FLORIDA DEPARTMENT OF TRANSPORTATION

SING SYSTEM HANDBOOK

A Complete Technical Reference For Use
With The Electronic Field Book
Data Processing System

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Chapter One - Introduction

The Electronic Field Book Processor (EFBP) uses a wide variety of mathematical techniques derived from surveying and statistics textbooks. Every user does not need to fully understand the theoretical basis for these techniques. Understanding what the report files indicate are more important. Most users can simply refer to the EFBP user's guide for most questions that deal with production issues. A user unfamiliar with EFBP would need to read the EFBP user's guide before taking advantage of the information in this document.

There are times when a user wants to look at some broader background descriptive information regarding certain algorithms in EFBP. This document serves that purpose, and points the to more source documents of information as this is not intended to eliminate those references. In addition, many users are asked technical questions by others go beyond their knowledge base. Those questions can now be forwarded to this document.

This document should be used in conjunction with the Electronic Field Book Processing Handbook and any currently available Electronic Field Book (EFB) documentation. A user not familiar with EFBP would need to refer to the EFBP user's guide before utilizing information in this document. The Electronic Field Book was developed for field survey collection by the Florida Department of Transportation, and the subsequent processing of it by EFBP. While EFB relies exclusively on EFBP for coordinate production, EFBP accepts other field system's survey measurements if the data is translated to the ASCII raw data file format (.OBS) which is read by EFBP. The .OBS file and its format must be understood (see EFBP user's guide) before understanding this documentation as many references are made to its contents.

Discussion Of Components Of The Documentation

The following topics are covered in this handbook :

- ***Chapter Two*** of this handbook deals with the correction of systematic errors in surveying measurements.

- ***Chapter Three*** discusses analysis of repetitive survey measurements.
- ***Chapter Four*** discusses how a weighted average can be used to derive a realistic "average" from repeated observations which have different error estimates.
- ***Chapter Five*** discusses correction of systematic errors due to earth curvature and atmospheric refraction.
- ***Chapters Six*** discuss horizontal datums.
- ***Chapters Seven*** discuss vertical datums.
- ***Chapter Eight*** highlights state plane coordinate computations as they relate to EFBP and the use of its generated coordinates in other software systems.
- ***Chapter Nine*** discusses the automatic sideshot identification algorithms in EFBP.
- ***Chapter Ten*** discusses the importance of error estimation in least squares analysis as it relates to EFBP. Reasonable strategies which enable integration of various measurement types are presented.
- ***Chapter Eleven*** discusses how one validates the quality of survey measurements based on the least squares analysis output.
- ***Chapter Twelve*** discusses the interpretation of least squares post-adjustment error estimates of final coordinates.
- ***Chapter Thirteen*** presents the basic theory of least squares analysis, its application to nonlinear equations (most survey measurements are of this form), efficient strategies for solution, and generation of post-adjustment coordinate error estimates.

Conventions Used in this Handbook

The following conventions are used within this manual:

italics	words which appear in italics emphasize important details
[ENTER]	words enclosed in square brackets represent keyboard key strokes
concept	important concepts will be highlighted for easy recognition

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Chapter Two - Instrument Calibration

All survey field instruments can contain systematic errors due to the nature of the mechanical components in them. Personal and environmental systematic errors can also exist. These errors can be minimized through proper field techniques and office processing mechanisms. Instrumental systematic errors can be minimized if a calibration process is performed, and mechanical or mathematical means are used to correct any systematic error that is detected. EFBP uses mathematical means to correct systematic error in ways that are now discussed.

Systematic vs. Random Error

Error can be systematic or random. Systematic error follows some mathematical rules which can be modeled and corrected by proper techniques or survey data processing. Random error follows the laws of probability which are evaluated using statistical processes such as least squares analysis. Sources of error in surveying are instrumental, personal, or environmental. Instrumental systematic errors in surveying can include total station/theodolite horizontal and vertical collimation errors, electronic distance/prism combined offset and scale errors, a differential level's line of sight not being horizontal, and a tape containing offset (short or long) or scale errors. Instrumental random errors are due to the mechanical nature of survey instruments being limited in absolute measuring ability.

An example of a personal systematic errors is not applying the correct pull to a tape. A good example of random personal error is our inability to point perfectly with a total station or theodolite. Environmental systematic errors include earth curvature and atmospheric refraction. Heat waves, making pointing difficult, are an example of an environmental random error.

The distinction between systematic error and random error can become difficult in some cases. An electronic distance measuring (EDM) device is affected by temperature and pressure. At an instance of time there is a temperature and pressure that can be used to model systematic error corrections. You obviously would not record temperature and pressure every time you make a measurement, so it is difficult to define the drift in temperature and pressure as totally systematic or random.

