AD-A066 750 LITTON SYSTEMS INC WALTHAM MASS INFORMATION SCIENCES LAB F/G 17/1
TRESI, AN AUTOMATIC ACTIVE TARGET CLASSIFICATION SYSTEM,(U)
JUN 64 G SEBESTYEN NOBSR-85474

UNCLASSIFIED NL

| OF |
ADA
066750

END
DATE
FILMED
5-79
DDC

AD A0 66750

DDC FILE COPY

Copy 4 of 10

CDC NO. 1300

Charged to: ____________

UNCLASSIFIED

~~CONFIDENTIAL~~

~~SECURITY INFORMATION~~

~~THIS IS A COVER SHEET~~

~~Confidential papers attached will be locked within a three-combination file when not in actual use.~~

Good

MOST Project -3

LEVEL II

THIS DOCUMENT IS BEST QUALITY PRACTICABLE.
THE COPY FURNISHED TO DDC CONTAINED A
SIGNIFICANT NUMBER OF PAGES WHICH DO NOT
REPRODUCE LEGIBLY.

LITTON SYSTEMS, INC.
Data Systems Division
6700 Eton Avenue
Canoga Park, California

DDC
RECEIVED
APR 3 1979

UNCLASSIFIED

640611-0221

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

DISCLAIMER NOTICE

CDC 1300

Copy 4 of 10

UNCLASSIFIED ~~CONFIDENTIAL~~

6

TRESI, AN AUTOMATIC ACTIVE SONAR TARGET CLASSIFICATION SYSTEM

10 George Sebestyen

11 1 Jun 64

LITTON SYSTEMS, INC.
Information Sciences Laboratory
Waltham, Massachusetts

12 25p.

"This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sections 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law."

15 NObsr-85474 (p.23)

DOWNGRADED AT 3 YEAR INTERVALS; DECLASSIFIED AFTER 12 YEARS
DOD DIR 5200.10

1 June 1964
see p.21

ABSTRACT

An active sonar target classification system is described which extracts automatically a set of classification clues from the audio and video outputs of a sonar set such as the AN/SQS-23 and presents these to a Clue Evaluator which renders a classification decision according to information stored within its memory. The stored information is obtained adaptively from quantities of sonar contacts of known classification from which estimates of the joint probability densities of sonar classification clues are obtained for both submarine and non-submarine contacts. Principles of operation, hardware features, and preliminary performance characteristics of the TRESI classification system are described. The system is currently undergoing tests at sea.

ACTIVE SONAR TARGET CLASSIFICATION

By use of its radars a surface ship such as a destroyer can maintain surveillance over substantially all surface and airborne targets in its vicinity. By means of its sonar, under favorable conditions, the surface ship can detect undersurface reflectors of acoustic energy and pinpoint their locations in range and bearing. If a reflector is detected by sonar that is not detected by radar as well, it must be concluded that the detected target is submerged. The purpose of active sonar target classification is to differentiate, among such targets, between submerged submarines and submerged non-submarine reflecting phenomena (such as marine life, convergences, underwater currents, pinnacles, wrecks, temperature layers, and others causing target-like appearances on the detection displays of the sonar equipment).

Early investigations in sonar classification were directed at the discovery of various sensible attributes of submarine targets in which they are distinguishable from sonar contacts of non-submarine origin. The MAD gear (Magnetic Anomaly Detector) operates on such an attribute of the submarine by virtue of the fact that the submarine's steel hull disturbs the earth's magnetic field locally which, at close range, can be detected by sensitive equipment. Unfortunately, such a "fool-proof" clue cannot be obtained from sonar signatures to distinguish between submarine and non-submarine targets. Nevertheless, through usage, several target characteristics have come to be regarded as good indicators of its classification. Among these are counted "echo quality" (a subjective measure of the "sharpness" of the onset of the echo), target doppler (a component of target-speed-of-advance), echo strength, and others. As the hunt for reliable indicators of contact classification has uncovered no "fool-proof" clues, it has come to be realized that even if such clues existed, their observation would be unlikely because of the interfering effects of the complex acoustic propagation characteristics of the ocean through which the transmitted pulse and the return echo must travel. Consequently, the necessity to take into account a number of different classification clues as a simultaneous pattern has come to be accepted. The first classification system utilizing a pattern of simultaneously observed classification clues, in its present form, is the manual device called HHIP (Hand Held Information Processor). In this system target classification is obtained through use of a table look-up procedure where the probable classification of each observable clue value combination is tabulated from a careful prior consideration of observable target attribute patterns.*

---

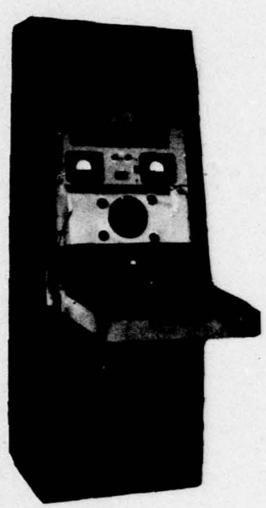
* For a review of the short history and recent status of active sonar target classification, the reader is referred to "Surface Ship Sonar Contact Classification" by H. R. Eady, U. S. Navy Journal of Underwater Acoustics, Volume 13, No. 3, July 1963.

