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A QUICK LOOK AT SPALL USING CLUSTERING TECHNIQUES

Morton A. Hirschberg

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USA BALLISTIC RESEARCH LABORATORIES
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This report delineates the analysis of spall produced by one round of a 3.2 inch precision shaped charge using ISODATA, a centroid method clustering algorithm. Clustering was performed on the three spacial dimensions, x, y, z, by which the spall had been collected. The mass of each particle which was a priori categorized as low, medium-low, medium high, and high was then associated with its particle (by category) according to the particle's cluster membership. In general, low mass particles clustered nearer to the center of dispersion than

20. the high mass particles, a result which had been observed in earlier two dimensional regression analyses.

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I. INTRODUCTION

A good portion of the data collected at the Ballistic Research Laboratories is multidimensional, consisting of spacial coordinates, velocities, accelerations, temperatures, masses, times, chemical compositions, etc.

In attempting to derive information from such data, many analytical and statistical techniques have been used. This paper delineates the use of an analytical procedure, clustering, which has had wide application in the social and biological sciences. Clustering is simply the grouping of similar objects. It is almost synonymous with classification.

As a practical example of the applicability of the technique, spall data was chosen for analysis. The spall data consists of 228 fragments of round 1198.[1] The dimensions of the problem were restricted to x,y,z coordinates (in inches), mass (in grams), and later spray angle (in degrees).

The method chosen for clustering was ISODATA,[2] a k-means[2,3,4] centroid type algorithm.

Briefly, the ISODATA algorithm works as follows: a number of objects are selected as a trial subset of centroids. The entire data set is then partitioned by placing each object in the subset to which it is closest distance-wise. The average of each enlarged subset is used as the new centroid. Trial subsets are modified only after all objects have been assigned. In general, this algorithm tends to minimize the sum of the squared distances of each object from its subset mean. The user has some control over the number of clusters, as well as subset merging and splitting thresholds. In addition, the user has the option of letting the algorithm converge to a final solution, or stopping the process after a given number of iterations.

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[1] Rodin, B.H., Documentation of Spall Produced by a 3.2 Inch Precision Shaped Charge, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, BRL Memorandum Report No. 2407, August 1974. AD #923573L.

[2] Rice, C.E. & Lorr, M., An Empirical Comparison of Typological Analysis Methods, ONR Contract N00014-67-A-0214, TASK0005.

[3] Hartigan, J. A., Clustering Algorithms, New York, Wiley 1975.

[4] Anderberg, M. R., Cluster Analysis for Applications, New York, Academic Press, 1973.

II. ANALYSIS OF SPALL DATA

The conditions under which the charge was fired, the method of collection, the masses, and the x-y coordinates are all documented in Reference 1 and will not be repeated here. The z coordinate was taken to be halfway into the sheet in which it was found (sheets were 0.5 inches thick). There was also a 24 inch offset, so the z coordinates are given by

$$(24 + 0.5(S-1) + 0.25) \qquad (1)$$

where S is the sheet number. Spray angle was calculated using (2) below.

$$\mathrm{TAN}^{-1} \frac{\sqrt{x^2+y^2}}{z} . \qquad (2)$$

Particle masses were divided into four groups as shown in Table I.

TABLE I

DISTRIBUTION OF PARTICLES BY MASS

Mass Grams	Number of Particles	Percent of Particles	Group
0-.002	46	20	(L) Low Mass
.002-.006	63	28	(ML) Medium-Low Mass
.006-.04	62	27	(MH) Medium-High Mass
.04 and heavier	57	25	(H) High Mass

ISODATA was run clustering the true x, y, z coordinate data of the particles. Twelve clusters were produced. The centroid data for the twelve clusters is shown in Table II.

The masses of the particles were then associated by category to the cluster to which they belonged. Table III summarizes those results.