Total Station/Theodolite

If the vertical circle of a theodolite was in perfect adjustment, it would read zero degrees when pointed at the zenith. A horizontal circle would be in perfect adjustment (except for circle graduation errors in a theodolite) if the direct and reverse circle readings when pointing (with no personal error) to the same object would differ by exactly 180 degrees. Both of these errors are minimized by measuring equal number of times in direct and reverse position and averaging.

Many situations, such as topographic data collection, do not justify repeated measurements in direct and reverse. It is still highly desirable to eliminate instrument systematic error in all measurements. This is why EFBP is able to process what are called numerical calibration records.

A theodolite/total station calibration is an equal number of direct and reverse readings to the same object. Obviously the object should be very well defined so precise pointings can be made. While one (1) direct and one (1) reverse reading will suffice, multiple pointings are recommended so the surveyor can ensure no blunders exist, obtain a more reliable measurement through averaging, and obtain an estimate of the operator's pointing error. EFBP averages the direct readings and computes standard deviations in a single observation for horizontal and vertical pointings. The same is performed in the reverse position. The standard deviations indicate if a blunder exists, and in absence of a blunder indicate pointing ability.

If the instrument was in perfect vertical adjustment, the sum of the average direct and reverse vertical circles would be 360 degrees. The difference from 360 degrees represents twice the error. As an example, assume the average direct and reverse vertical pointings were 90° 00’ 30” and 270° 00’ 20”. The sum is 360° 00’ 50” and indicates every zenith circle reading should have 25 seconds subtracted from it. A sum less than 360 degrees would require an addition of the error value to all zenith circle readings.

The amount that the average direct and reverse horizontal circles are from being 180 degrees different again is twice the error. In this case the sign of the correction will be opposite as applied to horizontal angles measured in the direct and reverse positions. As an example, consider the average direct and reverse horizontal circle pointings in a calibration to be 190° 00’ 10” and 10° 00’ 30” respectively. Horizontal angles measured in direct would have +10 seconds added to them, while the correction added to reverse horizontal angles would be -10 seconds. Calibration values are applied to all measurements collected after it until another calibration that contains numerical data is reached (a user can store a calibration without circle readings using EFB as it contains other pertinent information). If no calibration exists at the beginning of an .OBS file the calibration corrections are zero until a calibration with numerical data is reached. If two or more distinct calibrations are in consecutive order in an .OBS file, the last is always used.

Due to the calibration process, EFBP treats direct and reverse readings as unique measurements because they can be corrected for the systematic errors which were the major reason for measuring in direct and reverse. Thus four direct and four reverse measurements are corrected for systematic calibration errors, summed, and divided by eight to obtain an average. Many methods used by surveyors recommend averaging direct and reverse measurements in obtaining four (4) values which are then averaged. This is no longer necessary due to the calibration record.

Differential Level

A differential level is usually calibrated for line of sight not being horizontal by a peg test. This test is described in all basic surveying texts, and usually involves one backsight/foresight combination at midpoint (this corrects systematic error) to a backsight/foresight combination where the sight distances are not equal.

EFBP performs no systematic correction based on a peg test calibration in an .OBS file as it is assumed the surveyor adjusted the cross hairs as a result of the test to create the horizontal line of sight.

Electronic Distance Measurement (FIXIT)

An EDM/prism combination can contain offset (constant) and scale (parts per million - ppm) systematic errors. The offset error remains constant for any measured length of line. The scale error grows (or shrinks) as a linear function of the length of the line.

An EDM/prism combination can be tested for correct distance measurement by one of three methods:

(1) Lay out a precisely measured distance with a steel tape and compare that value to what you measure with the EDM. This will not resolve scale error as a precisely taped distance will be too short in length to derive it.

(2) Set two collinear points A, B, and C. Measured distances AB plus BC should equal measured distance AC. The difference is the error in the EDM and prism combination. Since this test usually uses short lines the scale error is usually not measurable.

(3) An EDM calibration range (a base line) is utilized which has a series of known distances which vary in length. The shortest distance determines the offset error, and the scale error is modeled by how the difference between the known and measured distance values vary for different lengths of lines. Public domain programs are available for computation of systematic error corrections from base line measurements.

Some total stations or EDM's allow a user to dial in corrections for offset and scale error so that the distances in a data file (.OBS file) will be already corrected for any systematic error influence. If this is not performed, an auxiliary program to EFBP called FIXIT allows you to apply offset and scale corrections to measured EDM distances before you actually process your data with EFBP. FIXIT allows an accidental prism offset or incorrect temperature/pressure problem to be efficiently corrected.

Tape (FIXIT)

A tape is like an EDM and is suspect to offset and scale errors. A tape is usually laid out on a known baseline to obtain this information. Taping is usually a small part of an .OBS file. With a text editor one should separate total station and taping measurements before performing FIXIT type corrections. The text editor can then be used to again merge the total station and taping measurements into one .OBS file again.