TRESI (Target Recognition by Extraction of Statistical Invariants) recognizes the basic unreliability of even the best of classification clues and regards target classification as a problem in statistical decision making. Decisions are rendered on simultaneously measured classification clues by a procedure which is designed to minimize the probability of incorrect classification. The decision process is constructed adaptively from large quantities of sonar contacts of known classification. Initial experimental investigations leading to the development of an automatic classification system were begun in late 1960 under contract NObsr 85474 and, at present, equipment designed to extract classification information from the sonar signals automatically and to render decisions automatically is undergoing tests at sea.

PRINCIPLES OF OPERATION

Functionally, the classification system is composed of three major blocks: clue extraction (a representation of the sonar contact by means of a set of measurable attributes), clue evaluation (rendering a classification decision based on observed set of clues), and auxiliary console functions consisting of target designation, displays, etc. In its present form, these three blocks of the system are also physically separated in the three cabinets shown in Fig. 1. A fourth major block is also implicit in the classification system. This block, which is not part of the equipment, is a general purpose computer, which processes automatically the clue value combinations collected on known submarine and non-submarine targets to update adaptively the content of the Clue Evaluator memory. Updating is performed periodically whenever large quantities of new data have been collected. These functional parts of the system will be discussed in the following pages.

Before entering upon a system description, it is necessary to discuss first the mathematical basis of the statistical method of target classification employed by TRESI.



