1.0

4.5
5.0
5.6
6.3

2.8　2.5

3.2　2.2

3.6

4.0　2.0

1.1

1.8

1.25　1.4　1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A
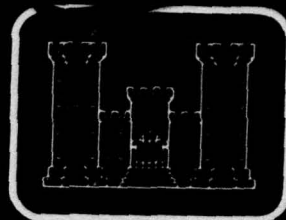
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(10) Allen Klinger

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method to use terrain elevation data for guidance is presented. Tree structure representation of contour trend data over regions is the basis of the method. Regions of different sizes obtained by quartering given elevation matrices are used; region size corresponds to tree position.

Two computer functions are discussed: analysis methods to use tree-structured contour-trend information, suitable for onboard inflight computations; and storage reduction methods to present elevation data as a

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new digital mapping product (tree-structured contour-trend data), computable off-line on the USAETL Computer Sciences Laboratory STARAN array processor.

Six figures detailing the analytic and data storage concepts discussed are given. An example illustrating the improved penetration possible from these methods is presented.

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LIST OF FIGURES

1. Introduction

Discussions of elevation data at the Engineer Topographic Laboratories, August 1978, raised the issue of its use by agencies such as the Strategic Air Command. This document concerns such uses of this data and suggests the desirability of a specific type of encoding of terrain elevation data which could be efficiently computed off-line at the USAETL Computer Sciences Laboratory using the STARAN array processor there. The advantages of the encoding discussed here are in enabling new methods of onboard guidance for cruise missiles to revise the trajectory so as to best utilize the information in the elevation database. A new standard DMA product can be foreseen involving such an encoding of terrain elevation data. Brief comparisons with other possible elevation-data reduction methods are presented. The relative advantages of all the methods for cruise missile guidance is discussed. The title and emphasis of this report is the same as a presentation given 11-17-78 at the Defense Mapping Agency Conference on Digital Terrain Elevation Data, St. Louis, Missouri.

Previous analysis of the survival rate (S. R. below), a quantity also referred to as $P(n,x)$, penetration probability, for a vehicle having n air-to-air missiles and x expected encounters with enemy interceptors where each missile has p (probability) success rate in destroying enemy interceptors, was reported in [1-3] (preliminary investigations for the B-1 manned aircraft). This report describes how the analytical and computational work described in [1-3] can be combined with hierarchical (tree) encoding [4] of elevation data. If the terrain elevation data along a cruise missile trajectory were available, methods analogous to those in [1-3] could be used to improve cruise missile penetration.

1

Analysis and programming based on the data proposed here could yield:

    a. off-line computations of preferred trajectories

    b. on-board guidance adjustments to avoid potentially difficult-to-penetrate geographic entities.

The basis for the analysis is optimization of a product of objectives just as in the B-1 study; the factors would involve survival rates at decision points. Prior independent study of typical terrain-profile/trajectory-direction combinations would determine these rates. Optimization variables of choice are the directions of continuing the curise missile flight. See Figure 1 for an overview of the storage and analysis process.

Elevation data encoding is proposed to match the requirements of on-board guidance computations, and methods are presented for using the encodings with computers that can be flown. A "chain-code" representation of contour lines is presented along with methods for structuring such data for optimization of flight path computations. Two forms of elevation data inputs are described:

    a. elevation data matrices, and

    b. contour plot maps.

Conceptual descriptions of computer programs to process both forms of data to obtain chain-code representations, are given. Simplifying methods for such programs to speed execution can be based on tree structure results in [5]. The tree data structure can be used to store the different survival rates that are found as a missile crosses or passes parallel to contour lines in local regions; see Figure 2.