Chapter Three - Repetitions and Comparisons

Repeated measurements provide the surveyor with checks for blunders and a way of estimating the quality of one's measurements. Certain types of repeated measurements are more generic in testing for blunders. As an example, repeated measurements from the same instrument setup does not check if a user set up the total station or prisms over the station(s) properly. Another setup at that station, or a setup which measures a common line but in the opposite direction, is a better check as the quality of the instrument setups can be made.

Averaging and Standard Errors

These values can be derived from repeated measurements at the same instrument setup. Note, standard error and standard deviation are used interchangeably in this discussion. Slope distances, zenith angles, height of instruments, and height of targets are converted to horizontal distance and mark-to-mark elevation change before any averaging or standard error computation begins. This is especially required for elevation differences in case a change in height of target occurred during the repetition process.

Horizontal circle readings are converted to horizontal angles based on a unique backsight station before averaging and standard error computations begin. This allows any movement in the horizontal circle plate to be accounted for between repetitions. This is analogous to the process of "moving" an initial horizontal circle reading when turning a series of repetitions. The difference between horizontal circle readings (horizontal angle) provides a more generic comparison mechanism.

The backsight station for a particular setup is the station which was sighted the most times. If a given number of stations were sighted the same number of times, the first station of that group after the setup record is selected as the backsight. The .OBS file is usually time sequenced, and thus the backsight is commonly measured to first at a setup.

The EFBP users guide has a series of examples of averaging and standard error computations, and thus one can refer to these examples if one needs to look at numerical examples.

Simple Averaging

A simple average is performed for any repeated measurements at a setup. A simple average is the sum of the individual measurements divided by the number of repetitions. It does not take into account that the individual measurements could vary in quality. A weighted average, which is used by EFBP in some other situations and is discussed later, can take into account measurements of varying quality.

One point to make is that the .OBS file allows for multiple pointings to exist on the same position number and in the same (direct/reverse) face. This is common when one has performed a large number of topographic measurements, and one wishes to "check in" on the backsight at the end of the setup. Some surveyors like to routinely check in on the backsight in some pre-defined chronological fashion. Slope distances/zenith angles of this fashion are treated as separate measurements. Thus one (1) measurement in position one (1) direct, one (1) measurement in position one (1) reverse, three (3) measurements in position two (2) direct, and one (1) measurement in position two (2) reverse of slope distance/zenith angle will be treated as six (6) measurements.

The same is not true for horizontal circle readings as the three (3) measurements in position two (2) direct will be averaged. At this point, a unique horizontal circle reading exists in position one (1) direct, position one (1) reverse, position two (2) direct, and position two (2) reverse. These four (4) values are used in computing horizontal angles from horizontal circles, and the horizontal angles are then averaged. Thus, one (1) unique horizontal circle reading exists for each position number and face (direct/reverse) prior to the horizontal angle computation/averaging process. This eliminates the problem of how many horizontal angles exist from station A1 to A2 in position one (1) reverse if station A1 was measured to four (4) times and A2 once. By EFBP's algorithm, the four (4) circle readings to A1 are averaged and one (1) angle for that position number and face is computed.

The averaging of horizontal circle readings on the same position/face setting produces the multiple pointing error values which are displayed in the abstracting report (the .GEN file).

Reiterating, slope distances and zenith angles are not averaged, instead their reduced horizontal distances and elevation differences are averaged. It is possible to average a horizontal distance(s) in an .OBS file with those in an .OBS file that are derived from slope distance/zenith angles. Horizontal circle readings on the same position and face are averaged before horizontal angle computation occurs. Each position/face produces a horizontal angle which is subjected to the averaging process.

The simple averaging process is thus a fairly simple computation which is well documented in statistics texts and surveying textbook sections on statistics as it applies to surveying.

Standard Error In A Single Observation

The standard error is the square root of the variance. To compute a standard error one must first compute the difference between each individual observation and the average. These are residuals in a averaging process. The residuals are squared and then summed. That sum is divided by the number of observations minus one to obtain the variance. The square root of this variance is the standard error in a single observation.

Residuals are squared because they will be both positive and negative in sign - a simple sum of residuals from a simple average yields zero. The division by the number of observations minus one is similar to dividing by the number of observations in simple averaging. The "minus one" is with reference to the number of observations beyond what you minimally need (one observation does indeed determine a value for that measurement). This could also be referred to as the number of checks or number of degrees of freedom. There is no standard error unless you make at least two measurements.

The physical meaning of the standard error in a single observation is if you made one more observation under the same conditions with the same equipment you would be approximately 67% (one sigma) confident that you would fall within the range defined between the average minus the standard error to the average plus the standard error (average plus or minus the standard error).

If your worst residual (maximum spread in the .GEN file report) is more than the standard error that is not cause to be alarmed. Approximately 33% of your data will fall outside, so obviously we cannot