Classification Console   Clue Extractor   Clue Evaluator

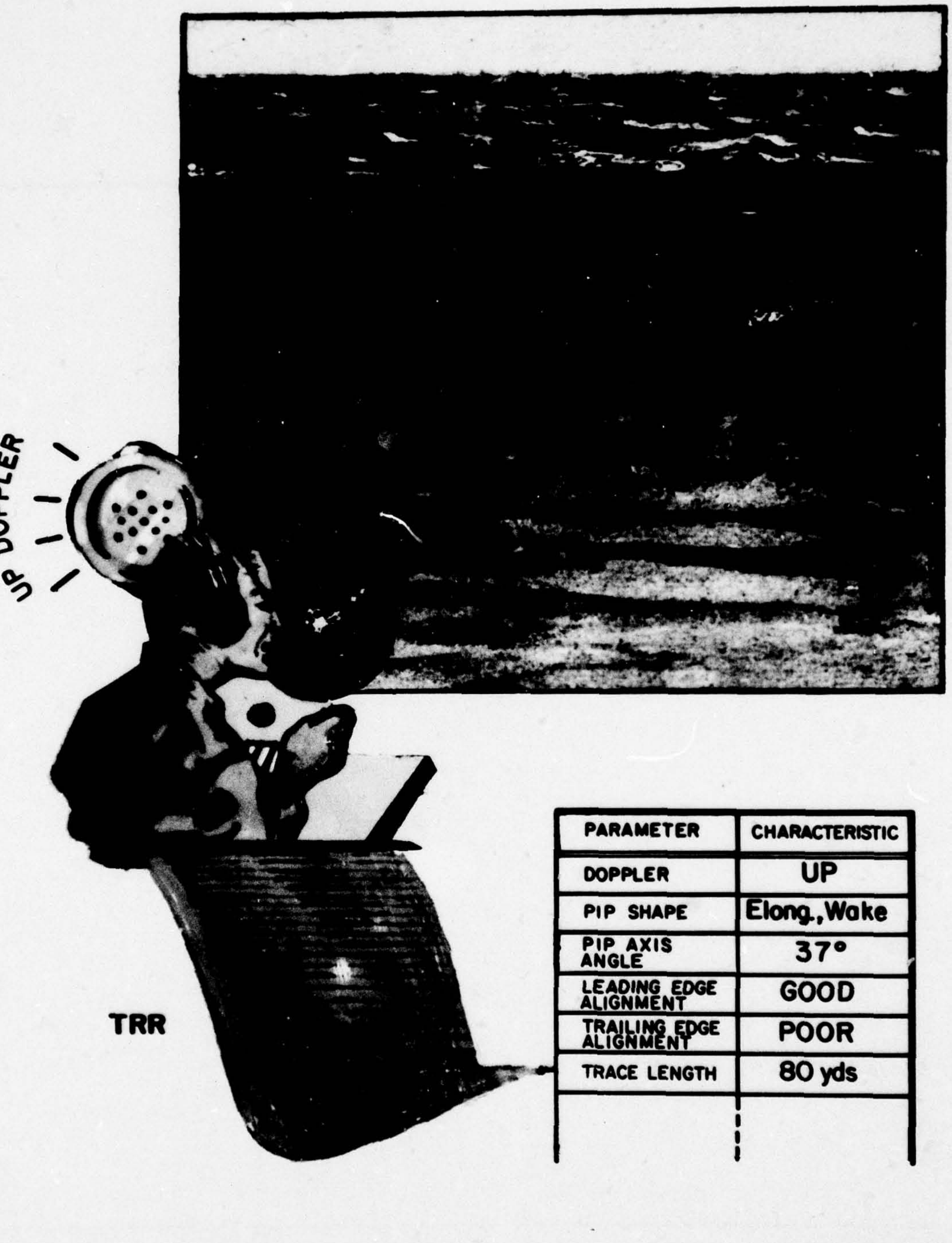
Fig. 1. Functional Blocks of TRESI

Representation of Sonar Signals by Classification Clue Patterns

Aspect
doppler
PPI
TRR-1283

Consider the situation shown in Fig. 2, which illustrates a submarine at bow aspect displaying an "Up" doppler on the audio and an "elongated pip with wake effect" on the PPI presentation at approximately 37° pip axis angle (acute angle between the audio cursor and the principal axis of the elongated pip shape on the PPI). The Tactical Range Recorder indicates that the "leading edge alignment" of the target is good and the "trailing edge alignment" is poor. The length of the trace on the TRR display is about 80 yards. The six classification clues listed in the above description of the target submarine are those used in the Hand Held ~~Information~~ Processor. Each classification clue serves as a descriptor of the signal, indicating the nature of the target. Each clue is the numerical value of a measurement that can be made on the sonar signal. Singling out two of these six descriptors (doppler and leading edge alignment) for purposes of illustration, it is possible to portray the simultaneous observation of the classification clue values as a single point in two dimensions. If more than two clues are used to describe it, the target can be represented by a point in an n-dimensional space, where n is the number of different classification clues. Each dimension of the space expresses a property of the sonar signal, i. e., a type of observation that can be made about it. The total information available about the signal can be represented by a vector $\underline{v} = (v_1, v_2, \ldots, v_n)$, the coordinates of which are the numerical values of the n classification clues.

If observations were made on several submarines at bow aspect, or indeed, if the classification clues were observed on the same submarine at different times, we would note that the clue value combinations from time to time and from target to target would not be identical. This fact is illustrated in Fig. 3 which shows that observations of different submarines



PARAMETER	CHARACTERISTIC
DOPPLER	UP
PIP SHAPE	Elong., Wake
PIP AXIS ANGLE	37°
LEADING EDGE ALIGNMENT	GOOD
TRAILING EDGE ALIGNMENT	POOR
TRACE LENGTH	80 yds

Fig. 2. Classification Clues of a Bow Submarine

~~CONFIDENTIAL~~

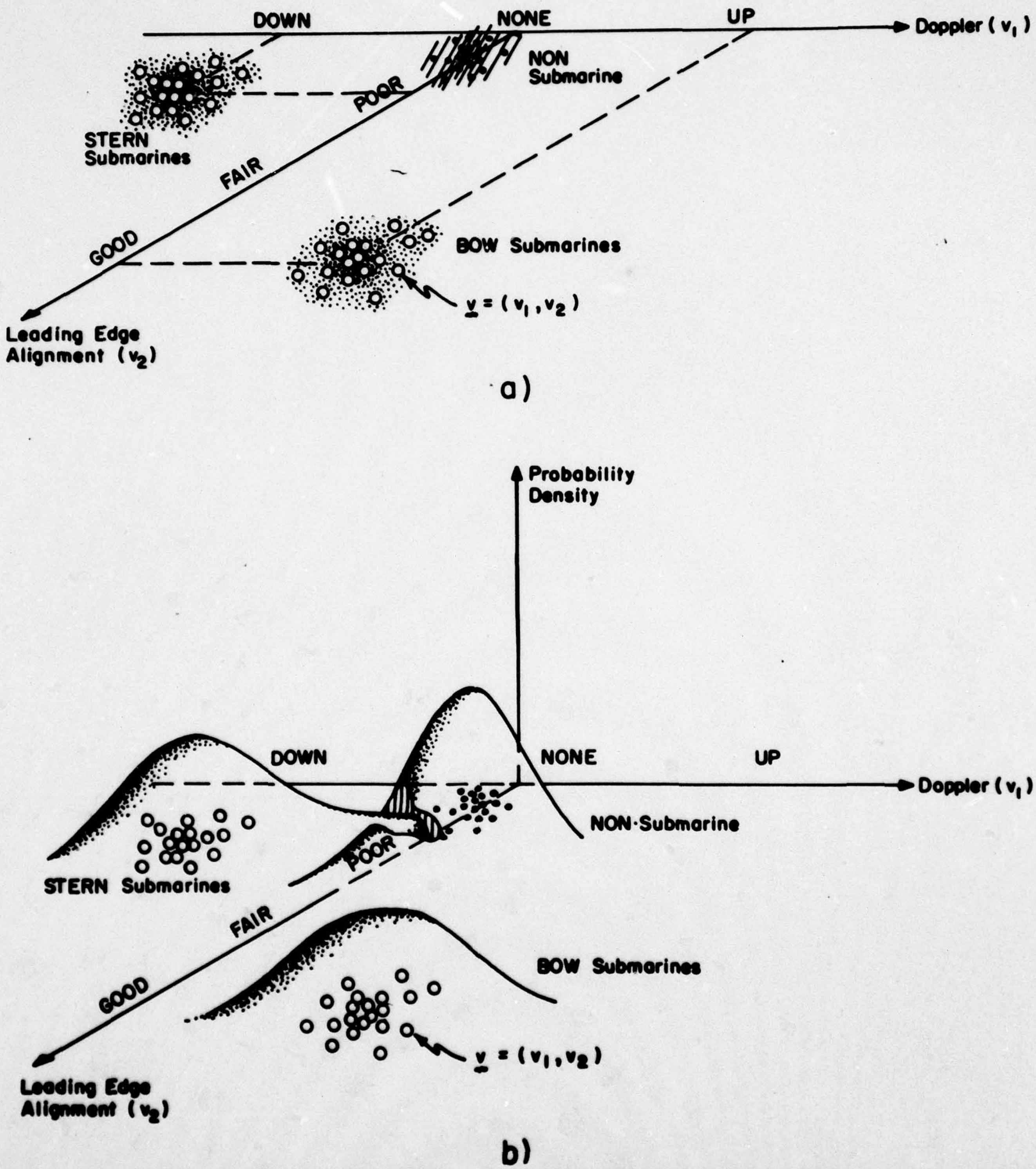


Fig. 3. Vector Representation of Sonar Contacts

~~CONFIDENTIAL~~

and observations made on different pings result in non-identical clue value combinations. Typical clue value combinations corresponding to bow and stern submarines are shown in the figure.

