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ACCURACY STATEMENTS USED IN PHOTOGRAMMETRY

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INTRODUCTION

Mensuration from satellite photography plays an important role in the intelligence community. Analysts and imagery interpreters need mensuration in such varied tasks as calculating missile silo hardness, assessing aircraft capabilities, [redacted] and computing the velocities of ships. In order to use mensuration correctly, however, it is essential to understand the accuracy statements that accompany mensuration products. The purpose of this report is to explain why accuracy statements are needed, what they mean, how they are derived, and how they can be used. 25X1 25X1

WHY ACCURACY STATEMENTS ARE NEEDED

"A reported value whose accuracy is entirely unknown is worthless."

--Churchill Eisenhart[1]

Why do we need accuracy statements? In short, because mensuration results are not perfect. A photogrammetrist does not obtain the true size of an object by measuring it with a steel tape. Rather, he obtains an *estimate* of the true size, using the art and science of photogrammetry. An estimate, by definition, can differ from the true value. This difference, or error, arises from many sources.

The most important source of error in most measurements under 50 feet is the quality of the imagery. The image on the film may be degraded and distorted by spread functions, adjacency effects, halation, and other factors. These effects are particularly noticeable under the high magnification (60X to 200X) used for mensuration. Each photogrammetrist interprets and measures these blurred edges differently. Apart from interpretation of the edge, some error is inherent in each photogrammetrist's ability to position the measuring reticle accurately. This error source is usually negligible for monoscopic measurements but can be significant for stereoscopic mensuration. Other sources of error occur in the film processing, the measuring devices, the parameters which are input to the photogrammetric equations (math model) and, to a much lesser degree, the math model itself. All these factors can cause the photogrammetrist's estimate to be in error -- hence the importance of accuracy statements to indicate the extent of the possible error.

[1] Former Chief of the Statistical Engineering Laboratory at the National Bureau of Standards, Washington, D.C.

We also need accuracy statements to avoid "implied" accuracy statements. It is common practice in science and engineering to report values to the least significant digit. [redacted] 25X1

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DEFINITION OF CONFIDENCE INTERVAL

The most generally accepted type of statement of uncertainty or possible error is the confidence interval. Since 1968 NPIC has been using the confidence interval for the accuracy statements that accompany mensuration. An example of an accuracy statement follows:

> Dimensions are accurate to within [redacted] at a 95% confidence level. (The phrases "at a 95% confidence level" and "within a 95% confidence interval" are used interchangeably.) 25X1

A confidence interval is composed of two parts: (1) an interval and (2) a percentage which indicates a degree or level of confidence. The interval itself often consists of two parts as in the example above: a foot portion, referred to as pointing error, and a percentage portion, referred to as system error, which is dependent upon the size of the dimension. The two parts of the interval must be added together to obtain the total interval. For example, a [redacted] 25X1

The degree or level of confidence quoted in the above example is 95 percent. This means that there is a 95 percent chance that the interval [redacted] includes the true diameter of the missile. This does not mean that each value within the interval can be considered equally likely. The most likely dimension is the *one* value reported by the photogrammetrist, i.e. [redacted] The next most likely values are ones very close to the reported dimension. The values less likely to be correct are at the extremes of the interval. The 95 percent confidence level also means that 5 percent of the time, or one time in 20, the interval will fail to include the true object size. 25X1

If the interval seems large, it is because there is a high level of probability (95 percent) that it will include the true size. If the level of confidence were statistically reduced to 67 percent, the interval would be reduced to half its size. In the example the 67 percent confidence interval would be [redacted] However, throughout the years scientists and analysts have chosen 95 percent[1] as a reasonable degree of confidence to be required of an estimate. 25X1

DERIVATION OF STANDARD ACCURACY STATEMENTS

The Photogrammetry Division, NPIC, derives "standard" accuracy statements for each camera system, for each photographing mode (monoscopic and stereoscopic), and for each type of measurement. These statements are called "standard" because they quantify the measurement error for one coverage of a target measured by any photogrammetrist on any instrument. They serve as the basis for most of the accuracy statements reported by NPIC. Two techniques are used in deriving standard accuracy statements: empirical and theoretical.

Fundamental to the empirical approach is a good source of ground truth. [redacted] 25X1

[1]One exception occurs in cartography, where the national "map accuracy standard," which is the accuracy statement for geodetic positions on a map, is given at a 90 percent confidence level.

When satellite coverage of a ground truth area is obtained, photogrammetrists measure selected dimensions on that coverage under typical working conditions. The differences between the ground truth values and the values measured on the photography are tabulated.

