ROBERT E. THURBER

DATA FUSION FOR NAVY TEST RANGES

An earlier article in the *Johns Hopkins APL Technical Digest* described the use of advanced signal processing components for processing data from surface surveillance radar at Navy test ranges. This work has led to the development of a data fusion system for range surveillance and tracking sensors using a distributed microprocessor-based system.

INTRODUCTION

In an earlier article in the *Johns Hopkins APL Technical Digest*,[1] I focused on the application of new technology to radar signal processing for detecting sea surface targets by land-based radars. That work represented an independent research and development effort on signal processing that resulted in a development task for the Navy test ranges to automate the detection and tracking of surface targets for range safety and control applications.

The earlier article, "Advanced Signal Processing Techniques for the Detection of Surface Targets," described signal processing algorithms that were developed and implemented using high-speed digital integrated circuits, analog-to-digital converters, and microprocessor-based monoboard computers. The resultant signal processor provided target declaration at a low, well-regulated false-alarm rate with good detection potential for small- and large-surface targets when connected to a surface surveillance radar. The system developed for the Pacific Missile Test Center, Pt. Mugu, California, places this signal processor on three noncollocated surface surveillance radars and links the target detection data to a central site for automatic target tracking, track data display, and, ultimately, for range tracking and control (see Fig. 1 for the location of the radars and Fig. 2 for a system block diagram).

The automatic track initiation, target tracking, graphic data display, and data interface functions that make up the automatic target tracking system are implemented in a distributed microprocessor-based architecture using commercial monoboard computers. This method of data fusion for sensor track data proved to be efficient and effective and has the potential for much wider application in the fusion of real-time sensor track data. At the Pt. Mugu center, this potential was recognized and efforts were expanded to include a comprehensive sensor track data fusion system.

THE NEED FOR SENSOR DATA FUSION AT NAVY RANGES

The Navy operates several test, evaluation, and training ranges that support development projects and operational readiness exercises. Operations at those facilities may comprise one participant (aircraft, for instance) engaging one target or searching for another participant such as a submarine. Operations may also be more complex, entailing whole carrier battle groups engaging air, surface, and underwater targets simultaneously with multiple weapons.

Typically, the range facilities must control these exercises and provide data that represent the results of an exercise or test. The facilities therefore must generate a large database that contains "ground truth" positional data and positive identification (ID) on all exercise participants. The positional and ID data originate from several different sensors and tracking systems, depending on the type of target (aircraft, submarine, surface vessel, or controlled target) and the target location. To provide the necessary data and displays for exercise control and exercise reconstruction, all sources of sensor track data must be fused to create a single, coherent track picture in real time that is recorded for postoperation evaluation. To meet these needs, the APIS (Automated Precision IFF [Identification Friend or Foe] Surveillance) system was created.

THE APIS SYSTEM

The Pacific Missile Test Center asked APL to develop a data fusion system that would accept data from the
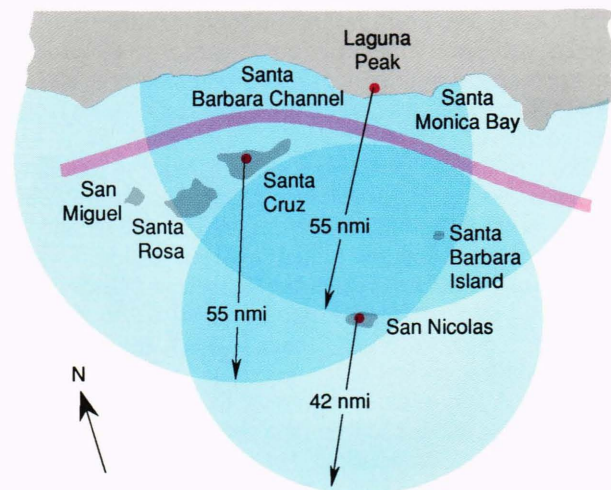