Target Classification

If the number of available observations on submarine and non-submarine targets is increased, the relative frequency with which different clue value combinations (considered as points in the observation space) are observed can be displayed as a density of points. This is illustrated in Fig. 3 where different shading is used to indicate the regions in which submarine and non-submarine targets have been observed. Rather than search for ~~a magic~~ single classification clue, however useful that may be, the characterization of a class of targets called "submarines" can be given in terms of the shaded regions in the observation space. These regions graphically portray the permissible and non-permissible clue value combinations that result from submarine and non-submarine targets. By "permissible" we mean those clue value combinations which are consistent with those obtained from known submarines. Considering the fact that the observations are made in a noisy environment, on targets operating under different conditions and exhibiting slightly different characteristics, the relative frequency with which different sets of observations occur (indicated by shading) is also important. This can be plotted more conveniently as the height of a surface erected over the vector space.

A mathematically exact expression can be given to the notion described above. A target class such as "submarine" is characterized by the joint probability density of the classification clue values, when the observations from which the probability density is constructed are made on a large number of targets known to be submarines. Similar characterization of known non-submarine targets is contained in the joint probability density of non-submarine clue value combinations.

In terms of the probability $P(S)$ of observing submarines prior to making measurements on the sonar signals, and the conditional probability densities $p(v_1, v_2, \ldots, v_n | S)$ and $p(v_1, v_2, \ldots, v_n | N)$, respectively, of simultaneous observations from submarine and non-submarine contacts, the probability of the contact being a submarine, given a set of n classification clue values, can be expressed by the equation below.

$$P(S | v_1, v_2, \ldots, v_n) = \frac{P(S)\, p(v_1, v_2, \ldots, v_n | S)}{P(S)\, p(v_1, v_2, \ldots, v_n | S) + \left[1 - P(S)\right] p(v_1, v_2, \ldots, v_n | N)}$$

The above expression of a posteriori probability is an expression of how likely the observations were to have been caused by a contact of submarine origin and is the quantity to be used and interpreted by the human operator. The confidence to be placed in the decision increases as the a posteriori probability approaches zero or one.

The data-dependent terms in the above equation are the probability densities which are functions of the n-variable vector observation. The function of the adaptive learning program implemented by the general purpose computer is to estimate the probability densities from contacts of known classification, while the clue evaluation function is principally that of evaluating these two functions of n variables on each ping at the point in the vector space corresponding to the set of observed clue values.

The probability density, as any other function, can be evaluated by two basically different procedures. In one of these, the function, expressed in an analytical form, is stored in memory and the numerical value of the function is computed for the specific set of observations represented by the vector $\underset{\sim}{v}$. By another method of evaluation we store the values of the function at a sufficiently large number of points of the vector space, determine the stored point "nearest" to the point $\underset{\sim}{v}$, look up the value of the function at the nearest stored point, and, perhaps, interpolate among stored values of the function near $\underset{\sim}{v}$.

Illustrative examples may clarify these two methods of computing a function at a point v. Suppose the function is $f(v) = v^2 + kv$. The function f(v) can be evaluated from its argument v, according to the first method described, by instrumenting the operation of squaring, addition, and multiplication by a constant. These operations can then be arranged in the appropriate sequence so that the function f(v) is constructed as an operation to be performed on v. In this case the computer is the operator.

In the second method of computing f(v), precomputed values of f(v) at, say, increments of 0.1, can be stored in a "look-up table" in a manner similar to tables of trigonometric functions or logarithms. When f(v) for a specific value of v must be computed, we enter the table at the two entries that stradle the specific value of v, look-up the stored value of f(v) at these two points, and interpolate between them to obtain a sufficiently accurate estimate of f(v). If stored values of f(v) are tabulated at sufficiently densely spaced values of v, the interpolation is not necessary, and we can look up the stored value of f(v) at the tabulated value "nearest" to the required value.

Because of the complicated nature of the conditional joint probability densities, their computation by the first method described above is not economical. Since the region of the vector space of interest in the active sonar target classification problem is small in relation to the total volume of the vector space, the tabulation of the probability densities at a relatively small number of stored points, judiciously selected for their representative nature, is a more practical method of approximation.

Just as a 1-dimensional probability density can be approximated by a histogram-like staircase approximation by use of a look-up table, similarly an n-dimensional probability density involving the joint probability of occurrence of n different numerical values can be approximated by the n-dimensional equivalent of a staircase approximation.

This method of approximation of a 2-dimensional probability density would take the shape of a terraced surface similar in appearance to a rice paddy. That is to say, in different regions of the 2-dimensional plane, representing the combination of 2 parameter values, the surface of the probability density would be flat, but in each region the density would have a different magnitude. The overall effect is that of a rice paddy, shown in Fig. 4. Of course, n-dimensional probability densities can no longer be pictured in the same way, but the mathematical representation of the approximation can be handled with equal ease.