2

2. Elevation Trends

There is a need for an intermediate-complexity description of elevation for flight path optimization. We define _elevation trends_ as the dominant contour direction in a geometric region. If any contours cross the region, their principal chain-code is assigned to it. (If the contour angle changes, the code that best represents the average direction is used). A chain code is a digit between 0 and 7 (or 0 and 15, or 0 and 31) representing motion along a line lying within a prechosen angle range. An example is: 0, $(0^0, 45^0)$; 1, $(45^0, 90^0)$; ...; 7, $(315^0, 360^0)$. Figure 3 shows the chain code representations for an incident missile trajectory. If a map section is regularly decomposed by fourths (quarters of quarters, etc.) as shown in Figure 4, the chain-code function of the zone is the digit associated with it, the original section, along with the four digits associated to its one-lower tree-level quarters and their tree-positions. In any zone or quarter, the value would be the predominant direction of contour lines through the zone, or if no contours were found, a null indicator. This is illustrated in Figure 5 where a detailed example is presented.

Research has been published on condensing elevation data [6] to obtain a structural description of the scene. Other methods for condensing such data can be based on well-established pseudo-gradient line-extraction operators; these could also be used to derive a contour plot map from elevation matrices. Because a large volume of data would have to be processed, a parallel processor, such as STARAN would be best able to handle such reduction of data. Chain-code elevation trends from a contour plot also would be obtained by parallel processing procedures, and simplified algorithms could be designed if only "trends" given "elevation matrices" were required. (Line-finding routines, smoothing and extrapolation, and hierarchical processing would be applied.) Recent work on these subjects is reported in [7] and [8], the former having used Kirsch operators and thinning to determine lines followed by tree-structured area-encoding,

3

the latter involving a hierarchic (tree) description of roads for shortest path computations.

Quartering storage and retrieval methods are taken to a software system level of detail in [9], where digitized imagery is the data. Figure 6 illustrates this process and gives the notation used, and the equivalent tree structure, for storage and rapid data retrieval. The combination of quartering methods with chain-code trend representations is only one possible intermediate-complexity elevation description. There is need for a detailed evaluation of the merits of three separate elevation descriptions:

1. Chain-code function (see this report, paragraph one, section 2)

2. Polynomial representation (J. Jancaitis, USAETL)

3. Statistical parameterization (I. Evans, University of Durham, U.K.)

A qualitative comparison of these three approaches reveals more similarity than differences since each involves reduction of a large elevation data array to a small number of parameters. The principal differences between the chain-code function proposed above and the descriptors in [10] or the polynomial fits in [11] are that the former involves:

1. region-specificity: greater detail can be represented in critical areas.

2. iterative refinement is possible.

By contrast, adding higher moments [10] or more polynomial terms [11] has general, rather than local, consequences.

The region-specificity of the chain-code function is well-suited to computations for choosing a best flight-path. A basic computer method, tree data structures, is used there. This enables further refinement in accord with guidance computations' needs. (Refinement could continue until the limit of resolution of the elevation data.) Furthermore, the successor nodes in descending through a tree structure that stores the contour-direction trend by region (each region is associated with a tree node), are reasonable decision variables for an optimization algorithm.

4

3. Tree Structure and Flight Path Optimization

The analysis problem takes advantage of the limited number of successor nodes at every tree structure level, and the possibility of many levels in the hierarchy. Adjustment of the flight path to avoid crossing contours can be built into the operational plan, by using recursion on future trajectory revision in locally-adapted guidance calculations. We assume that at a given flight position $\underline{x}$, a missile moving along a local trajectory with angle θ to the preflight calculation, can best proceed through the immediate geographic region with a survival rate S.R.$(\underline{x},\theta)$; that achieving this rate requires optimum survival from any subsequent point $\underline{y}$ (usually closer to the destination than $\underline{x}$); and that the rate can be achieved only by the following maximization. Let q, the quadrant of greatest trajectory length as the missile flies through the region centered at $\underline{x}$, be chosen so that:

$$\text{S.R.}(\underline{x},\theta) = \max_{q} \quad \{\text{S.R.}(q,\underline{x}',\theta) * \text{S.R.}(\underline{y},\phi)\}$$

Here $\underline{x}$ represents the UTM location, θ the approach angle of the missile measured from the horizontal axis (in the direction of flight), and a,b,c,d are node labels in a tree structure keyed into elevation data centered at $\underline{x}$ (and they are also values that the variable q can take). The remaining variables $\underline{x}'$, $\underline{y}$, and ϕ are:

$\underline{x}'$: the UTM location of the entry point to the elevation array centered at $\underline{x}'$.