Figure 1. Locations of the surface surveillance radars (red circles) and their optical horizons at the Pacific Missile Test Center, Pt. Mugu, California.
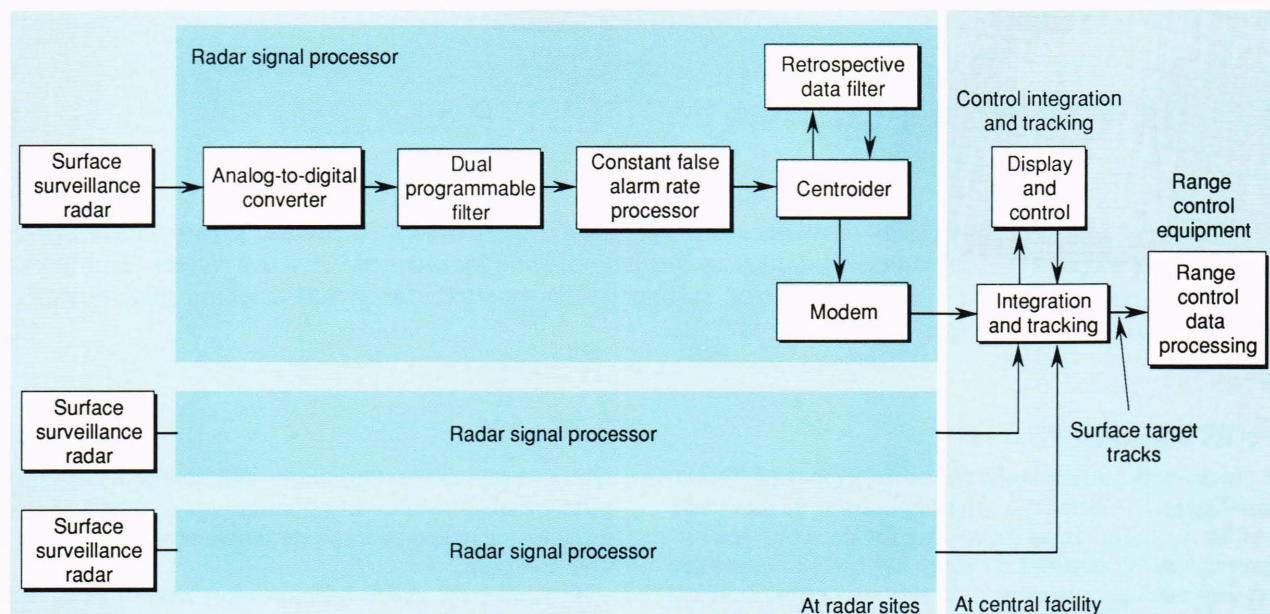
Figure 2. The automated range surveillance system that was developed at APL for the Pacific Missile Test Center. The system is an integrated automatic detection and tracking system based on the signal processing technique developed for the detection of surface targets.

existing range sensors and also develop a composite track database for tracking, control, and output to the range's computer system for display and data archiving. The general categories of vehicles that are tracked are underwater, surface, and air, each requiring different types of sensor data to generate the tracks. The end use of the track data places certain requirements on the accuracy and precision of the data and, therefore, places requirements on the type of sensor that provides the data.

The APIS system was developed for the training range off the coast of Kauai, Hawaii, that supports all forms of tests and exercises, including training exercises for the entire carrier battle group. Several sensor systems provide the track data. For underwater vehicle tracking, a large underwater array of hydrophones is used to precisely locate the position and provide identification of targets equipped with active sonic beacons. The information is processed by the range's underwater tracking system to provide track data (position and velocity) and the vehicle ID.

For surface vehicles, two sources of track data exist. The first source is surveillance radar data, which can originate from the range's surface surveillance radars on the islands of Kauai and Niihau or from the air surveillance/beacon radars located on Kauai and Oahu. Data from the latter radars are only received if the surface target is equipped with a standard IFF transponder. (Most Navy ships and range test support boats have IFF beacons.) All surveillance data must be processed to form radar tracks, and IFF beacon data must also be processed to determine ID information. The second source of track data for surface vehicles is from precision tracking radars, which are designed to follow a single target and provide very accurate track data on that given target. If the target is equipped with a coded beacon at the ra-

dar frequency, the vehicle ID can also be obtained. Eight such radars are located on Kauai, and they are assigned to provide data on targets that require very precise data for control or exercise evaluation.

