A Training Program for Men Measuring Tree Heights with Parallax Instruments

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ABSTRACT: *A program for the training of men in the use of parallax instruments for tree height measurement is described. This program is controlled by constant testing to establish when an operator has reached his natural level of competence, i.e. he is no longer able to systematically reduce his errors. The utility of several common statistical measures for control of such a program is examined. The measures showing the greatest promise are: the mean of the absolute errors, the mean of the algebraic errors, and the standard deviation of the algebraic errors. The latter two are particularly valuable since they provide data for the evaluation of subsequent work. The mean algebraic error provides a measure of operator bias which can be used as a correction factor. The standard deviation of the algebraic errors provides a measure of the residual random error which cannot be compensated without repeated measurements.*

INTRODUCTION

THE ability to control a training program is essential whenever a manual skill is involved. In the organized building trades this is accomplished by making each budding carpenter, plumber, or electrician undergo a relatively lengthy apprenticeship during which he learns procedures and gains skill by constant practice under close supervision. In the case of individuals with great inherent ability this period of apprenticeship is excessively long, but, since no absolute standards have been established in these fields, it is necessary to make all candidates complete the full period of training in order to protect the reputation of the trade. This is uneconomic use of manpower. It would be more desirable to set up standards and to promote the men as soon as they are capable of meeting or exceeding these standards.

The problem of training in a specific skill was encountered in the course of a research project initiated in the Department of Forestry, Agricultural Experiment Station of the Alabama Polytechnic Institute. The project involved the measurement of tree heights on vertical aerial photographs using parallax methods. Since skilled photo-interpreters were not available, it was necessary to train student volunteers to carry out the work.

In the initial planning phases of this project, it was felt that supervised practice for a specified number of hours would produce operators with the required degree of skill. This idea corresponds with the apprenticeship plan used in the building trades. Subsequently, however, it became evident that the main project would consume a very considerable amount of time and, if the team was not to be broken up by graduation before the project was completed, the training program would have to be as short as possible. As a result, a testing program was developed that provided a running check on the operators' progress, making it possible to move the men to the main study as soon as they gained a satisfactory level of proficiency. This program is described in the remainder of this paper.

REVIEW OF LITERATURE

A thorough search of the literature failed to yield much information that would help in setting up a training program. Sharp (4), in his discussion of education and training in photogrammetry, indicated that training in the use of instruments is usually received on the job or through short courses; he did not discuss such training programs in detail. Custer and Mayer (1) stated that military photo-interpretation courses provide 12 to 52 hours of training in photometrics, but he did not specify how this time is allocated or give any details on the training.

Getchell and Young (2) have reported on an experiment designed to determine the length of time needed to reach a satisfactory level of proficiency with a parallax bar instrument and with the parallax wedge. This report provides some useful information. Apparently only one operator was used so that it is impossible to draw general conclusions safely from this experience. The training program used in this experiment consisted of a short familiarization period with one of the instruments, and then 10 cycles of measurements on 20 trees of known height on a set of vertical aerial photographs at a scale of 1:15,840. These 10 cycles required approximately 18 hours to complete. At the end of this period, the operator was considered to be reasonably proficient in the use of the instrument. He was then given a short familiarization period on the second instrument and the 10 cycles were repeated. The second 10 cycles required only 12 hours to complete. The operator's proficiency at the end of the training program was tested by the measurement of 21 new trees. In their report Getchell and Young did not analyze these measurements statistically. The following statistics can, however, be computed from the published data:

1) the mean error for the parallax bar instrument was −0.8 feet, while that for the parallax wedge was −0.7 feet;

2) the standard deviation of the errors with the parallax bar instrument was ±2.72 feet, and that with the parallax wedge was ±3.78 feet.

Getchell and Young were probably correct in their assumption that the operator was sufficiently trained for most tree height measuring operations. In personal correspondence with Getchell and Young, the evidence resulting from this experiment was confirmed from past experience by Dr. R. N. Colwell, of the School of Forestry of the University of California and formerly with the U. S. Navy Photo Interpretation Center, and by K. E. Moessner of the nation-wide Forest Survey conducted by the U. S. Forest Service.

