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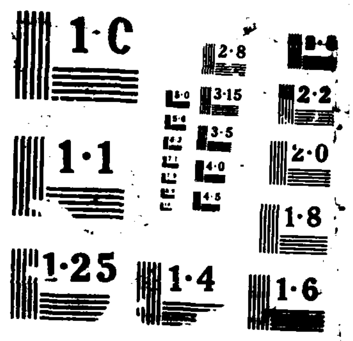

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U.S. ARMY INTELLIGENCE CENTER AND SCHOOL
SOFTWARE ANALYSIS AND MANAGEMENT SYSTEM

IMPACT OF DETECTOR LOCATION AND ORIENTATION ERRORS ON THE PERPENDICULAR METHOD - AN INTRODUCTION

TECHNICAL MEMORANDUM NO. 13

MARC

Mathematical Analysis Research Corporation

EXTENDED EAAF FAMILY
ALGORITHM ANALYSIS

03 October 1985

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

This memo discussed the effect of location and orientation biases of the sensors in obtaining a location estimate (fix) from LOB data. This fix is computed via the Perpendicular Method algorithm. This study, while treating both correlated and uncorrelated biases, is only an initial assessment of the problem.

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PREFACE

The work described in this publication was performed by the Mathematical Analysis Research Corporation (MARC) under contract to the Jet Propulsion Laboratory, an operating division of the California Institute of Technology. This activity is sponsored by the Jet Propulsion Laboratory under contract NAS7-918, RE182, A187 with the National Aeronautics and Space Administration, for the United States Army Intelligence Center and School.

Impact of Detector Location and Orientation Errors on the Perpendicular Method - An Introduction

INTRODUCTION

The objectives of this report are:

i) Identify questions regarding detector location and orientation error impact on the perpendicular method. This identification together with sponsor direction is intended to provide a set of objectives for subsequent modeling/simulation efforts.

ii) Definition of
   a) The Perpendicular Method for obtaining a fix
   b) Location of Detector Error (independent)
   c) Location of Detector Error (dependent)
   d) Error in measuring true North (independent)
   e) Error in measuring true North (dependent)

iii) Derivation of an adjusted perpendicular method given independence

iv) Presentation of several approaches to the study of these error types together with a discussion of comparative features of the different approaches.

In the case of definition of the perpendicular method there exist ambiguities in the reference material used by MARC which should be resolved at the earliest available opportunity. These ambiguities are given with the definitions.

The topics discussed above are introduced in corresponding sections.

I. QUESTIONS

A. How much would the estimate of emitter location change if it reflected available information about detector location error and error in measuring true North? (Or is this question imprecise because there is no single best estimate?)

B. How much would the error ellipse change if it reflected available information about location error and error in measuring true North?

C. Is the difference between the theoretical desirability of minimizing least square angular error and the perpendicular method washed out by the detector location errors and errors in measuring true North?

D. Are there simple means of correcting for detection location error and error in measuring true North?

E. What impact do errors owing to detector location errors and errors in measuring true North have on subsequent algorithms (in particular, ellipse combination and test for combination?)

II. DEFINITIONS

The five definitions are under headings A-E respectively.

A. THE PERPENDICULAR METHOD FOR OBTAINING A FIX:

1. Notation

$\hat{\theta}_k$ = the observed angle (clockwise from north) of the kth line of bearing (LOB)

θ_k =the true angle from an emitter to the detector of the kth LOB

$(\hat{\varepsilon}_k, \hat{\eta}_k)$=the measured location of the detector of the kth LOB

(x_k, y_k)=the kth estimate of emitter location

$A_k = (\cos\hat{\theta}_k, -\sin\hat{\theta}_k)$

ψ_θ =variance of θ_k (in the version of the perpendicular method available to MARC this was independent of k)

ψ_k =covariance matrix of (x_k, y_k)

2. Formulas

$$(x_k, y_k) = [\textstyle\sum_{i=1}^{k} ((\hat{\varepsilon}_i, \hat{\eta}_i) A_i^T A_i)] [\textstyle\sum_{i=1}^{k} (A_i^T A_i)]^{-1}$$

Note that there is no weighting by angular uncertainty or other use of measurement variance in this expression. Further investigation into other sources for this algorithm is needed.

ψ_k = unspecified in our sources

B. LOCATION OF DETECTOR ERROR (independent)

This refers to the uncertainty in location of the detector. In the independent case we assume that each bearing is taken from a different location and that the error in determination of that location is independent of the errors in determination of detector locations for other bearings. Finally, for lack of other information we assume that this error is normally distributed. Let G_k denote the covariance matrix of the kth location estimate error.

Note that in some cases analysis might be simplified by separating error into a dependent error and an independent error.

C. LOCATION OF DETECTOR ERROR (dependent):

Many sources of dependence are possible. The simplest is the case where multiple LOBs would have the same sources of detector location error. One example of this would be multiple LOBs being taken from the same location. The full range of means of introducing dependence between location estimates may turn out to be out of scope of this study.

D. ERROR IN MEASURING TRUE NORTH (independent):

By this is meant errors which affect the bearing angle which is reported. The independent case really requires no special study. The error distribution simply adds to the detector's inherent angular error in taking measurements. This is particularly simple if the errors are assumed to be normally distributed.

E. ERROR IN MEASURING TRUE NORTH (dependent):

As in the case of location detector error it is unclear if the full range of types of dependence can be determined.

III. MARC'S MODEL FOR THE INDEPENDENT CASE

Note: This model is referred to as MARC's model even though it seems to be a natural approach because there exists a different approach described in a Sylvania document.

We assume as discussed above that error in measurement of true North may be reflected in the variance of angular measurement (because of indepence).

We assume tnat error due to inaccuracy in location is normally distributed and that distribution adds (is independent of) to the error owing inaccuracy of angular measurement.

Observe that the emitter location estimate (given above) is a linear combination of the detector locations. (It is also of interest to note that this would remain true even if weighting modifications were made to the formula for emitter location.) Linear combinations of normals are normal.

If X_i are $N(0,G_i)$ then $\sum_{i=1}^{k} B_i X_i$ is $N(0, \sum_{i=1}^{k} B_i G_i B_i^T)$

Thus the inclusion detector location error merely adds a new zero-mean normally distributed error term. This term can be expressed in terms of notation already introduced.

$$\text{Total Error} - N(0, \psi_k + \sum_{j=1}^{k} \{[\sum_{i=1}^{k} (A_i^T A_i)]^{-1} [A_j^T A_j] G_j [A_j^T A_j] [\sum_{i=1}^{k} (A_i^T A_i)]^{-1}\})$$

This looks like more computation than it actually is since portions can be recursively updated and since most of the computation is already needed for the point estimate.

Furthermore since the distribution is still normal with mean zero the point estimate need not be changed. (Note-the method for computing ψ_k was not needed to get this result but further work would require it.)

Although we have given this result in terms of the perpendicular method, weighting will allow broader application (for example application to Guardrail with appropriate weighting modifications is under investigation with some interesting results already derived.)

IV. ALTERNATIVE APPROACHES

Alternative approaches must be considered in part because the perpendicular method itself is not exact even without detector location error and error in measurement of true north. Ultimately the question is not whether MARC's generalization of the perpendicular method or the method mentioned in connection with Sylvania is a more natural approach. The question is which classifies better. These approaches need not even be improvements. Demonstration will probably require simulation and other techniques.

Since details are still lacking concerning dependency and also concerning the perpendicular method itself, it is difficult to predict all the alternatives that might be considered. We believe the approach developed in Section III of this report will prove fruitful. MARC is beginning to develop simulation capabilities which would allow more concrete assessment.

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