For air vehicles, three sources of track data exist. The first is air surveillance radar data, which also include IFF beacon data. As with surface target tracks, surveillance data require processing to generate target tracks and decode the target ID. The second source of air target tracks is the eight precision single-target tracking radars such as those described for surface vehicles. The third source is provided by the Integrated Target Control System (ITCS). The ITCS data are track data generated by the target control system for remotely controlled air targets. The locations of the various sensors are shown in Figure 3.

In addition to the track data generated by the sensors generic to the test range, data are provided over the Navy's tactical data links. These data are track data generated by sensors on board the Navy's tactical platforms (ships or aircraft) in the area and can be tracks of air, surface, or subsurface vehicles. The link data are available to the data fusion system as an additional track source.

Given these data sources, the function of the APIS system is to generate a composite track database from all sensor data. To accomplish this, data from all sensors must be correlated to determine which sensor track data belong to the same target, and the positive target ID must be assigned if available. The fused database is then generated for output to the range, with only one source supplying track data on a given target. The data source for a target is selected by the APIS system on the basis of accuracy and quality of the reporting sensor data.

The fused track data set is used by the real-time systems of the range to generate the tracking and control dis-
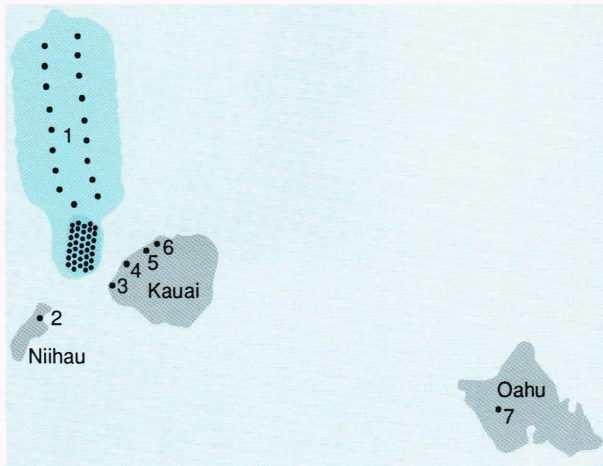
are processed by each redundant half in parallel, thus providing on-line backup in case of failures during test operations.

Two major processing elements in the APIS system are the beacon/skin track processor (BSTP) and the track priority select processor (TPSP). In addition to the processing elements, eight color graphic workstations display track and status data in real time for system control.

The processing elements consist of multiple microprocessors bused together in a distributed processing architecture. Each microprocessor is a commercial monoboard computer with firmware developed to perform the required function resident in programmable read-only memory on the computer card. The concept yields a system that is instantly available on power-up and requires no program loading; a built-in fail-soft feature is provided by the distributed architecture and complete redundancy. This architecture also makes expansion to more functions easy because of the modular design.

Beacon/Skin Track Processor

The function of the BSTP is to accept all surveillance data and generate track data with ID when possible for input to the TPSP. A block diagram of the BSTP is shown in Figure 5. It has two basic elements: one that processes data from surface surveillance radar and one that processes air and IFF beacon surveillance data.