An unreported training program has been used by Professor John C. Sammi, of the College of Forestry, State University of New York, while teaching a course concerned with the application of photogrammetry to forest mensuration (3). The author knows of this program from personal experience. In this course a portion of the laboratory work consists of making a timber inventory using Spurr's (5) "plot approach." In order to obtain reasonably satisfactory results with this procedure, the photo-interpreter must be skilled in tree height measurement. To gain a modicum of this skill Professor Sammi instructed his students to measure the heights of six to eight objects, located on the Syracuse University campus, for which height data were available. These measurements were repeated five or more times within a given "set." The standard deviation of the height measurements on each object was then computed. Standard deviations for the several objects were then averaged to obtain the mean standard deviation for the set. These mean standard deviations were plotted over the number of the cycle. Theoretically a trend should have developed that flattened out as the program developed, and finally showed a more or less constant value, indicating that the operator had reached his natural level of proficiency. In practice several drawbacks to this plan developed. The most critical of these was that too few objects were measured in a single cycle within a set. Several cycles could be completed in a single laboratory period, and consequently memory bias became a very significant item. However, this general method, if properly administered, has the great advantage that development of operator skill is under constant surveillance; and, when the operator reaches a natural level of competence, he can be graduated to more serious work.

Procedure

Because it provided a guide to the development of operator skill, Professor Sammi's basic idea was used as the foundation of the training program. It was modified in some respects in an attempt to make it somewhat more effective. In addition, it was expanded in order to provide information concerning the relative merit of several common statistical measures as guides to operator competence.

A group of six students began the program. These men met as a class at the beginning of the indoctrination phase. Instruction in properly setting up a stereoscopic pair of photographs and in operating the instruments was provided. The instruments used were U. S. Forest Service parallax wedges, printed in red on a flexible film base, and an Abrams Contour Finder. Every technique known to the author concerning use of these instruments for tree height measurement was demonstrated and explained. The operators were urged to try these techniques and to use those that seemed most effective. This familiarization period required approximately 3 hours and the time seemed to be well-spent.

Three sets of vertical aerial photographs were provided for the experience-gaining phase of the program. These were standard U. S. Department of Agriculture photographs taken in late winter of Lee and Macon Counties, Alabama. The sets covered areas near Auburn, Opelika, and Tuskegee. Ten trees, whose heights had been measured with an Abney level, were marked on each set. An attempt was made to secure a wide range of species and heights. True average photographic scales were determined from measured distances or from computed distances between bench marks. From these data the true differential parallax for each tree was computed. These true differential parallaxes provided the standard for subsequent testing of the operators.

Instructions to the operators stated that the three sets of 10 trees each were to be measured one after the other in a strict sequence. A group of 10 tree height measurements made with one instrument from a single set of photographs was called a "trial" and the statistics for such trials

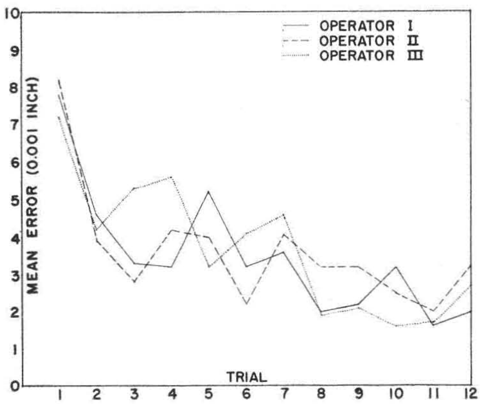

FIG. 1. Learning curves. Mean absolute errors for the parallax wedge.

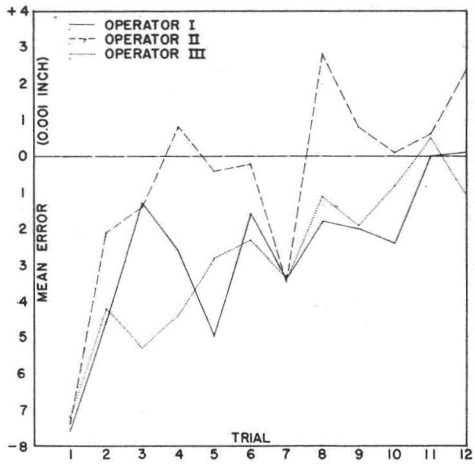

FIG. 2. Learning curves. Mean algebraic errors for the parallax wedge.

were used as a guide to the operator's development (see Figures 1 through 6). These trials were repeated, with at least one day between successive trials, using the same instrument, until the operator was judged to be ready for serious work. The strict sequence and the required time lapse between successive trials with the same instruments were specified in the program design in order to reduce, as much as possible, the effect of memory bias.

