High Precision Positioning Unit 1: Accuracy, Precision, and Error Student Exercise

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This assignment follows the Unit 1 introductory presentation and lecture. It introduces the concepts of accuracy, precision, and error, which will be fundamental to understanding the results of precision positioning through GNSS surveys.

Introduction

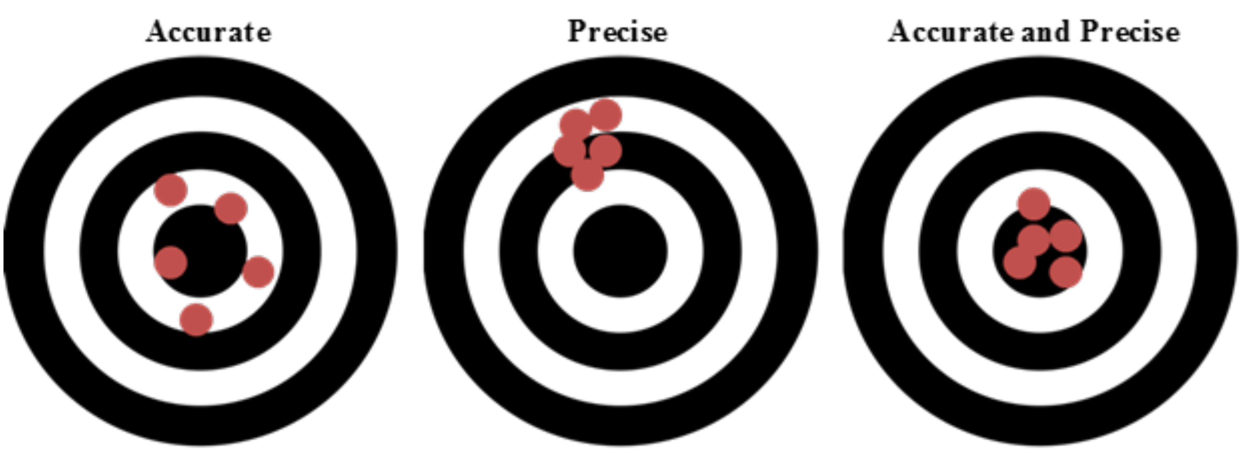
Accuracy, precision, and error are the metrics by which we analyze the quality of measurements. They are each fundamental qualities of every measurement, which assist in understanding and interpreting the results of our measurements and can often lead to insight into the measurement process itself.

The goal of GNSS systems is to provide accurate and precise positional measurements with as little error as possible. However, this is not an integral feature of the system. GNSS surveys require proper preparation, good survey design, and careful execution to produce the quality of results that the equipment is capable of.

Accuracy and Precision

Accuracy is how close a measurement replicates the true or actual value. You can view this as hitting near the center of a target. With replication or continued measurements, you would expect to continue to produce values that average to be near the true value, even though the individual values may appear to be scattered around the true value. This amount of scatter is known as precision.

Precision is how close individual measurements are to each other. They may not necessarily be accurate to the true value but are easily replicable. Precision of measurement often indicates that consistent measurement techniques were used but that some discrepancy or calibration error may be offsetting the measurement from the true value. GPS devices often report positions with high precision (sub-meter coordinates), though those coordinates are not the true value. Be cautious of instruments reporting your position with high precision but low accuracy.



Error

Error can result from many sources. It is often split into two categories, systematic and random. Systematic error is the simplest to detect and correct. Systematic error is prevalent equally across all measurements and is usually the result of a flaw in equipment, calibration, experimental design, or incorrect execution of a survey. These are easy to correct because their distribution across all measurements allows us to easily subtract them once identified. We may realize systematic error exists if the data is of high precision but low accuracy. For example, you may notice that the elevation of a point taken at a benchmark is consistently 10 cm too high. If it is unlikely the benchmark moved, a check of the equipment and field notes may indicate an inconsistency, such as the length of the measuring rod changed by 10 cm between surveys. If you completed an entire survey with this equipment, this offset would have occurred across all your points. You can correct it by simply subtracting the offset from all the positions.