Data from three noncollocated surface surveillance radars are input to the BSTP. The input data are digital target-position data that are produced by a radar signal processor at each radar site. The signal processor accepts raw analog data from the radar and produces digital contacts through a statistical thresholding process. These contacts represent potential targets and are further processed in the signal processor to reduce the quantity of data. First the contacts are centroided. The centroiding function takes all the contacts that could be associated with one target as the radar sweeps past the target and
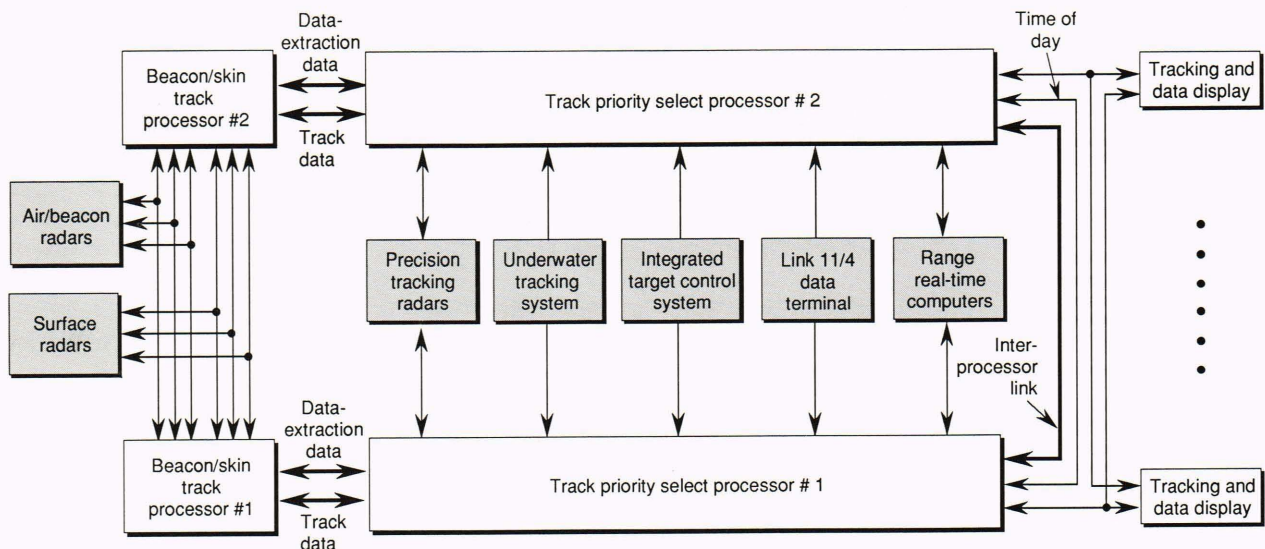

Figure 3. Locations of the tracking sensors at the Barking Sands Test Range, Hawaii: underwater hydrophone sensor array (1); surface surveillance radar (2, 4, and 6); air surveillance/IFF beacon radar (4, 6, and 7); precision tracking radar (3, 4, and 5); and the integrated target control system (4). (Dark blue areas are underwater sensor boundaries.)

plays and to provide acquisition data to sensors. The data set is then archived by the real-time systems for postexercise reconstruction and analysis. It also is used in the APIS system to generate graphic displays of all tracks in real time for system performance verification and system control. This fused database is also archived in the APIS system along with all input data that generate the entire database and all system setup and control inputs. The APIS-archived data can be used to validate system performance through analysis and by playback into the APIS system in real time for complete system testing.

Functional Description of the System

A block diagram of the APIS system is shown in Figure 4. The system is completely redundant; all inputs