$\underline{y}$: the UTM location of the next array center derived from the exit point from the quarter of the elevation array centered at $\underline{x}$ called "q".

ϕ : the approach angle to the $\underline{y}$-centered elevation array.

Conceptually, a preflight trajectory would be computed and used as a baseline ("in-the-flight-path" refers to this trajectory). A condensed

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elevation database would be onboard and used for guidance functions. This data would be referenced to "in-the-flight-path," the horizontal-axis direction; that, and a vertical-axis orthogonal to the flight, divide an array centered on $\underline{x}$ into four regions. The regions correspond to tree nodes which have labels a, b, c, and d, corresponding to upper left, upper right, lower left, and lower right areas of the original terrain elevation data array. Off-line data processing to derive the contour-trend tree-structure condensed elevation database will be described in subsequent reports.

There is a basic advantage to the tree structure approach for condensing elevation data. Note that the recursive relationship for survival rate includes a factor $S.R.(q,\underline{x}'\theta)$. That is,

$$S.R. (a,\underline{x}',\theta)$$
$$S.R. (b,\underline{x}',\theta)$$
$$S.R. (c,\underline{x}',\theta)$$
$$S.R. (d,\underline{x}',\theta)$$

all must be evaluated to perform this maximization step. In essence we need to know an estimate of survival rate through each quarter of the terrain elevation array centered at $\underline{x}$, the quantity represented above showing explicit dependence on actual location ($\underline{x}'$) and angle (θ) of entry to the array, as well as the quarter-designation a,b,c, or d. Note that there is no array-size restriction to this process, and this means that an algorithm could function at all tree-levels obtained by refinement (quartering). Hence when a terrain obstacle is encountered in the quadrant (say "a") located by the UTM coordinates $\underline{x}$, the four more detailed representations of elevation data (in our proposed elevation trend method) for the regions a.a (upper left), a.b (upper right), a.c (lower left), a.d (lower right) that are quarters of "a", would be examined. This process of refinement could continue indefinitely constrained only by the limitations of resolution of the original terrain elevation data and the availability of computing time. In

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an actual cruise missile flight the coarse evaluations (from combining elevation-trend-value over array quarters with approach angle) of S.R. $(a,\underline{x}'\theta)$ ect. would be replaced by values derived from the next lower tree level when needed by the trajectory optimization algorithm. The array sections needed would be computed pre-flight at USAETL, and at a minimum would be those labeled a.a, a.b, ..., a.d, .,., d.a, d.b, ..., d.d. These would be used in a relation like (1) to derive a detailed guidance plan for routing the missile through a region to avoid crossing contour lines, to limit the number of contours crossed, and to reduce its overall vulnerability. A hand example showing how this could minimize contour crossings using successive refinement (quartering) and trend data is given in Figure 5.

4. Conclusion

The availability of regularly refined elevation data matrices as a new cartographic produce could be a valuable tool for improving missile penetration. A basis for that product (see [4] and [9]) is the series-of-rows representation of overall area elevation data followed in secondary storage by a series-of-rows representation of each quarter of that area. Given the *USAETL Staran Computer*, a multi-level refinement of an original area for which elevation data were given could be created for this new product.

An intermediate tool for using regularly refined elevation data matrices, the contour trend (approximate local chain code value for the equivalent contour map), can be the basis of a simple traversal-route selection algorithm. Smoothing contours, and avoidance of closed contour loops for trend-number evaluations, are areas where further work is needed (an inverse to curve fragmenting - see [12] - is needed).