A simplified method of storing and evaluating n-dimensional histograms is best understood by considering the following computational procedure. Select a set of "typical" samples.* Each region in which the probability density is approximated by a surface of constant height contains a "typical" sample. Each "typical" sample is stored in memory and, associated with each typical sample, the height of the approximated surface is stored as well. Assume that a new input v is applied to the system and the height of the surface at the point v is to be computed; that is to say, the value of the staircase approximation of the probability density at the point v is to be evaluated. This can be achieved by computing the distance between v and each of the stored samples until the nearest stored typical sample (nearest to v) is found. The height of the approximated probability density associated with the nearest typical sample is then retrieved from memory. In this way the probability density is evaluated, not exactly at the point corresponding to the input v, but at a point that is very near v. Depending on how near

---

* For a similar procedure published in the unclassified literature see "Pattern Recognition by an Adaptive Process of Sampel Set Construction by G. S. Sebestyen, IRE Transactions on Information Theory, Vol. IT-8, No. 5 September 1962

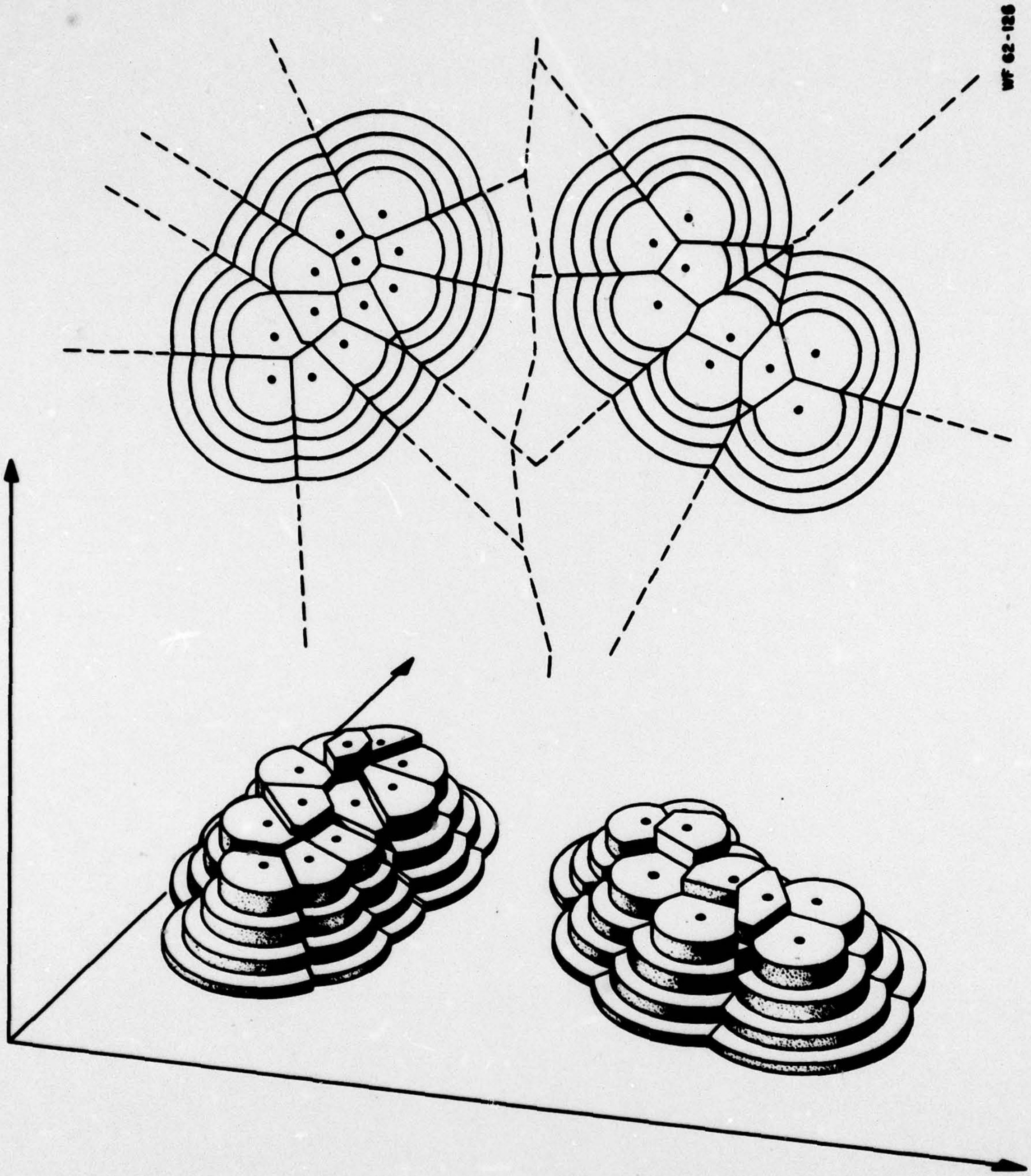


Fig. 4. Approximation of a Function of Two Variables by the TRESI Clue Evaluator

v is to the nearest stored sample, the value of the probability density is modified according to a procedure whose discussion is beyond the scope of this article. As it relates to the implementation of the Clue Evaluator, the procedure is described in reports issued on contract NObsr 85474.*

The essential feature of the Clue Evaluator is that it stores in memory a set of typical samples and the height of the probability densities of the submarine and non-submarine populations associated with each of the typical samples.

The task of the computer program used in the adaptive design and updating of the content of the Clue Evaluator memory is to compute the locations of the typical samples, estimate the values of the probability densities in the vicinity of each sample, and determine the best distance measures to be used in measuring proximity to the typical samples. A more detailed description of the techniques used in adaptive approximation of probability densities will appear shortly in the unclassified literature.