Figure 4. Block diagram of the APIS (Automatic Precision IFF [Identification Friend or Foe] Surveillance) system. The sensor systems provide inputs and the redundant architecture. (Shaded areas indicate systems interfacing to the APIS.)
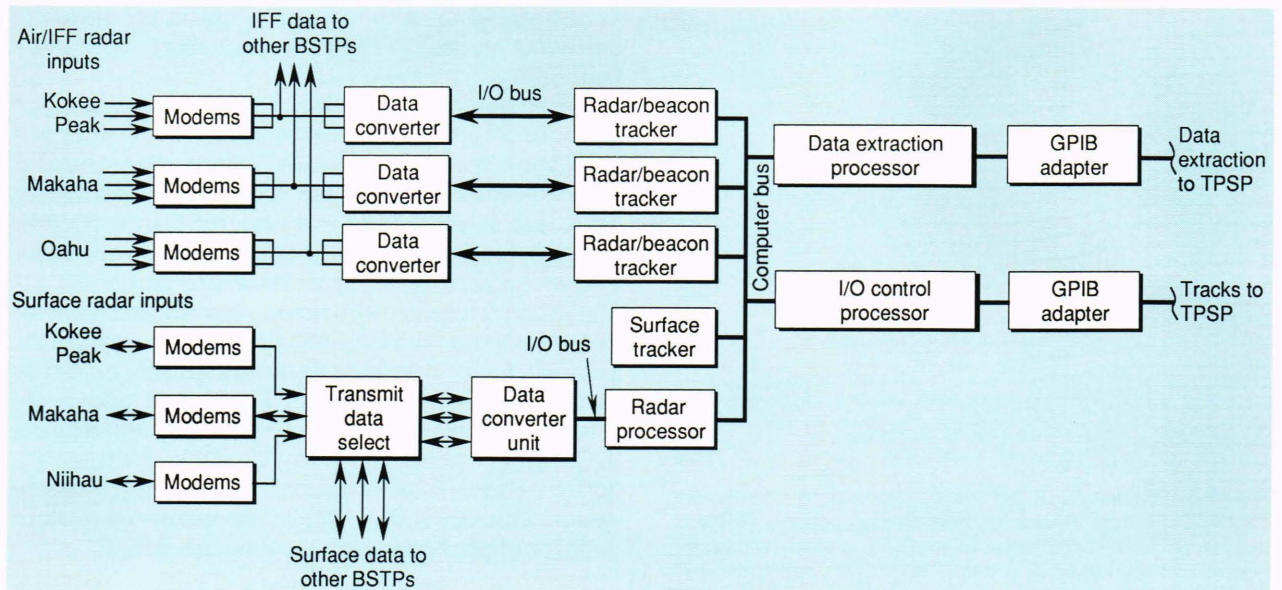
Figure 5. Block diagram of the beacon/skin track processor (BSTP), which accepts surface radar contact data, air surveillance contact data, and IFF beacon contact data. The BSTP also generates air and surface track data for input to the track priority select processor (TPSP). A data path for data extraction and playback is provided for test and evaluation. GPIB = general-purpose interface bus.

forms one report that represents the estimated central position of the target. The data are then filtered on a radar scan-to-scan basis to reduce false alarms and are output over a serial digital communications channel as the position of potential target tracks in the local radar coordinate system.

The serial data from the three radar sites are converted to parallel data for input to the processing system and are read by the radar processor's microprocessor. Here, each centroid is time tagged and converted to a central coordinate system. These data are sent to the surface tracker's microprocessor for automatic target tracking. The function of this processor is to take the centroids from the three radars and generate, update, and (when necessary) delete target tracks. This is done through a logical process of saving contacts, associating saved contacts, promoting contacts to tracks, associating contacts with tracks, resolving multiple associations, updating the tracking filter, and predicting track positions. The system implemented for the surface radars uses a Kalman filter in the x,y-coordinate system for tracking and has a track capacity of 511.

The three air and IFF beacon surveillance radars are handled differently. Here, each radar has a separate tracker in the BSTP, and tracks are sent to the TPSP individually for each air radar, whereas the surface radars provide one common surface track to the TPSP from all three surface radars. The air/IFF radars also have a different radar signal processing function at the radar sites. For these radars, the processor performs many of the same functions as the surface processor on the raw search radar data. The processor also decodes and processes the IFF beacon data. The IFF transponders are found on all commercial and military aircraft and military surface craft. When interrogated by an IFF-equipped

radar, these transponders respond with a coded message that provides position and vehicle ID data.

The air radar data are received as digital serial data by the BSTP and are converted to parallel data for processing by each air radar/beacon track processor. In the radar/beacon track processor, all the functions described for the surface tracker are performed using the radar and IFF data. These processes form the track database for radar only, IFF only, or radar with IFF contacts. This database, which can hold up to 255 tracks, is sent to the TPSP from each radar/beacon track processor.

