AR-004-954

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

WEAPONS SYSTEMS RESEARCH LABORATORY

TECHNICAL REPORT

WSRL-0514-TR

HIGH-POINT DESCRIPTOR TECHNIQUE FOR THE
IDENTIFICATION OF SHIP SILHOUETTES AT VARIOUS ASPECT ANGLES

B.E. Furby

S U M M A R Y

A 'High-point' descriptor technique is developed for the
identification of binary grey level silhouette images of
ships. These descriptors are theoretically invariant to
translation, dilation and rotation and this is verified.
A   High-point   descriptor   comprising   only   two
characteristics is shown to be sufficient to adequately
characterise a ship silhouette.

Euclidean distance is used to compare shapes and an
identification threshold is defined, above which a high
probability of identification occurs. The technique
compares favourably with Fourier descriptor techniques.

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1. INTRODUCTION

The technique described in this paper evolved from a Fourier descriptor technique which has been the basis of several papers(ref.1 to 4). The Fourier descriptor technique was found to give good match results for the broadside silhouette of ships of binary contrast - matches comparable with the human observer were obtained. No attempts were made to vary the aspect angle of the silhouettes, so the application of the method to the real world was somewhat limited.

One advantage of the Fourier descriptor technique is that it can quite simply be made invariant to translation, dilation and rotation in one plane by normalisation processes. These are necessary processes for the identification of targets which can move in two planes simultaneously. Ships essentially can move in only one plane but can be viewed from any point within a hemisphere about the ship, which is equivalent to the ship moving in two planes simultaneously. If differentiation between the bow and stern cannot be made, an ambiguity arises between the image and its mirror image. A linear transformation of the image is required to generate the alternate image and an ambiguity resolving method is required to differentiate between the images. Another important advantage is that the global characteristics of the target shape can have some influence on the Fourier descriptor, resulting in the probability of greater discrimination between similar targets.

The main difficulties with the use of Fourier descriptors are the size and complexity of the programme and the preparation of a representative continuous contour. The minimum number of coefficients which will adequately describe a ship silhouette has been found to be 8(ref.4). If it is required to account for aspect angle changes in two planes the total number of coefficients which will be required to describe a ship target residing at the centre of a hemisphere and viewed from anywhere upon its surface, at say 5° intervals, is approximately 20 000. The time taken to identify a ship using several library shapes is therefore large, probably in the region of tens of seconds - far too long for real time identification in a real sea environment.

The work described in this paper arose from the desire to overcome the computing time penalty for the real time operation of an autonomous identification algorithm by using a simpler shape descriptor than the Fourier descriptor technique. The technique adopted uses what has been called High-point descriptor named from the use of the high points of a ship silhouette for the characterisation of shape.

2. HIGH-POINT DESCRIPTOR

2.1 Aspect ratio

During the work on Fourier descriptors it became evident that the amplitude of the first negative frequency, centre-ordered coefficient was a good first order identification characteristic. This coefficient gives an indication of the ovality or the aspect ratio of the target. Aspect ratio can easily be measured and it is invariant to dilation, translation and rotation about an axis normal to the plane of the image.

It is, however, highly dependent on aspect angle due to rotation about axes in the plane of the image and therefore does not lend itself to use as an identification characteristic in the general case. Furthermore, the thin mast structures which often dominate the vertical dimension of aspect ratio measurements may not be apparent in the total ship image due to poor dynamic response of the digitising system, long range or low scene contrast. Thus while aspect ratio can be a useful identification

characteristic, it can also be deceptive and, further, alternative characteristics must be introduced before confidence can be placed in using aspect ratio in any identification criterion.

2.2 High-point descriptors

With reference to figure 1 it is seen that aspect ratio is given by:

$$\frac{x(m)}{y(m)}$$

where $x(m)$ and $y(m)$ are the maximum horizontal and vertical extent respectively.

The heights of parts of the superstructure and the position of those heights from some identifiable point on the x-axis are two identifiers which characterise the shape, provided either the shape is symmetrical about the x axis or its extent into the negative y direction is zero. If the height is measured from the waterline this latter condition is satisfied. By measuring several of these heights of various parts of the superstructure and their position along the horizontal axis from some point on the axis of the ship, a target descriptor of an ith silhouette can be formulated viz:

$$h_i = \left(\frac{x(1)}{x(m)}, y(1)\right), \left(\frac{x(2)}{x(m)}, y(2)\right) \ldots \left(\frac{x(n)}{x(m)}, y(n)\right) \qquad (1)$$

which is a set of coordinates of the highest points of the silhouette described by a total of n individual coordinates.

Equation (1) is invariant to rotation about a vertical axis. It can be made invariant to rotation about an axis along the waterline of the ship by normalising the height $y(n)$ with the result:

$$H_i = \left(\frac{x(1)}{x(m)}, \frac{y(1)}{y(m)}\right), \left(\frac{x(2)}{x(m)}, \frac{y(2)}{y(m)}\right) \ldots \left(\frac{x(n)}{x(m)}, \frac{y(n)}{y(m)}\right). \qquad (2)$$

This descriptor, H_i, is invariant to translation, dilation and rotation about any axis.

2.3 Directional ambiguity

A difficulty arises when attempts are made to define a specific point from which measurements can be made without ambiguity regardless of size and orientation. In practice the problem is to select a point along the axis from which measurements are taken, such as the bow of the ship, which can be recognised in silhouettes of different size and orientation. But how can the bow of a ship be defined? It is often more pointed than the stern but to differentiate between the bow and stern at long ranges is often impossible. It is also the first part of the ship to reach a fixed point in space along the velocity vector. Unless there is temporal information gathered from other sources this information is not available from a snapshot image and is certainly irrelevant when using silhouettes of drawings. One possible solution is to make a statement of direction in which the ship is pointing. In the laboratory it is easy to specify the direction in which the ship is pointing or alternatively to arrange for all

silhouettes to point in the same direction. It is then known that measurements taken from the left hand extreme point for ships pointing left will correspond to all images and there will be no need to test the mirror image for ambiguity. This is the solution adopted in this paper.

