Force. Mr. Willey is a member of the American Society of Naval Engineers and the Society for Information Display.