After sufficient data is accumulated it is statistically reduced to give a standard deviation which is then used in the accuracy statement.

These statistical analyses have shown that mensuration error is approximately normally distributed about a mean error of [redacted] In addition, a system error not exceeding 1 percent of a measured dimension may occur. 25X1 25X1

The theoretical approach to deriving standard accuracy statements is the use of error propagation, which is a complex mathematical and statistical process. It requires knowledge of the magnitude, distribution, and interrelationships of the various errors that affect mensuration. Each of these individual errors is propagated through a math model to obtain a final accuracy statement.

The Photogrammetry Division relies primarily on the empirical approach for establishing accuracy statements. The theoretical approach is undertaken by the Applied Photo-Science Division, NPIC, to predict the accuracy that can be expected from a new or modified camera system. It also serves to indicate how data should be acquired in the empirical investigation. The accuracy statements generated by the two techniques have been in close agreement.

A new accuracy statement investigation is conducted whenever there is an *a priori* indication that the previously derived accuracy statements should be changed, for example when improvements are made to the camera, film, or mensuration procedure. There is also routine mensuration of ground truth on each new mission to insure that the mission meets current accuracy standards.

An assumption must be made when applying the results of these error investigations to measurements on foreign targets. It must be assumed that the errors observed [redacted] statistically from the same population as the errors which occur on foreign coverages. This assumption is valid to the extent that the variety of ground truth objects is representative of actual foreign targets so far as contrast, size, complexity, etc., are concerned. Also, the quality of the photography [redacted] and foreign targets, with regard to scale, graininess, resolution, etc., should be the same. The photogrammetrist will subjectively modify the foot portion of the standard accuracy statement when these conditions are not met. 25X1 25X1 25X1

SPECIALIZED ACCURACY STATEMENTS

The previous discussions of standard accuracy statements referred to accuracy statements which are used for most measurements made at NPIC. These statements represent a randomization over different instruments, photogrammetrists, types of objects, and situations. However, such statements can be too general for certain critical measurements.

Specialized accuracy statements are often produced when multiple coverages are used or several photogrammetrists measure the same object. These accuracy statements are based on the fact that an average of several independent measurements is more precise than a single measurement.

A new technique called "max-min" has been developed to provide a special, hand-tailored accuracy statement. An experienced photogrammetrist can make a subjective measurement of the possible error in a given image. In effect he actually measures the bounds of the confidence interval. This technique has proven effective in assigning a suitable accuracy statement to mensuration from imagery which is either considerably better or worse than the imagery from which accuracy statements are normally derived.

The current effort in specialized accuracy statements involves locating and quantifying the individual sources of error. It is known that there are different variances among instruments, photogrammetrists, target types, image sizes, and contrast. By quantifying these separate sources of error it will be possible to obtain not only better accuracy statements but also more accurate measurements.

HOW TO USE ACCURACY STATEMENTS

An accuracy statement dictates how a measured value should and should not be used. For example if the geodetic coordinates of an airfield are reported as accurate to within ±10,000 feet at a 90% confidence level, the coordinates may be used to locate the airfield on a map but should probably not be used for [redacted] If a missile length [redacted] 25X1 25X1

The accuracy statement can be used to compare and contrast items. If two tanks have been measured and their lengths are different but the confidence intervals overlap, a statistical test can be performed by the Photogrammetry Division to ascertain, at a given level of confidence, whether the two might actually be the same size.

Many times dimensional information is used in conjunction with information from other sources to perform analysis. Most of these other inputs have accuracy statements associated with them. A standard statistical procedure referred to as error propagation can be performed by the Photogrammetry Division to produce an accuracy statement for the final result.

SUMMARY

The accuracy statement is a statement of chance or probability. It tells how confident one is that the true value is within a certain interval. There is not an equal likelihood that any value in the interval is the correct dimension. *The best estimate of the true value is the one value given by the photogrammetrist.*

Since accuracy statements for linear dimensions are always given at a 95 percent confidence level, the size of the interval serves as a measure of the reliability of the measurement. The size of the interval also suggests what decisions should be made based on the mensuration.

Accuracy statements can also be used in a more rigorous statistical way to compare or contrast items or to calculate an overall error through error propagation.

The methods of producing accuracy statements are in a continuing state of improvement. NPIC is striving to improve not only the accuracy and precision of its mensuration but the reliability and usefulness of its accuracy statements as well.

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Comments and queries regarding this report are welcome. They may be directed to [redacted] 25X1
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