3. DIGITISING EQUIPMENT

The equipment used to digitise images has been described in reference 4. The camera used in that equipment has been replaced by an IKEGAMI Model CTC-8001 camera with a 15 MHz bandwidth giving a 950 line horizontal resolution and 440 line vertical resolution.

Measurements of the dynamic response to a white/black edge using a CRO have determined the time delay equivalent of less than 3 pixels which gives a significant improvement over the camera used for previous work(ref.1) where the equivalent time delay was greater than 3 pixels. The resulting image is noticeably clearer and greater definition of thin structures is evident on both the display on the monitor connected to the camera and the digitised image.

4. IDENTIFICATION TECHNIQUE

4.1 Library High-point descriptors

The technique developed for the automatic measurement of the dimensions of a silhouette is likely to be different from that adopted for military images in a real environment. In this paper, consideration is only given to application of the technique to the laboratory environment where the aim is to provide binary images. This aim is not easy to fulfil as it is difficult to obtain uniform true white and uniform true black. Even consistency in the actual black and white obtained on the image as a result of the photographic single silhouette on matt paper and a fixed light system has been found to be unachievable. All of these difficulties have been discussed in reference 4.

The technique of identification which has been adopted is to store the descriptors of a number of library silhouettes and compare these with a test silhouette, both descriptors having been obtained using a brightness threshold. An initial difficulty arises in respect to the changes in background brightness level from image to image which clearly affects the shape of the silhouette(ref.4). Library descriptors are calculated by measuring the maximum brightness in either top corner as an average over a four by four pixel block and taking the threshold as 10 grey levels (from a dynamic range of 64 grey levels) below this average. A vertical search through the pixels determines the first and last pixels above this threshold and summation of the number of pixels between these points gives the height of the silhouette at each location across the screen. The result of this threshold technique is shown in figure 2 which depicts several histograms of ships determined by the above technique. The histograms raise an immediate question in the choice of which height charactertistics should be used to describe the silhouette. The method adopted is to select the maximum height, the second highest point and so on, eliminating points either side of the particular point to a minimum contour value, provided this minimum is greater than $\dfrac{3x_t(m)}{x_1(m)}$, where the m refers to the maximum value of x (length of ship) and t and l refer to test shapes and library shapes respectively. The proviso is included to remove the effects of noise and high frequency shape representation.

By recording the distances from the bow of the ship, the set of height characteristics to form a High-point descriptor can be calculated using equation (2).

Since applications of the technique are likely to require real time processing it is pertinent to investigate the minimum number of height characteristics which can be used for High-point descriptors in order to reduce the computing time and storage to a minimum.

4.2 Test silhouette High-point descriptors

A similar technique to the one described above for the determination of library High-point descriptors is used for test High-point descriptors. The differences are:

(a) A maximum value of the background brightness average over a block of five by five pixels is used instead of the corner value of a smaller block of pixels. This has been done to overcome illumination problems arising from images digitised at different aspect angles.

(b) Several threshold levels are used, ideally spanning the library shape threshold, from -12 to -3 below the background grey level. This method was developed to overcome the effects of different background levels and consequent shapes variations and was described in reference 4.

4.2.1 Aspect angle

Changes in aspect angle are effected by rotating the same silhouette about the horizontal and vertical axes within the plane which is normal to the camera axis.

Aspect angles much higher than 45° are not considered because, for the three dimensional real world case, structure in the depth of the target has an influence which increases with angle. Parts of the superstructure with a lower height are hidden by foreground superstructure or alternatively are lost in the body of the target.

4.3 Euclidean distance

Two shapes are compared using Euclidean distance which is defined as:

$$E = \left\{ \sum_{r=1}^{n} \left[\left(\frac{x_1(r)}{x_1(m)} - \frac{x_t(r)}{x_t(m)} \right)^2 + \left(\frac{y_1(r)}{y_1(m)} - \frac{y_t(r)}{y_t(m)} \right)^2 \right] \right\}^{\frac{1}{2}}$$

where r denotes the individual height characteristics in order of decreasing amplitude to a total of n, (figure 1), m is the maximum value and 1 and t refer to library and test shapes respectively.

Let

$$E_d = E^2$$

for computational efficiency, then each value of E_d for individual grey level threshold value is a measure of the goodness of match between the test shape and the library shape. The minimum value of the squared Euclidean distance E'_d for the spread of threshold values is taken as the best match value and the corresponding library shape is accepted as the best match shape.

4.4 Match threshold

Regardless of whether a replica of the test shape is present in the set of library shapes or not, one value of E_d will be computed which is lower than the other values. In the previous section this was the criterion adopted for identification, ie the best match between the test shape and all the library shapes. It is required to have a measure of the goodness of match in a global sense.

A perfect match gives a value which is likely to be other than zero due to differences between the scene and its replica and noise and errors in the digitising system. The maximum value E'_d can reach for a replica is required. If this value could be obtained the identification threshold value would be known. A method for the Fourier descriptor technique using standard shapes was described in reference 4. The results of that method were found to verify an identification threshold level obtained by plotting all the results of matches between library and test shapes, indicating the correct and incorrect matches and drawing the threshold line by eye. This is the technique adopted in this paper.

5. MATCH RESULTS

5.1 Number of height characteristics

In compliance with the condition for minimum computing time and memory space, the number of High-point characteristics selected was 4 or less. Minimum E_d was used as the match criterion and the results for 2, 3 and 4 characteristics are shown in figure 3. Along the x-axis is plotted the average target height for targets at the same range and approximately the same length measured as the number of TV lines over target. The ordinate is match performance which is the number of correct matches from 10 library shapes as a percentage, irrespective of the value of the minimum E_d. The results clearly show that 2 High-point characteristics are adequate to represent each shape ie, n = 2 in equation (2).

Identification is close to 100% for size of target down to about 18 TV lines over target. This plot assumes that the test target silhouette is represented by a shape amongst those represented by the library shapes.