THE CLASSIFICATION EQUIPMENT

Functions of the equipment can best be understood by a detailed consideration of the Classification Console. The Console is the interface between sonar, the classification equipment, and the human operator who monitors and interprets the functioning of the classification system. The audio and video signals received from the sonar are displayed on an A-scan and on a range-bearing display, time shared on the same CRT. PPI classification clues obtained from an enlarged, target-centered range-bearing display are introduced manually by the selection of a switch position corresponding to a Pip Shape which is best matched to the observed shape on the range-bearing display. Pip Axis Angle (the acute angle between the major axis of the target Pip on the PPI and the cursor bearing) is entered by aligning a pointer with the direction of the apparent axis of the target. These are the only manually

*"Phase 2, First Interim Development Report for TRESI", E. Ott, Litton Systems, Inc. 30 August 1962.

introduced classification clues in the present equipment; and these have been left to the human operator's judgment because of the relatively infrequent adjustments required to alter these two parameters and the relatively high cost of automating them.

Either the classification console operator or the sonar operator can designate the target to be classified by positioning a cursor in range and bearing over the target of interest. In the classification equipment, the target area is automatically bracketed in range and bearing by a cell centered at the cursor tip. The size of the bracket is adjustable and all automatic computations are performed within this bracketed interval called the "Target Isolation Gate". Automatic target detection is accomplished by circuitry which extracts target highlights (local rise of signal level above the immediately surrounding noise background), and the range to the leading and trailing edges of each highlight are measured by counting range-clock pulses.

The simultaneous display of the target centered A-scan and the corresponding highlight extractor output is shown in Fig. 5(a) which illustrates the echo from a bow submarine illuminated by the sonar operating in the medium pulse mode. From the information obtained from the highlight extractor output over a set of consecutive target echos, target attributes or classification clues are extracted on every ping by a small stored-program computer called the Clue Extractor. This computer obtains classification clues such as:

a) Echo length (the range difference between leading and trailing edges of the echo highlight structure contained within the target isolation gate on the most recent echo).

b) Number of highlights (a count of the number of reflectors contained within the target isolation gate).

c) Leading edge alignment - a computation which measures the degree of alignment of the leading edges of echos on successive transmissions. This is a measure normally obtained visually from the Tactical Range Recorder (TRR). The Clue Extractor measures alignment as the average

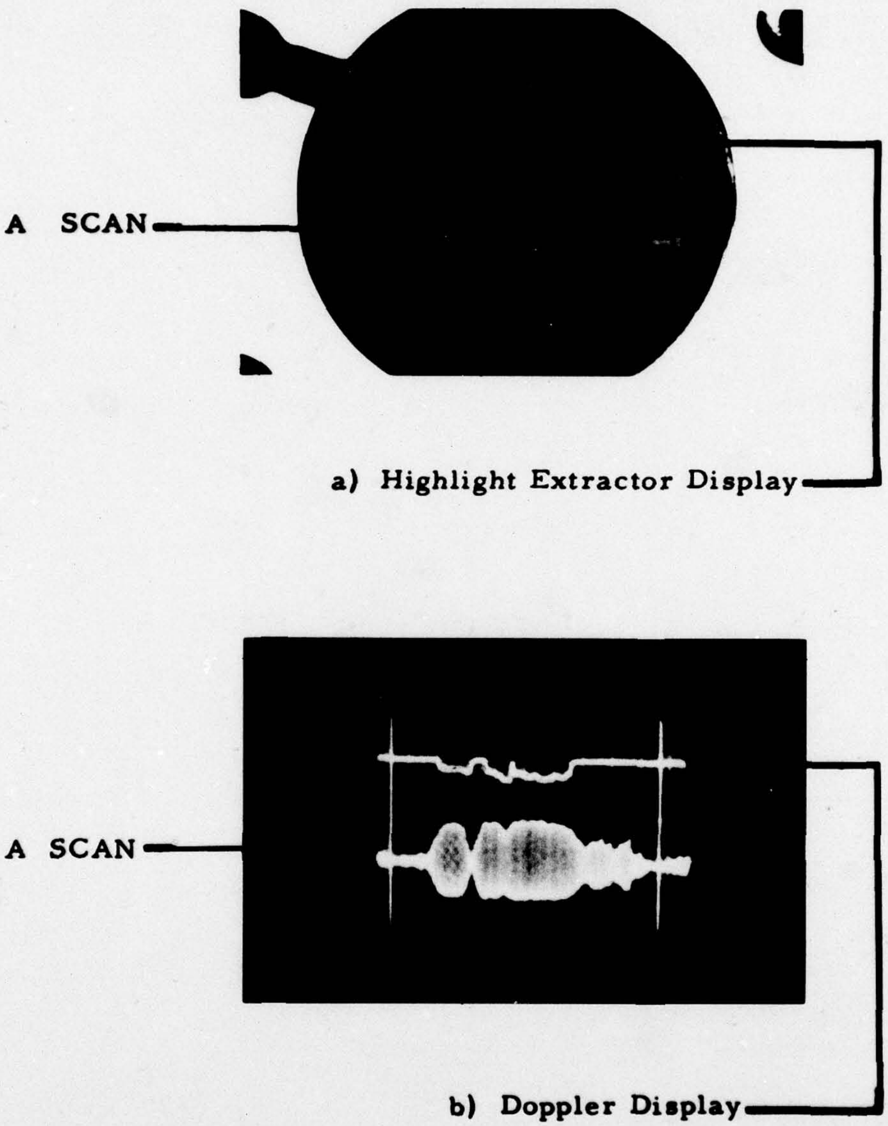


Fig. 5. Target Centered Displays

deviation between leading edges and the best fitting straight line passing through the leading edges.

d) Trailing edge alignment - a measure similar to that described above for measuring the consistency with which the trailing edges of echos over a time interval are aligned.

e) Target doppler - a highly accurate measure of the projection of the target speed-of-advance on the bearing angle. It is thus a measure of the target speed relative to the water surrounding it. Fig. 5(b) illustrates a display mode that permits the operator to examine the A-scan and the doppler versus range waveforms simultaneously.