Random error is more complex to identify and fix because it often varies in space and time. For example, as you measure points across a landscape, the tip of your measuring pole may sink into the ground on the soft soil but not the hard surfaces, or the wind may prevent you from holding the rod vertically. These random offsets to the positions will decrease accuracy and precision. Random error caused by human influences is difficult to correct after the fact, so it is important to be careful and precise in your technique.

Similarly, variations in the atmosphere, troposphere, and geometry of the satellite constellation will introduce both systematic and random error to individual measurement. This results in small but significant reductions in the accuracy of a position. However, GNSS systems have robust methods to identify and correct these errors through multiple methods including double differencing and differential correction.

There are many other sources of error in GNSS systems that are accounted for through a diverse set of methods including signal corrections, survey design, and post-processing and de-trending. Many of these require significant knowledge of earth models and how they apply to the types of measurements and the signals you are trying to measure. This is especially prevalent in processing mm precision points, such as addressed in Unit 3: Static GPS/GNSS Methods.

Consumer versus Mapping Grade or Precision GNSS Signals

Consumer devices (such as cell phones or handheld GPS units) generally only use the L1 GPS signal, whereas mapping and higher-grade devices (such as a survey instrument) can receive increasing types of signal including L1, L2, and C/P. This allows them to have more precise positions from the signal alone, along with taking advantage of error mitigating strategies such as differencing methods mentioned previously.

Exercise

This activity illustrates the concepts of accuracy, precision, and error through a comparison of positions measured with multiple types of GNSS receivers. The primary difference in the varying grades of GNSS equipment is their ability to produce accurate positions, with increasingly complex strategies to reduce error. Start the exercise by preparing several different grades of GNSS devices including smart phones, tablets, a consumer grade GNSS device, a mapping grade GNSS device, and a survey grade GNSS device. As a class, agree on one projection and/or datum that all devices will use before beginning. WGS84 (in decimal degrees) is common on most devices. If you can collect all data in UTM (in meters), this simplifies the process.

Instructions

Before beginning, consider what coordinate system your devices and software use. If you collected in WGS84, it is recommended to convert coordinates into UTM, which is measured in meters. This can be done with the VDATUM tool available from https://vdatum.noaa.gov/. You only need worry about horizontal (North and East) positions for this assignment.

1. Identify one point that can be measured in the field that has sufficient sky and lack of other obstacles or access issues. It is best is the point is monumented with a predetermined coordinate from a long-occupation, survey grade, static position. If there is no accessible, quality benchmark, it is best to create one and determine its position ahead of the activity using a survey-grade GNSS instrument.
2. Use at least two consumer or mapping grade (if you know how) devices to collect positions over the known point or monument. Collect a time series of points with a fixed interval and location, such that you have many position recordings of the same location. Take care to be as precise as possible in your execution. This could be as simple as placing them on the same spot on a picnic table.
3. Once finished, take down all equipment and return to the classroom.
4. If available, use a shared spreadsheet for the whole class to combine and share all positions into a single dataset. The survey or geodetic grade (highest accuracy) position will be provided by the instructor at the top of the sheet and will be considered the "true" location ± uncertainty. Use the following columns:
    a. date, time, device, user, latitude or *x* position, longitude or *y* position.
5. Compare horizontal positioning in latitude and longitude by graphing them as *x* and *y* values on a two-dimensional plot (or map) with a new series for each device. It may be useful to subtract the base station's location from your other points. This yields local position coordinates that are relative to the known base station position:
    a. The highest accuracy (geodetic or survey grade) position should be the center of your axes or map. The symbol should be a plus (+).
    b. Plot the different grades of GNSS receivers with different symbols on the same plot. The scale should match the largest extent needed to see all points.
    c. Individually plot each grade of GNSS receiver on its own plot. Adjust and note the difference in scale needed to plot each different grade of receiver.

6. Calculate a metric of precision; in this case we will use CEP. Calculate the circular error probable (CEP), the radius of a circle that contains 50% of all of your values. This is just one potential metric of precision, many others exist and are used in the literature.
   a. CEP = 0.59(STDEV(X) + STDEV(Y))
   b. Plot the CEP circle on your individual receiver grade plots (Step 5c above).