The number of results for 4 characteristics reduces dramatically for target size below 15 TV lines over target because the number of identifiable High-point characteristics reduces to one at extreme ranges, ie the ship silhouette degenerates into a triangle with the apex at the top.

5.2 Match threshold

The minimum value of E_d, E'_d, for each test shape is plotted against the number of TV lines as shown in figures 4, 5 and 6. It is shown that E'_d

decreases as the number of High-point characteristics decrease and E'_d increases as the size of the silhouette decreases. These results were demonstrated and explained in reference 4 for the Fourier descriptor case.

The values of E'_d for 4 characteristics and duplicate full size shapes are plotted in figure 4. The differences between the library shapes and test shapes are brought about by the different methods of background grey level determination which demonstrates the sensitivity of the technique to background grey level.

For 2 characteristic High-point descriptors it can be said with reasonable certainty that identification always occurs if E'_d is less than 0.00016. This is an identification threshold. When some incorrect identification can be tolerated the threshold can be moved further to the right: in fact only a 10% identification error is incurred if E'_d is increased 0.0006.

5.3 Aspect angle variation

Results of aspect angle changes of 53° and 45° are shown in figures 6 and 7 and demonstrate that they are similar to those for the broadside silhouette. The invariability of High-point descriptors to aspect angles up to 45° is verified.

Difficulties in providing uniform illumination both for the individual scene and from scene to scene were experienced resulting in a large variation of background grey level which, however, was not reflected in a reduction in the validity of results.

The case of simultaneous changes in elevation and azimuth angles has not been addressed. However, apart from simple changes in the algorithm which measures the values of x to take measurements along the axis of the ship instead of along the horizontal, the technique is expected to give satisfactory results for combinations of aspect angles.

5.4 Match performance comparisons

Plots of size (as specified by maximum height), against match performance are given in figure 8 for the 2 characteristic High-point descriptor (HPD), as reproduced from figure 3. The curve obtained using Fourier descriptors (FDs) from reference 4 is also plotted together with results on Moment Invariants (MI), obtained from reference 5. These latter results were achieved using pentomino shapes and could, because of their distinctive shape differences, be expected to generate superior match performance values. This is the case. However, comparison between HPD and MI match performance results is not appropriate because of the shape difference.

The achievement of a human observer is demonstrated by the 'eye' plotted on the same figure. This result was obtained using Johnson's criterion(ref.6) and is shown to be inferior to the High-point descriptor technique, which gives 50% probability of identification for a target height of 12 TV lines.

6. CONCLUSIONS

The technique of High-point descriptors is shown to be viable for the autonomous identification of binary contrast ship targets from any aspect angle. As few as two characteristics (each of which requires two x-y coordinates) are required to give a match performance which is better than the human observer can achieve.

An identification threshold value, based on a Euclidean distance criterion, has been obtained where almost 100% identification can be achieved. If 90% identification can be tolerated this threshold value can be increased fourfold.

Comparison of High-point descriptors with other autonomous identification techniques is highly favourable. Match performances are higher than those obtained using Fourier descriptors(ref.4) while the programme complexity and memory storage are considerably reduced. Comparison between match performance of the High-point descriptors and Moment Invariants is not appropriate because the targets were very different, however computational complexity is much lower for High-point descriptors.

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6	Biberman, L.M.	"Perception of Displayed Information". p 4, Plenum Press, New York 1973
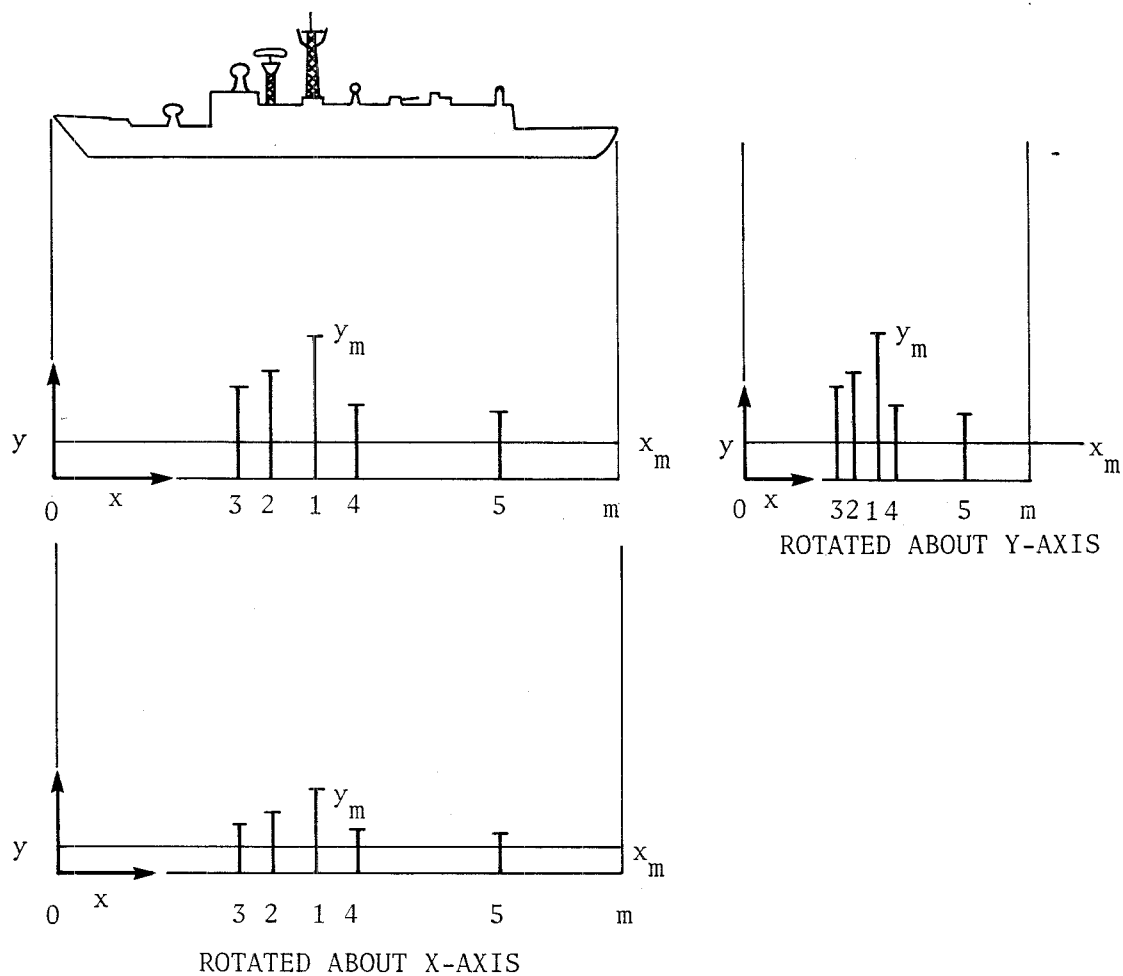
$x_m = x(m)$