The BSTP supplies all track and raw contact to the TPSP for recording on digital magnetic tape. A separate bidirectional data path is provided for this function, allowing the raw data to be played back into the BSTP and processed as if the data had originated from the source radars. The resultant tracks can then be output to the TPSP over the primary data bus. Complete system verification can be accomplished using this feature and actual recorded-live data.

Both the primary and the data-extraction data paths to the TPSP are the standard parallel general-purpose interface bus (GPIB). This setup allows all the functions in the BSTP to be isolated from the TPSP because they do not share a common data bus and are only connected through the interchange of track and control data.

Track Priority Select Processor

The other major processing element in the APIS system is the TPSP, which correlates all track data and constructs a composite track database that can be used by the other range systems as the real-time track picture. This requires the TPSP to accept all track data in real time from all the sources described previously. The surveillance radar track data come from the BSTP, and all

other track data are input via the individual sensor tracking function. All data undergo a track-to-track correlation process as they are input. The composite track file created by this process links all sources that are tracking a given vehicle. The track file that is output to the users reports the data from only one source per vehicle, and that source is selected to be the most accurate and highest-quality source.

The TPSP also appends the positive vehicle ID to the track file for each track. The ID is determined by either the IFF code, the precision track radar beacon code, the underwater sonic beacon code, or by operator input. For the coded transponders, a table is input to the TPSP that cross-references codes to a specific vehicle for a given exercise. When no ID data are available, an ID is automatically assigned, and the system is alerted to an unknown vehicle track.

A block diagram of the TPSP is shown in Figure 6. The distributed bus architecture is clearly visible; individual functions are performed by separate microprocessors.

The primary function just described is handled by the TPSP processor card shown on this bus. This processor is also responsible for setting up and controlling the configuration of the entire APIS system, providing all correlated track data for internal display and data extraction, and providing output to the external range systems. The system configuration is set up and monitored by an electroluminescent display, which is connected to the TPSP processor via a serial interface.

Important aspects of system control are establishing, maintaining, and monitoring the configuration and operability of the redundant on-line backup system. To accomplish this control, the bus systems of the primary and backup TPSP are connected via a bus adapter, thereby allowing the primary and backup APIS system to share configuration, operability, and specific informa-

tion on track number assignment. A smooth transition between the primary and backup systems can therefore be accomplished if there is a failure in the primary system.

Also resident on the TPSP bus are processors that control the input and output (I/O) of data to the BSTP and all other range sensors and to the range's real-time systems. These I/O processes are tailored to the specific data source or data receiver. In addition to I/O external to the APIS system, the TPSP contains the processors that control the data extraction and playback functions and the data exchange with the APIS graphic display terminals. The TPSP also receives the common time-of-day clock used throughout the range to time-tag data.

Graphic Display System

The APIS system display and control uses a commercial color graphic terminal manufactured by Tektronix, Incorporated. A planar x–y display is generated of the entire geographic area of the test range showing geographic features such as land masses and important reference points such as sensor locations. Other references such as test range boundaries also can be displayed. The normal display is of target track data showing the present position as a symbol; previous positions are shown as history dots. The amount of history shown on the display is selectable from no history to about 15 minutes of history, enabling the user to view an exercise as it progresses. To optimize the displays for any given situation, a pan-and-zoom feature is included, which allows centering the display at any geographic location and changing the field of view. A typical display is shown in Figure 7.