While other parameters such as range, range rate, and highlight consistency are also measured by the Clue Extractor, the above listing is illustrative of the type of classification clues obtained automatically on every echo. Clue extraction computations commence with the leading edge of the target and they are completed about 50 milliseconds after the end of the Target Isolation Gate.

The parametrically represented echo is sent to the Clue Evaluator which computes the values of the stored conditional joint probability densities of submarine and non-submarine targets at the point in the vector space that corresponds to the observations made on the present echo. The method of storage of probability densities can be likened to a process of comparing the vector observation of the present target echo with a large number of echos in storage. The comparison between input and each stored vector is made by means of a quadratic forms, a different quadratic form being associated with each stored vector. If the quadratic form is regarded as a measure of "similarity", a different criterion of similarity is used when comparing the input with each different stored reference echo. This is an important characteristic of the method of clue evaluation used in TRESI, for it permits a different weighting of the relative importance of the same classification clue with the weighting depending also on the numerical values of all other clues. This feature is an expression of the notion that under some conditions a classification clue may be very important while under different conditions the same clue may have little significance. If all other characteristics of the contact indicate the presence of a beam aspect submarine, the exact value of doppler which reveals evidence of radial target motion is of great significance. If all other characteristics indicate a bow or stern aspect, precise knowledge of the target speed is of little importance.

A comparison of the input echo with all those in storage (using a different criterion of comparison for each stored echo) establishes the identity of the stored sample that best matches the input as observed through its clue values. The previously stored values of the probability densities of submarine and non-submarine targets are retrieved from memory, extrapolated if necessary, and sent back to the Clue Extractor for further processing. The identity of the best matching stored sample reveals something about the nature of the contact, and this too is transmitted back to the Extractor.

The Clue Extractor, upon receipt of the above information, computes an estimate of the a posteriori probability that the observed contact was of submarine origin. False alarm, false dismissal, and a priori probabilities are stored constants that can be varied by doctrine; in any event, they do not affect the calculations of trends indicated by the decision display available to the observer. The a posteriori probability is displayed, indicating how much more likely the target is a submarine rather than a non-submarine contact, based on information available from the present echo. Similarly, under the assumption that successive echos represent independent looks at the same target, the probability that the contact is a submarine, based on the last 16 echos is also displayed. These displays, at present, are analog meter readings which are illustrated by Fig. 6, which shows one of the panels of the classification console.

For diagnostic purposes, and for the purpose of providing a manual back-up mode of operation, the important classification clue values are also displayed on the console, and they are updated on each echo. These displays indicate the classification clue values by their color and by their numbers. The identity of the best matching stored vector is also displayed as a submarine or non-submarine subclass designation. At present, submarine subclasses are ordered according to target aspect, while non-submarine subclasses according to the reasons why they do not exhibit submarine-like behavior. In view of the fact that subsets of classification clues are sometimes missing, the Clue Evaluator is capable of computing marginal probability densities and is thus able to render decisions that are optimum even when not all of the classification information normally expected is available. For instance, during the beginning of the contact history, echo highlight structure consistency over a period of time (the alignment clues) are not yet available. If this happens, the best decisions are made on the remaining available clues. Near the top of the display panel of the classification console, shown in Fig. 6, are contained a set of numerical displays on which the classification clue values are visible. The two meters on which the classification decision based on the present echo and on the immediate past history of the target are displayedare located directly below the numerical clue displays. A doppler hold feature which permits holding reliable doppler values for use in clue evaluation is also a part of the present equipment.

The control panel of the Classification Console contains circuitry and switches for choosing among a variety of displays available for the CRT, for manually inserting the PPI parameters, various gain and threshold controls, a fine and coarse range cursor, and a target isolation gate width control which is used

~~CONFIDENTIAL~~

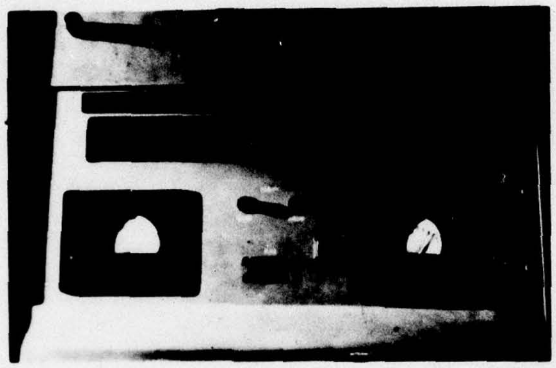


Fig. 6. Classification Clue and Decision Displays

~~CONFIDENTIAL~~

when the sonar operator does not choose to track the target in range. This happens near the initial stages of the classification process. Other controls include the "omit button" which is used by the observer to omit from the clue evaluation process an echo that is believed to be in error for one reason or another. Noise spikes triggering the circuitry when the target is lost is an example of an occasion where the omit button would be used. Range tracking can be transferred either to the sonar operator or to the classification equipment by means of a toggle switch.