$y_m = y(1)$

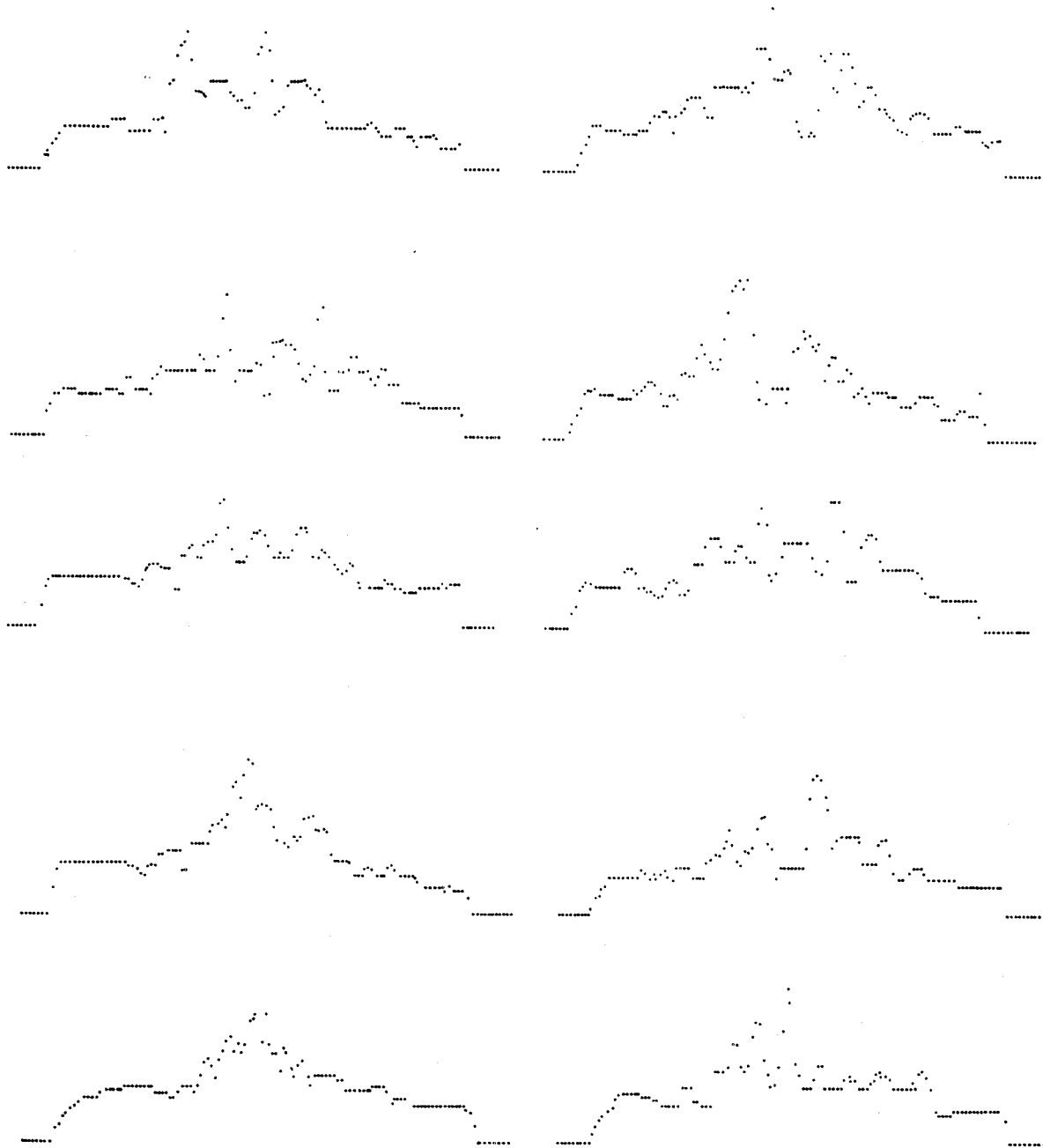Figure 1. Measurements of ship High-point characteristics