In addition to providing a graphic display of the tracking data, this display presents data alphanumerically on specified target tracks, shows all system status information, and provides the real-time control of all system fea-
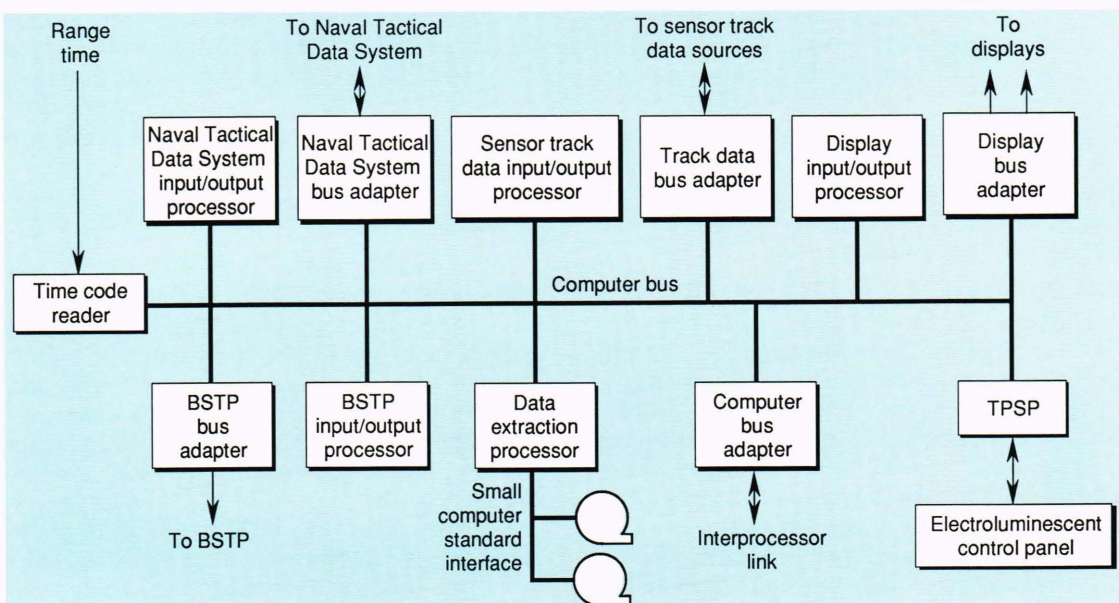

Figure 6. Block diagram of the TPSP (track priority select processor), a major processing element of the APIS system.

Figure 7. The APIS (Automatic Precision IFF [Identification Friend or Foe] Surveillance) system. **A.** Typical APIS display: the track symbol (1); track history dots (2); sensor locations (3); and underwater display boundary (4). **B.** Computer-generated status display (top) and track data for the track shown as (1).
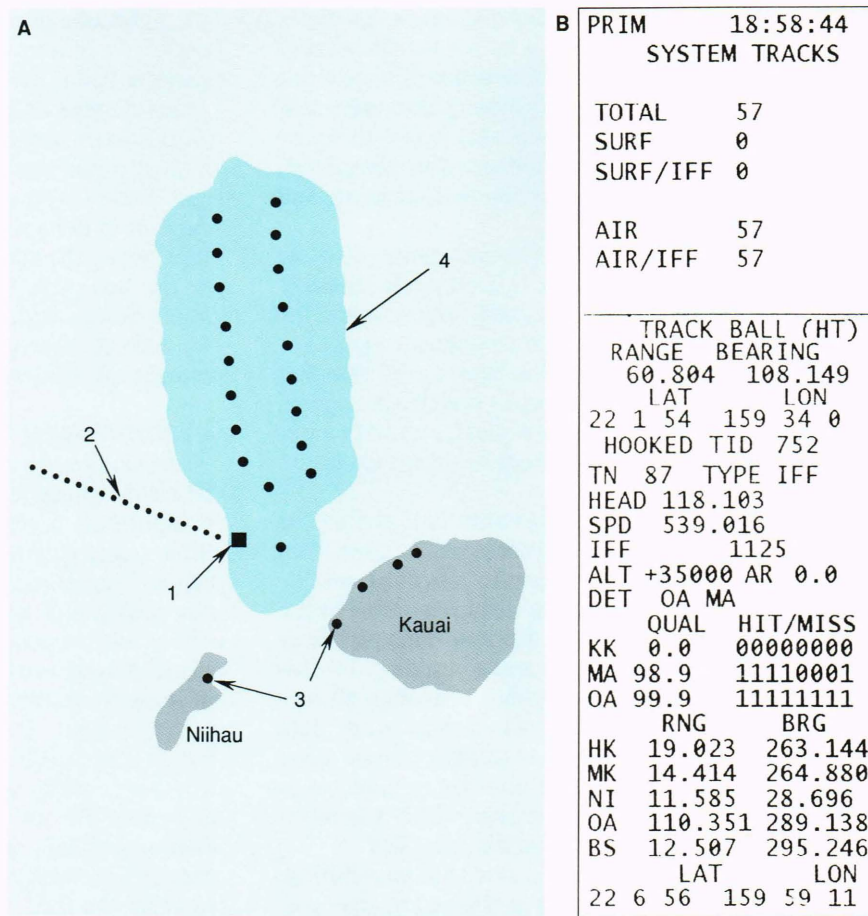
tures. It can also graphically display either contact or track data from selected sensors for performance verification and system trouble isolation.