TABLE II

CLUSTER CENTROID DATA

CLUSTER	x	y	z
1	-1.07	6.01	25.40
2	-13.91	2.45	25.36
3	-6.60	9.75	25.48
4	-2.28	13.55	25.66
5	11.40	9.12	25.55
6	5.86	5.21	25.46
7	-8.94	3.83	25.32
8	13.96	2.53	25.50
9	4.83	12.15	25.35
10	-12.81	9.19	25.75
11	-10.30	15.43	25.56
12	2.70	20.00	25.58

TABLE III

DISTRIBUTION OF PARTICLES BY MASS

	MASS				
CLUSTER	L(ow)	M(ed)L(ow)	M(ed)H(igh)	H(igh)	Total Particles
1	7	7	1	2	17
2	1	2	6	4	13
3	4	6	11	5	26
4	5	4	7	7	23
5	6	4	8	7	25
6	13	4	0	4	21
7	3	13	4	2	22
8	2	6	5	3	16
9	5	15	14	5	39
10	0	2	6	7	15
11	0	0	0	8	8
12	0	0	0	3	3
	46	63	62	57	228

Monte-Carlo simulations were run in order to establish the frequency with which the distribution of particles shown in Table III occurs. It was found that the distribution for clusters 1, 3, 6, 7, 9, 10, 11, 12 occurs below the chance level. That is, in general it was found that low mass particles clustered and high mass particles clustered.

Hafer[5] showed that the mass gets larger as the spray angle increases. Mean spray angle for each cluster is shown in Table IV. In addition Table IV contains the percentage of high mass (medium-high and high) particles in each cluster.

An intuitive grouping of the clusters shows a perfect qualitative relationship between spray angle and particle mass. These results are shown in Table V.

III. DISCUSSION

A one point sample of real spall data was analyzed using ISODATA, a centroid clustering technique. Particles were found to form natural spacial clusters. When an association of particle mass with cluster membership was made, the clusters were also found to be grouped by mass. That is, in general low mass particles were found to form clusters and high mass particles were found to form clusters.

When spray angle was associated with the clusters, a perfect qualitative relationship between spray angle and particle mass was found. This result supports Hafer's work.

The work described in this report took one week to do, including writing the report. There were 3 minutes of UNIVAC 1108 computer time used in running program ISODATA and doing the Monte-Carlo runs.

It is believed that clustering techniques will be a valuable tool in the analysis of multiple burst, multiple barrel type weapons, as well as other applications (e.g. fuel fires).

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[5] Hafer, A.S., An Empirically Based Scheme for Prediction of Some Characteristics of Behind-Armor Spall., Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, (Unpublished paper).

TABLE IV

MEAN SPRAY ANGLE AND PERCENTAGE OF HIGH MASS PARTICLES BY CLUSTER

CLUSTER	MEAN SPRAY ANGLE (DEGREES)	PERCENTAGE HIGH MASS PARTICLES
1	15.76	18
2	29.09	77
3	24.88	62
4	28.23	61
5	29.74	60
6	17.71	19
7	21.80	27
8	29.15	50
9	25.80	49
10	31.73	87
11	36.20	100
12	38.76	100

TABLE V

CLUSTER GROUPING BY SPRAY ANGLE

CLUSTER GROUP	MEAN SPRAY ANGLE (DEGREES)	PERCENTAGE HIGH MASS PARTICLES
1,6	16.84	18
3,7,9	24.51	47
2,4,5,8	29.06	61
10,11,12	33.92	92

An interesting adjunct to cluster analysis would be a dimensional analysis[6,7,8] performed first, whenever possible, to reduce the number of variables under consideration (or finding relevant variables for further analysis). Clustering (or factor analysis) applied to the reduced number of variables should provide a nice model. In addition, regression could now be performed on the resulting clusters to provide a comprehensive analysis.

Clustering therefore is useful for providing a model when none exists, quick response when little is known about the data, and pinpointing anomolies (refining a model).

It is hoped clustering techniques will be widely used in future analysis where great amounts of data exist.

IV. ACKNOWLEDGEMENT

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[6] Langhaar, H.L., Dimensional Analysis and Theory of Models, New York, Wiley, 1951.

[7] Hirschberg, M.A., A Computer Solution of the Buckingham Pi Theorem Using SYMBOLANG, A Symbolic Manipulation Language, Ballistic Research Laboratories Report No. 1824, Aberdeen Proving Ground, Maryland, August 1975. AD #A016901.

[8] Hirschberg, M.A., The Evaluation, Manpulation, and Identification of Nondimensional Numbers, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland (in preparation).

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