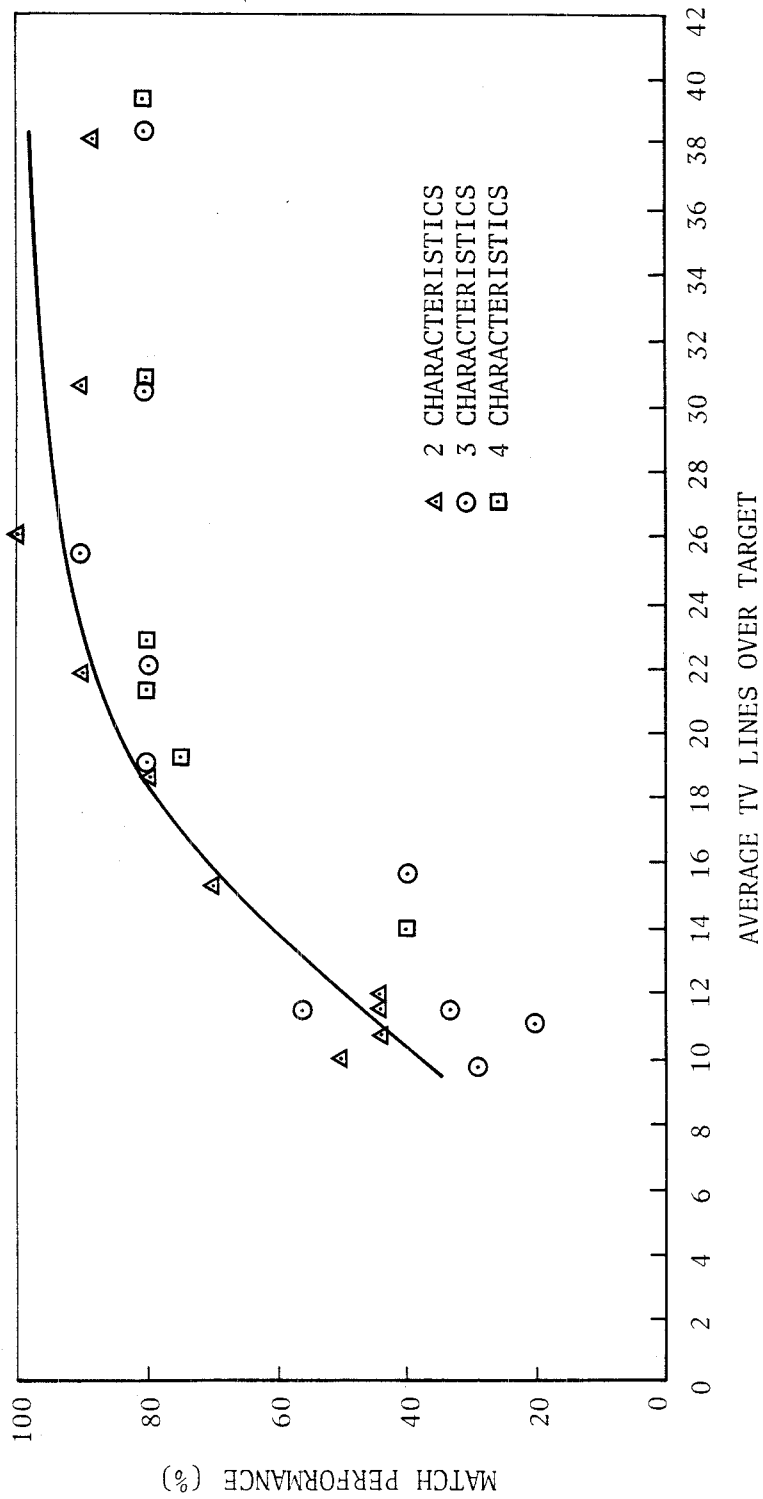Figure 2. High-point contours for library shapes

Figure 3. Match performance plotted against size of target for various numbers
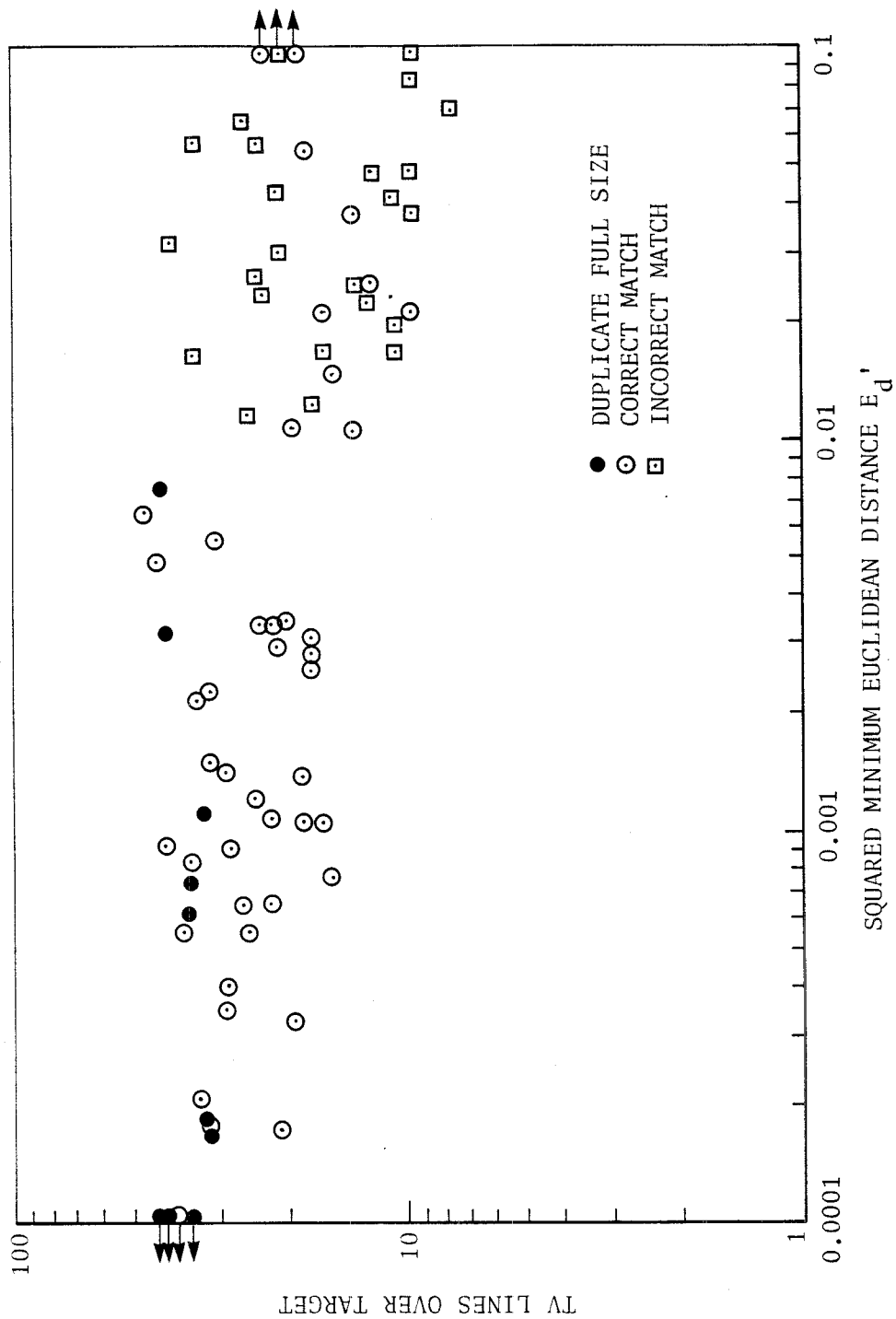of characteristics