Note: If extreme outliers appear, verify that you were mapping and analyzing data in the same coordinate system. The VDATUM tool from NOAA/NGS is available at https://vdatum.noaa.gov/

Interpretation

Write a summary of your findings addressing the questions below.

1. Assume that the geodetic or survey position is the highest accuracy point (true position).
   a. What was the average error of the consumer grade positions? Are they systematic in one direction or well distributed around the known point? Separately describe the precision and accuracy for each type.
   b. What was the average error of the mapping grade positions? Are they systematic in one direction or well distributed around the known point? Separately describe the precision and accuracy of the various receivers.
   c. What was the error of the known position? You should know the accuracy of the device that measured this position.
2. Do the different grades of receivers produce significantly different positions? What creates these varying results?
3. After stating the accuracy and precision possible with each grade of device, explain which types of surveys or research applications are appropriate for each? What would happen if you tried to measure changes that are smaller than the device's error? Name at least two applications for each: consumer, mapping, and survey/geodetic.
4. Why is it important to report uncertainty or error with each measurement? How could measurements without a reported uncertainty confuse the public regarding a natural hazard?

Component	Exemplary	Basic	Nonperformance
General	Exemplary work will not just answer all components of the given question but also answer correctly, completely, and thoughtfully. Attention to detail—as well as answers that are logical and make sense—is an important piece of this.	Basic work may answer all components of the given question, but some answers are incorrect, ill-considered, or difficult to interpret given the context of the question. Basic work may also be missing components of a given question.	Nonperformance occurs when students are missing large portions of the assignment, or when the answers simply do not make sense and are incorrect.
5 pts **Plot of Positions**	4–5 Plot uses correct symbology for different positions. Axes are labeled with correct units. Title and legend. All required points are present and in the correct locations	2–3 Plot missing some components (title, legend, positions, etc.) or has switched axes.	0–1 Multiple missing components (title, legend, positions, etc.). Missing data.
5 pts **Question 1**	5 Answered all of sub-questions correctly. Reports the average error correctly with appropriate units. Correctly distinguishes between precision and accuracy and assigns an appropriate grade (high, medium, low).	3–4 Answered all questions, mostly correct Reports the average error correctly but missing appropriate units. Distinguishes between precision and accuracy and assigns an appropriate grade (high, medium, low) but description is incomplete.	0–2 Answered a few of the questions correctly Incorrect reporting of the error and/or missing/incorrect units. Confuses precision and accuracy and does not use the correct grade.
3 pts **Question 2**	3 Correctly describes and explains differences in accuracy and precision between measurements types. Recognizes coordinated time-dependent errors.	2 Describes differences in accuracy and precision between measurements types. Struggles to articulate why time dependent.	0–1 Struggles to describe differences in accuracy and precision between measurements types. Cannot explain coordinated time-dependent errors.

3 pts **Question 3**	3 points: For each grade of GNSS device, correctly gave the accuracy, precision, and two uses. Identified that change cannot be detected if the reported error or uncertainty is greater than the amount of change measured.	1–2 points: Answered the questions correctly but failed to either correctly attribute error to the correct source or didn't discuss the differences in consumer versus commercial grade equipment And/Or Failed to identify change couldn't be detected.	0–1 points: Failed to correctly attribute error to the correct source or didn't discuss the differences in consumer versus commercial grade equipment And Failed to identify change couldn't be detected.
5 pts **Question 4**	5 Correctly attributed each grade of GNSS equipment with the correct accuracy and precision. Identified that commercial grade receivers are capable of higher precision than consumer grade because of the ability to correct signal deviations Lists two uses for each grade of device	3–4 Answered the questions correctly but failed to either correctly attribute error to the correct source or didn't discuss the differences in consumer versus commercial grade equipment And/Or Lists less than two uses for each grade of device	0–2 Failed to correctly attribute error to the correct source or didn't discuss the differences in consumer versus commercial grade equipment And/Or Lists less than two uses for each of grade
3 pts **Question 5**	3 Correctly explains the value in making uncertainties explicit with all measurements. Answer articulates how large uncertainties can make hazard assessment difficult to do confidently.	2 Correctly explains the value in making uncertainties explicit with all measurements. Answer starts to explain how uncertainties can obscure confident results.	0–1 Does not provide clear or correct answers.