A detailed analysis of the route survival improvements obtainable by this technique should be conducted based on the concepts in this report and references [1] - [5], and [9].
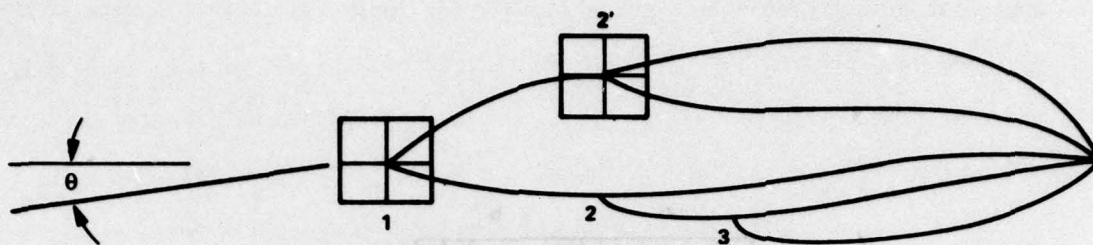
TRAJECTORY REVISION POINTS 1, 2, 3 or 1, 2'

ACTUAL DIRECTION CHOSEN BASED ON

• STORED ALTITUDE DATA AS FIVE ELEVATION ARRAYS, EACH IN "SERIES OF ROWS" FORMAT.

• ANGLE OF APPROACH

    θ
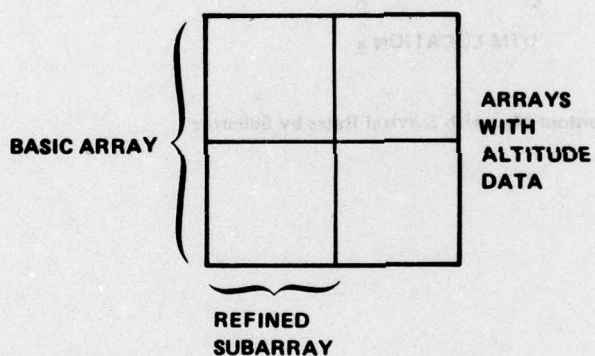
• ANALYSIS OF PENETRATION PROCESS

    COMPARISON OF PENETRATION PROBABILITY FOR 1, 2, 3 TRAJECTORY
    WITH I, 2' TRAJECTORY.

Figure 1. Concept for Storage of Altitude Data to Use Analysis to Improve Penetration

APPROACH ANGLE θ

a   b

CONTOUR ELEVATION AND SURVIVAL
RATES BY SUBARRAY

S.R. $(a,\underline{x},\theta)$

S.R. $(b,\underline{x},\theta)$

.
.
.

S.R. $(d,\underline{x},\theta)$

c   d

UTM LOCATION $\underline{x}$
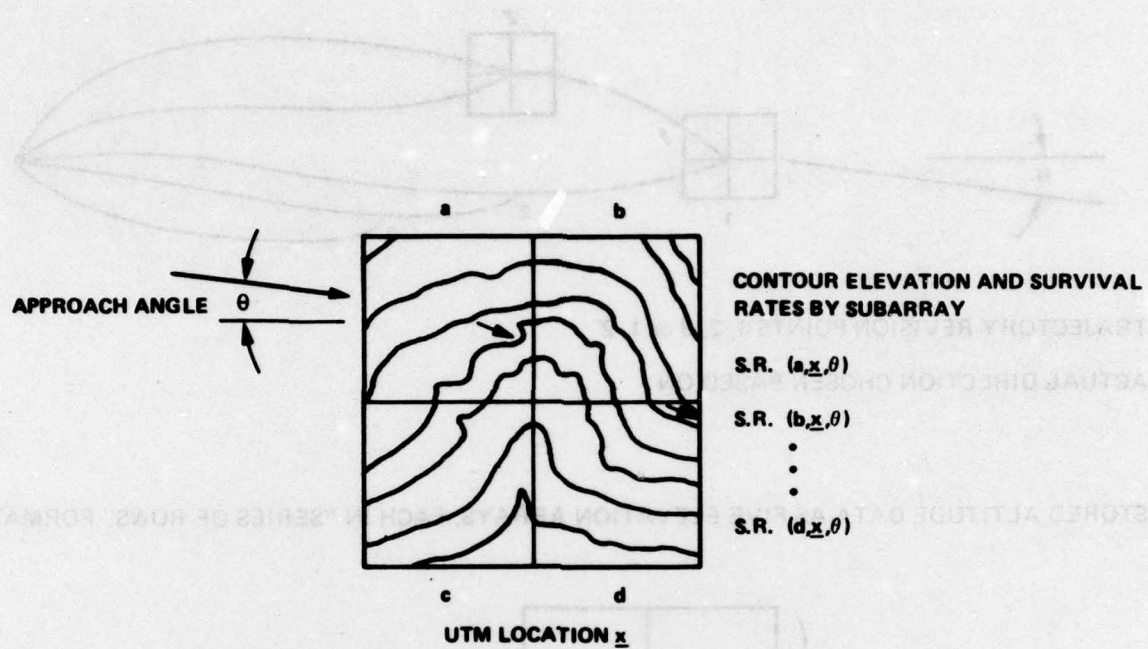
Figure 2. Contour Map with Survival Rates by Subarray
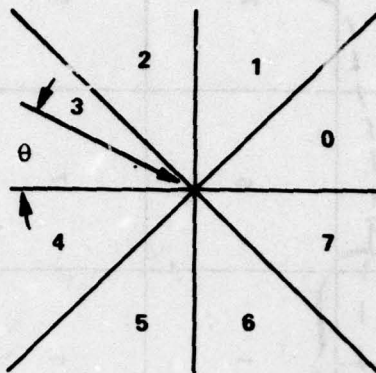
ANGLES θ REPRESENTED BY OCTAL (8) OR SIXTEEN VALUES. TRAJECTORY
SHOWN COULD HAVE INCIDENT ANGLE QUANTIZED TO 3 OR TO 7.