Figure 4. The relationship between the correctness of match and size for broadside views using 4 characteristics
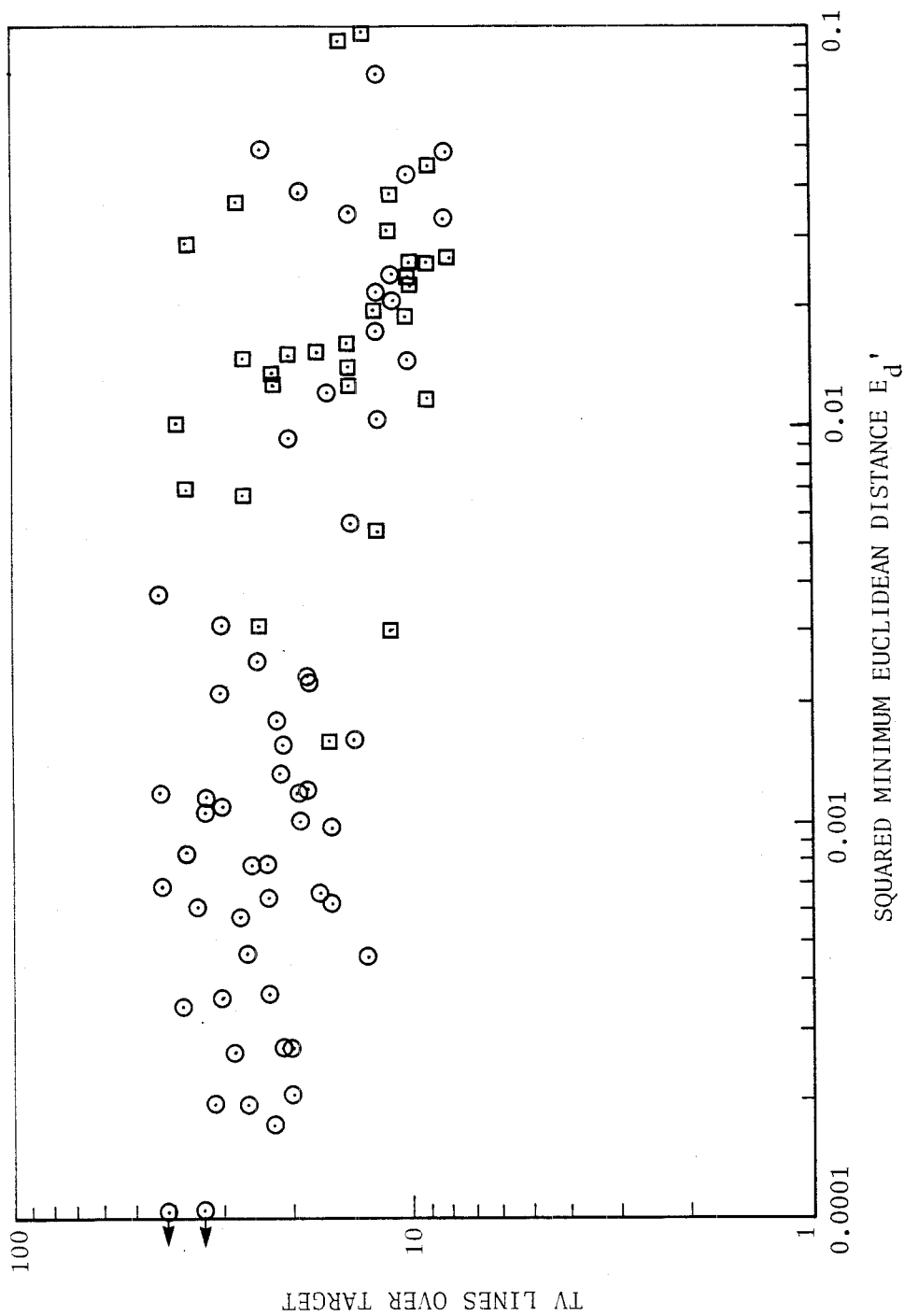
Figure 5. The relationship between the correctness of match and size for broadside views using 3 characteristics
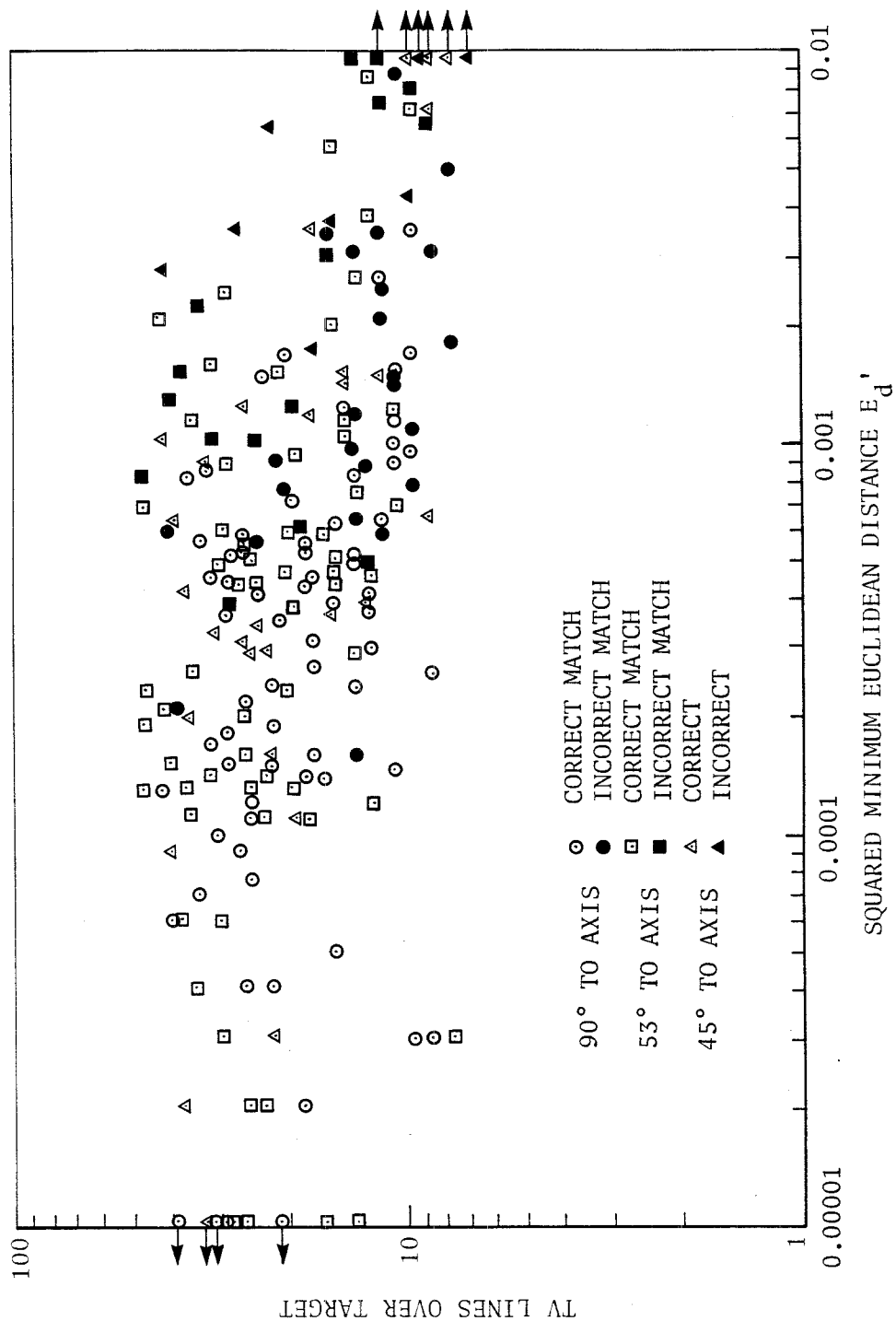