In order to keep the development of skill with one instrument approximately parallel with the second, a trial was first made with the parallax wedge on a given set of 10 trees, and then this was followed by a trial with the Contour Finder. Then both instruments were moved to a new set of trees. This, of course, meant that the same trees would be measured twice in close succession, but, since the instruments were so different in design and operation

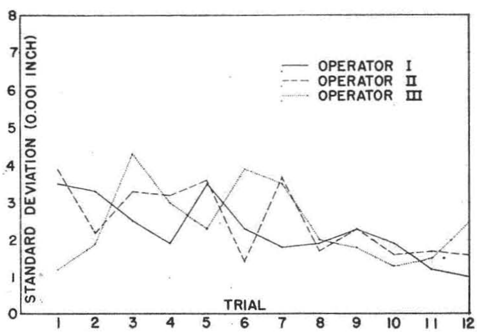

FIG. 3. Learning curves. Standard deviations of the absolute errors for the parallax wedge.

and since they were graduated in different units, it was felt that memory bias would have little effect on the readings.

In an attempt to further reduce the effect of memory bias, the operators were instructed to record the instrument readings at the top and bottom of each tree, but not to do any computation. The computation operations were all carried out by the author. The measured differential parallaxes were compared with the computed values. If suggestions for improvement of technique could be made, they were passed on to the operators. In no case, however, did the operators see their actual results until after the testing program was complete. In this way development of tree height measurement ability could be studied with relatively few photographs.

The first computational step was to determine differences between the computed and measured differential parallaxes. Then the mean absolute difference, or error, for each set of 10 trees, was computed and plotted over the number of the trial (see Figure 1). As the operators became more experienced their mean absolute errors tended to become smaller until they stabilized at relatively constant values. When this occurred it was felt that the operators had probably reached their natural levels of competence and were considered "experienced."

The algebraic errors were then examined. First the negative error values were eliminated by the addition of a constant (coding). The mean algebraic error for a given trial was then obtained by subtracting this constant from the mean coded error for the trial. The mean algebraic error was then plotted over the number of the trial, as was done in the case of the

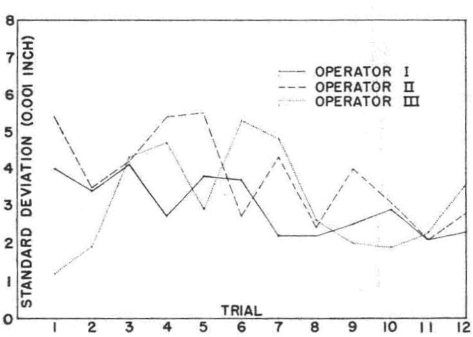

FIG. 4. Learning curves. Standard deviations of the algebraic errors for the parallax wedge.

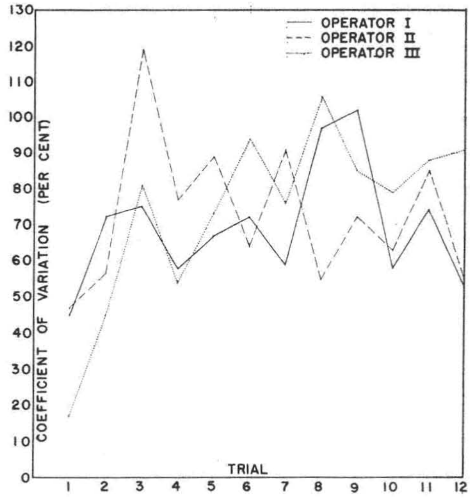

FIG. 5. Learning curves. Coefficients of variation of the absolute errors for the parallax wedge.

mean absolute errors. As can be seen in Figure 2, trends for the individual operators became evident as the program progressed. Theoretically, as the operators gain experience, these trend lines should approach, then flatten out, and finally parallel, the line of zero error. The mean differences between the trend lines and the zero error line are measures of the operators' biases in making differential parallax measurements. If these differences are subtracted algebraically from measurements made by the respective operators under similar conditions, the effect of the biases can be greatly reduced or possibly eliminated. The residual errors would then be non-correctable variables best measured by the standard deviation.