At the top of the classification console is located a paper tape punch which outputs 23 characters of information containing the numerical values of all classification clues, the ping number, the sonar operating mode designators, the Clue Evaluator decisions, and many other pieces of information necessary for bookkeeping purposes. This information is punched on paper tape for every echo. The TRESI equipment thus contains complete automatic data collection facilities for obtaining the data in large quantities necessary for the automatic analysis of contacts. These tapes are used as the inputs to the general purpose computer program that adaptively constructs estimates of submarine and non-submarine probability densities from data collected at sea. Data punching takes place immediately after the completion of clue evaluation and it takes on the order of one second.

A tape reader is located in the Clue Extractor and is used, with a small core memory as a buffer, to load updated probability density estimates into the Clue Evaluator memory and also to enter the clue extractor program into storage. The Clue Extractor is a stored program machine capable of performing 18 instructions most of which are especially tailored for the needs of the clue extraction calculations. The Clue Evaluator is a drum machine which, during normal clue evaluation operations, uses its memory in a read-only mode.

PRESENT STATUS AND PRELIMINARY RESULTS

~~CONFIDENTIAL~~

TRESI is currently installed on the U. S. S. Witek (DD848) and has been at sea since the Spring of 1964. Since the test and evaluation is still in progress at the time of this writing (June 1, 1964), all conclusions and results reported here are preliminary.

To date approximately 15,000 echos of contact history have been collected and represented parametrically by TRESI. Data collection has taken place in the Narragansett Bay and the Virginia Capes areas. Of the 15,000 echos, about 60 % are of submarine origin, representing all target aspects, speeds, operating depths of interest at ranges extending approximately to 12Kyds. The non-submarine targets collected to date are primarily of marine life and do not represent a fair cross-section of the non-submarine contact population. Data collection is continuing at present to increase the "representative" data based to be used in the adaptive approximation of submarine and non-submarine joint probability densities. The data collection program is under the supervision of the Navy Electronics Laboratory and the Defense Research Laboratory of the University of Texas.

The method of clue evaluation and the adaptive processes of approximating joint probability densities used in TRESI have been in use at the Information Sciences Laboratory of Litton Systems, Inc. for the last two years and have been tested in numerous applications. It is, therefore, not surprising that the Clue Evaluator performance was accurately forecast by the numerous simulations of this equipment on a general purpose computer over the last few years. The Clue Evaluator performance is entirely satisfactory, and the present equipment possesses more than sufficient flexibility and reserve storage capacity to meet any forseeable needs.

~~CONFIDENTIAL~~

The main question regarding clue extraction centers on the adequacy of the classification clues for containing information to permit discrimination between submarine and non-submarine targets. More specifically, this question can be divided into two parts as follows:

A. Do the clues used contain sufficient information to permit discrimination between submarines and non-submarines with a sufficiently low error rate for practical purposes?

B. Have the desired characteristics of the classification clues been translated correctly into operational definitions of measurements to be made?

The distinction between these two questions is a subtle one. The first asks whether the clues intended to be used are useful or not. The second asks whether the clues (as defined subjectively) are converted to measurable signal attributes well enough or not.

Preliminary conclusions based on observations to date and on an intuitive extrapolation of the results so far indicate that the following statements can be made:

A. Individual probability densities of each of the classification clues occupy completely overlapping ranges of clue values for submarine and non-submarine targets. Therefore, classification by any procedure that assumes the statistical independence of classification clues is doomed to failure. The relative complexity of the TRESI clue evaluation procedure and its ability to evaluate multimodal densities is not a luxury; it is a necessity.

B. Based on observations to date, it is estimated that on the order of 10% or less of the data from submarine and non-submarine observations overlap in the vector space. This indicates that TRESI should ultimately be capable of a classification error rate of the same order on individual echoes. The contact classification error rate is expected to be even less, since an averaging of the decisions over a large number of echoes is usually possible.

C. The present operational definitions of classification clues ~~is~~ are quite satisfactory when the equipment is manned by an experienced operator. Certain gain and threshold adjustments in TRESI, which were originally thought to require only occasional adjustment, appear to require continuous attention. Thus, it appears that the TRESI operator (as well as the sonar operator) can unduly influence the data on which classification decisions are rendered. The data collected so far indicates that, despite this dependence, error rates on the order of 10% should be achievable.

A high degree of agreement can be detected between clue value combinations observed on submarine contacts and clue value combinations that could be deduced from knowledge of the target aspect angle. An inconsistent clue value combination can usually be observed between observations made on a non-submarine contact and the clue values expected from submarines at any aspect angle.

The reliability of the equipment has surpassed expectations. So far, approximately 1250 hours of operating time have resulted in no failures of any kind. Present plans include a continuation of the test and evaluation and the data collection programs as well as the incorporation of certain equipment modifications designed to completely eliminate the influence of the operator on the data. The operator will only designate the target to be classified and will interpret the output displays to obtain his final classification decision.

ACKNOWLEDGMENT

The technical and financial support extended by the Navy Electronics Laboratory and the Bureau of Ships on contract NObsr 85474 are gratefully acknowledged. The generous help given by the members of the Defense Research Laboratory and the officers and men of the U. S. S. Witek made it possible to conduct a successful data collection and test and evaluation program. Special mention should be made of the assistance received from the OPTEVFOR detachment at New London, Connecticut. Last but not least, the outstanding work of the engineering staff and the data processing group of Litton Systems, Inc., should be acknowledged for their untiring efforts to meet the deadlines imposed by ship sailing schedules.