Figure 6. The relationship between the correctness of match and size for various aspect angles using 2 characteristics
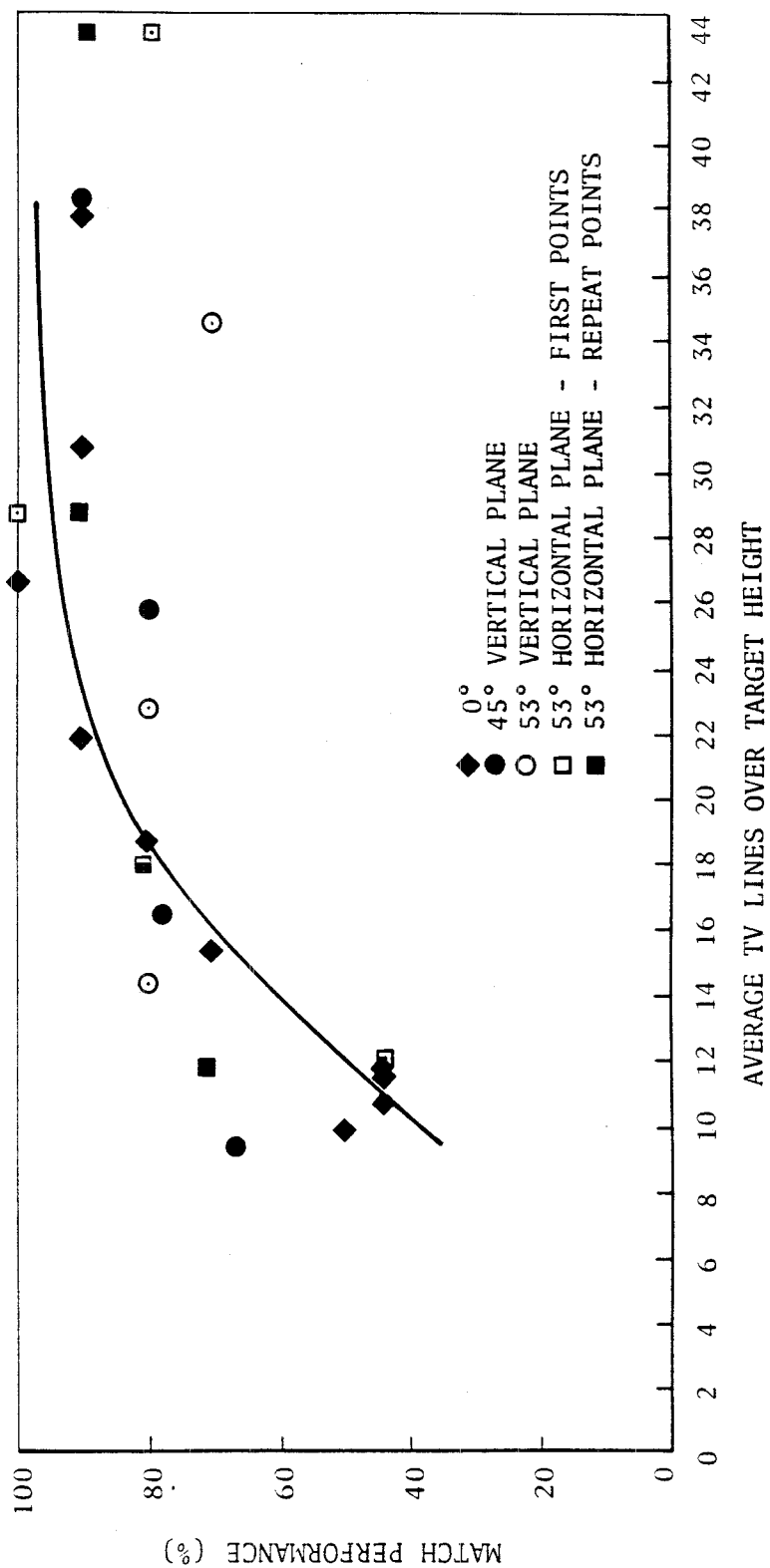
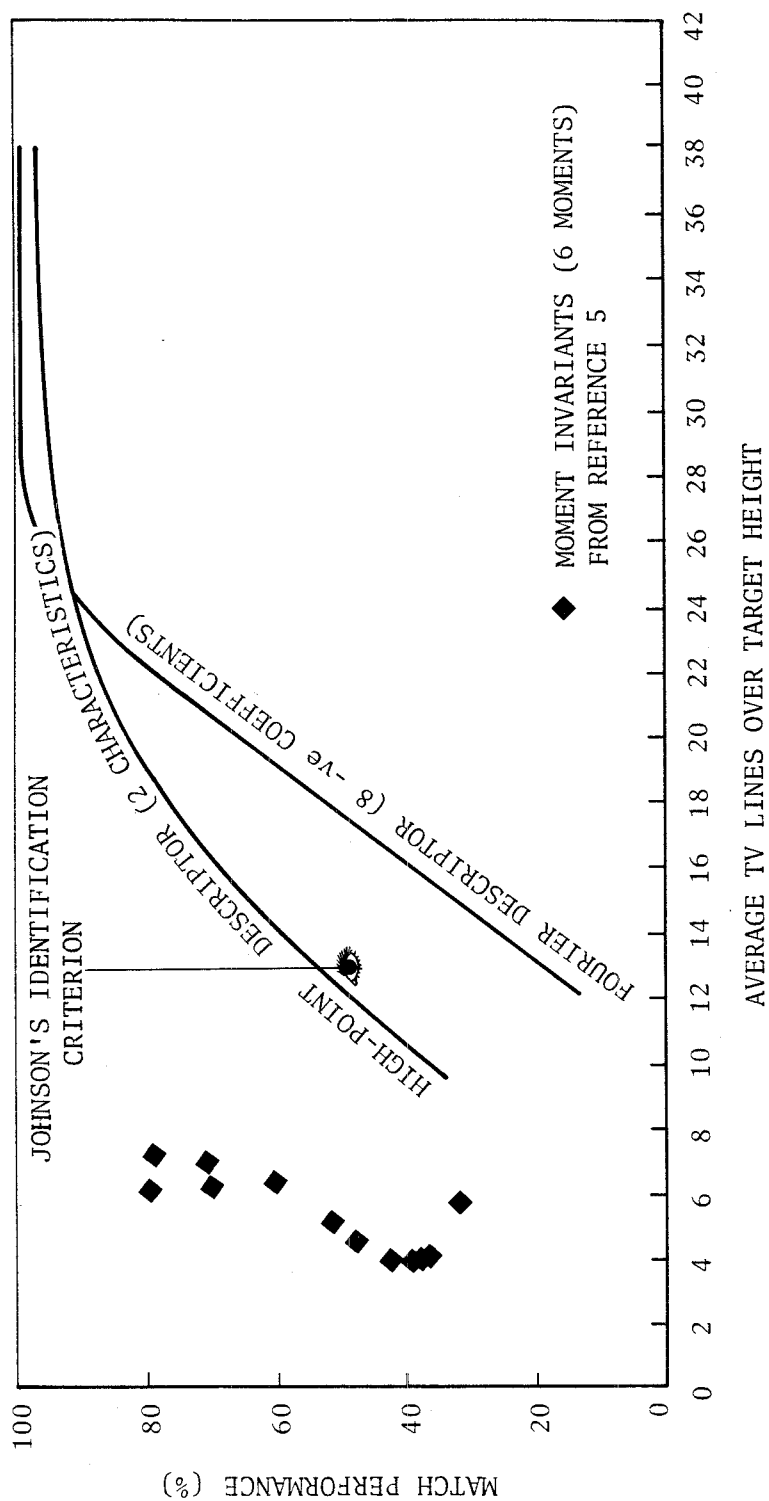Figure 7. Match performance against average size for various aspect angles