Figure 3. Trajectory Incident Angle Quantization

THE DIAGRAM IS EQUIVALENT TO THE USE OF TREE DATA STRUCTURES,
AND REGULAR REFINEMENT FOR MORE DETAIL.

Figure 4. A Regular Method for Refining the Stored Altitude Data

FINER DATA SHOWN
STORED AT LOWER
TREE LEVEL

ENTER AT ANGLE "1"; TRAVERSAL VIA "2" & "7"

Figure 5. Contour Trend Data: Storage of the Predominant Contour Directions
Showing a Trajectory Through the Array

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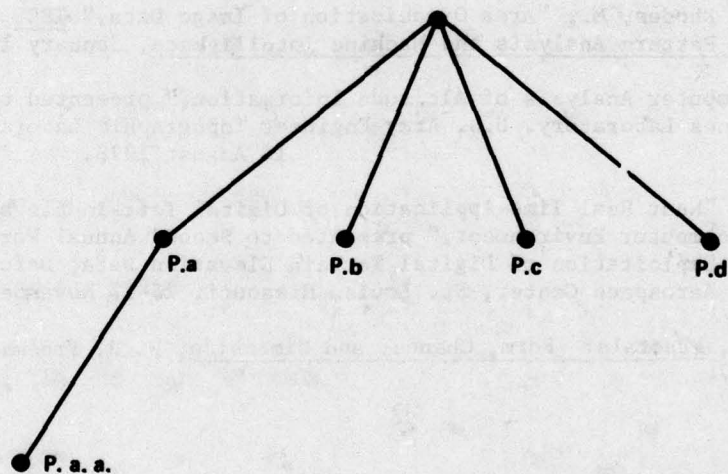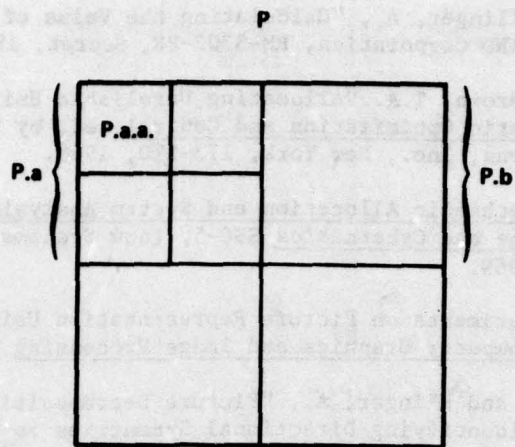[5] Alexandridis, N. and Klinger, A. "Picture Decomposition, Tree Data Structures, and Identifying Directional Symmetries as Node Combination," Computer Graphics and Image Processing, 7, 43-77, 1978.

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Figure 6. Notation for Array Refinement and Tree Data Structure

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