The display system comprises eight commercial graphic terminals, which are driven by a microprocessor-based distributed processing system. Each display connects serially to a microprocessor board containing all the processing algorithms necessary to generate the display graphics commands. All systems track, status, and contact data are available in the display processor system, and any individual display can independently generate any of the many possible display configurations. This not only provides complete system redundancy, but also allows the displays to perform any of the functions without affecting the other displays.

APIS System Status

The APIS system was designed and developed by members of the Fleet Systems Department at APL. This project began in May 1987, and the complete system was installed and evaluated at the Pt. Mugu facility at Barking Sands, Kauai, Hawaii, in August 1989. Since then, the system has been used during all test operations as the source of real-time tracking data for exercise control and postoperation reconstruction.

The system comprises 59 microprocessors on commercial monoboard computers in a distributed architecture. About half the microprocessors are 16-bit units and the other half 32-bit units. The clock speed of the individual units varies from 8 to 25 MHz, depending on the specific application.

Several custom circuit boards, designed and constructed at APL, are also available to provide specialized I/O and signal processing functions.

All the computer boards include custom firmware held in read-only memory. This firmware, designed and implemented by APL, provides the specific function for which each microprocessor board is used. It consists of both assembly-language program routines for time-critical functions and high-level C-language program routines for the remaining functions.

CONCLUSIONS

A data fusion system that combines tracking data from many sensors has been developed to support the Navy's test range operations. The system was specifically designed for the Navy training range at Barking Sands, Kauai, Hawaii, and has been operational there since August 1989. The function of the system is to provide the coherent picture of all exercise participants in real time, including ground truth positional information and positive ID.

The system that was developed is based on the latest commercially available microprocessor-based monoboard computers and is implemented as a very modular distributed processing system. This design could be easily adapted for use at other test ranges or for nontest

range application. The basic design and many of the components and firmware could be used to net sensors together for surveillance or command and control purposes. Potential applications include surveillance networks for drug interdiction or for base security. Adaptation for command and control could include vessel traffic control for surface traffic in congested areas or classic air traffic control.

REFERENCE

[1] Thurber, R. E., "Advanced Signal Processing Techniques for the Detection of Surface Targets," *Johns Hopkins APL Tech. Dig.* **4**, 285–295 (1983).

THE AUTHOR
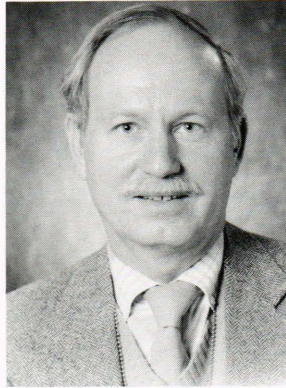
ROBERT E. THURBER received an M.S. degree in electrical engineering in 1970 from The Johns Hopkins University. Since joining APL in 1965, he has been involved in the design and development of several major radar and signal processing systems. Mr. Thurber's work has focused on the application of state-of-the-art components and techniques to enhance the real-time processing of surveillance radar data. He served as lead engineer for developing an automated range surveillance system to process and track all sensor data at Navy test ranges. He is now supervisor of the Digital Systems Development Group in the Fleet Systems Department.