Figure 8. Comparison of methods of match performance for variations in size of target

DOCUMENT CONTROL DATA SHEET

Security classification of this page   UNCLASSIFIED

1	DOCUMENT NUMBERS	2	SECURITY CLASSIFICATION
AR Number: AR-004-954		a. Complete Document: Unclassified	
Series Number: WSRL-0514-TR		b. Title in Isolation: Unclassified	
Other Numbers:		c. Summary in Isolation: Unclassified	

3 TITLE

HIGH-POINT DESCRIPTOR TECHNIQUE FOR THE IDENTIFICATION OF SHIP
SILHOUETTES AT VARIOUS ASPECT ANGLES

4 PERSONAL AUTHOR(S):	5 DOCUMENT DATE:
B.E. Furby	May 1987
	6 6.1 TOTAL NUMBER OF PAGES 16
	6.2 NUMBER OF REFERENCES: 6

7 7.1 CORPORATE AUTHOR(S):	8 REFERENCE NUMBERS
Weapons Systems Research Laboratory	a. Task: DST 91/485
	b. Sponsoring Agency:
7.2 DOCUMENT SERIES AND NUMBER	9 COST CODE:
Technical Report 0514	

10 IMPRINT (Publishing organisation)	11 COMPUTER PROGRAM(S) (Title(s) and language(s))
Defence Research Centre Salisbury	

12 RELEASE LIMITATIONS (of the document):

Approved for Public Release

Security classification of this page: UNCLASSIFIED

| 13 | ANNOUNCEMENT LIMITATIONS (of the information on these pages): |

No limitation

| 14 | DESCRIPTORS: | | 15 | COSATI CODES: |

a. EJC Thesaurus Terms

Identification systems
Ships
Silhouettes

0063F

b. Non-Thesaurus Terms

High-point descriptor
Target identification

| 16 | SUMMARY OR ABSTRACT: |
(if this is security classified, the announcement of this report will be similarly classified)

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