In the same manner as with the mean errors, the standard deviations of the absolute and coded errors were computed and plotted over the number of the trial (see Figures 3 and 4). Theoretically, the resulting curves should have trended downward and then leveled off indicating that as the operators became more experienced they became less erratic. In general, the actual curves agree with this theory. They show the downward trend but relatively little evidence of leveling off. A larger number of trials undoubtedly would have provided a better example of this phenomenon. After an operator attains stability and his curve of the standard deviation of coded (algebraic) errors remains relatively flat, the mean difference between his trend line and

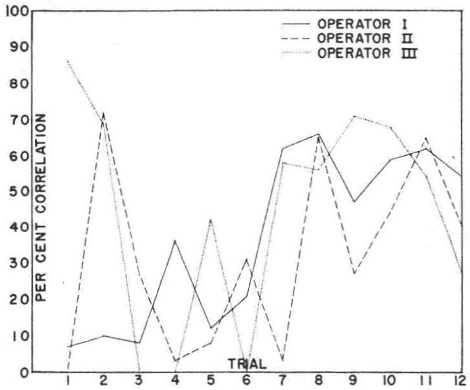

FIG. 6. Learning curves. Per cent correlation ($100r^2$) between computed and measured differential parallaxes.

the zero error line would provide a measure of the random variability in measurements to be expected from that operator, under the specific conditions existing when the data were obtained.

In most cases, when the coefficients of variation of the absolute errors were plotted over the trial numbers (see Figure 5), the scatter of points was so great as to prevent detection of any but the crudest of trends. Most such trends appeared to be essentially horizontal indicating that, as experience grew, the reduction in scatter of errors tended to keep in step with the mean error. There were, of course, exceptions to this rule. For example, see Operator III on Figure 5. This man reduced his mean absolute error quite rapidly compared to the rate of reduction of his variability. This resulted in an upward trend of the coefficient of variation. Actually this statistic is of minor importance when compared with the mean error and the standard deviation of the errors, for purpose of evaluating operator competence. It is unnecessarily sensitive to minor changes and does not reveal much information not already available. For these reasons it was not used as a judging tool.

The last statistic considered as a possible gauge of operator competence was the correlation between the computed and measured differential parallaxes. This was expressed as the correlation coefficient. Theoretically, when the correlation coefficients are plotted over the numbers of the corresponding trials, there should be an upward trend and then a levelling off as the operator becomes more experienced. This pattern is revealed in Figure 6. It is interesting to note that the levelling off portion of the curves for all the operators completing the program lay between 60 and 70 per cent. The correlation coefficient, while interesting, is, like the coefficient of variation, quite sensitive to minor changes in the error pattern and shows considerable instability. As a result it was not used in the evaluation of operator competence.

DISCUSSION

The controlled program of training as developed for this project contained faults and weaknesses, but it is believed that these were not due to the fundamental design of the program. Instead, they were due to the rather peculiar circumstances under which the program was carried out. The operators were senior students in the Department of Forestry of the Alabama Polytechnic Institute. These men had heavy academic loads and had to fit the photogrammetry training into their schedules where it would disrupt their normal school activities as little as possible. This caused the training to be more erratic than should have been the case. This also made it necessary to terminate the training before the leveling out of the training curves was clearly defined, in order to provide sufficient time for the operators to finish the main study before they graduated.

A time record was kept for wage purposes. This record substantiated Getchell and Young's (2) statement that it takes from 12 to 18 hours to become reasonably proficient in the use of a parallax measuring instrument. In this study, however, the operators trained on both instruments at the same time, rather than completing the training on one and then shifting to the other. The three men completing the training program required a total of 21 to 26 hours to attain reasonable proficiency with both instruments.

In summary, it is evident that a training program such as this would be very valuable to any organization utilizing parallax instruments for measuring object heights. With it a constant check is available on the operator's development, and his ultimate ability can be assessed. If he operates with a constant bias, it is revealed, and compensating factors can be applied. If a man requires an unusually long period of training to become proficient, or if a man shows no talent for the job, it becomes evident as the program develops. Indeed, it appears to be a very useful tool for the training of personnel engaged in the application of photogrammetry to forestry.

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