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Geometric configuration and reference-point distance as determinants of resection accuracy: Evidence from student surveying calculations

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Abstract: This study investigates how geometric configuration and reference-point distance affect the accuracy of resection in student surveying calculations, using RTK GNSS coordinates as the reference benchmark. Although resection remains a fundamental method in surveying education and practice, its accuracy is highly sensitive to network geometry and field setup quality, while empirical evidence from student calculation contexts remains limited. To address this gap, the study employed an empirical accuracy-assessment design based on campus field-practicum data generated by student teams using total station observations and RTK GNSS control coordinates. The analysis compared resection-derived and RTK-based coordinates through component-wise discrepancies and horizontal positional error and then interpreted the results in relation to the geometric properties of each resection configuration. The findings show that most observed configurations produced relatively small horizontal errors, indicating that resection can yield acceptable station coordinates in educational field settings. However, accuracy varied considerably across cases. Configurations characterized by balanced point distribution, moderate station angles, and proportionate reference-point distances generally produced more reliable results, whereas stretched or near-collinear configurations were associated with weaker accuracy. At the same time, the results indicate that favorable geometry alone does not guarantee strong performance, because observational execution also remains influential. The study contributes to surveying education by reframing resection as an empirical accuracy problem shaped by both geometric design and field practice.

Keywords: resection method; surveying education; geometric configuration; reference-point distance; RTK GNSS; positional accuracy

1. Introduction

Surveying education is increasingly shaped by the dual pressures of technological modernization and professional accuracy standards (X. Chen et al., 2025; Dragomir et al., 2025; Young et al., 2012). In surveying and mapping courses, determining the instrument station is a fundamental operation because it provides the spatial reference for all subsequent observations and calculations (Barazzetti, 2025; Ventura et al., 2024). Any error introduced at this stage propagates through the entire measurement workflow and directly affects the reliability of the resulting data (H. T. Chen et al., 2026; Ding et al., 2024; Yi et al., 2024). For this reason, surveying instruction must not only train students in computational procedures but also develop their understanding of the geometric and operational factors that govern positional accuracy. Within this context, resection remains one of the most important methods for determining the coordinates of an unknown instrument station from observations to reference points with known coordinates (Sestras, 2021; Zou et al., 2026).

The resection method, also known as backward intersection, is widely used in total station surveying because it enables the instrument to be positioned at a practically convenient location rather than directly over an existing control point (Osman et al., 2021). This flexibility is especially valuable in field situations where access to control points is limited or where direct occupation is operationally inefficient. In principle, resection determines the location of an unknown point by observing at least two or three known points and computing the station coordinates from the geometric relationships among angles, distances, and known coordinates (Osman et al., 2021; Ventura et al., 2024). As a result, resection remains highly relevant not only in professional surveying practice but also in surveying education, where students must learn how to coordinate solutions under realistic field constraints.

Despite its practical advantages, resection accuracy is highly sensitive to the configuration of the reference points and to the spatial distance between the instrument station and those points. In triangulation-based surveying, positional accuracy depends not only on the precision of the observed data but also on the geometric strength of the observation network. An unfavorable control-point arrangement or an unbalanced distribution across quadrants may weaken the solution and amplify coordinate error (Shahzad & Miao, 2025; S. K. Sharma et al., 2023). This issue is closely related to the classical Snellius–Pothenot problem, in which particular point configurations can lead to unstable or ambiguous solutions. One of the best-known manifestations of this instability is the danger circle, a geometric condition under which resection error may become extremely large or even theoretically unbounded (Cossarizza et al., 2021; Fu et al., 2021; Paliathanasis, 2021). Accordingly, the geometric relationship between the instrument station and the selected reference points is not a minor technical detail but a decisive factor in coordinate reliability (Kampczyk, 2020; Keßler et al., 2026; Specht, 2021).

This issue has become even more significant in the contemporary surveying environment, where GNSS-based methods are increasingly used as high-precision positioning references. Real-Time Kinematic GNSS is now commonly employed for efficient coordinate determination and for establishing campus control points or benchmarks (Bin Mohammed Na'aim & Abdul Manaf, 2024; Căţeanu & Moroianu, 2024; Ekaso et al., 2020; Maciejewska et al., 2024). In educational settings, such benchmarks can support practical surveying instruction by linking student exercises to globally referenced coordinate systems (Meng et al., 2023; Wang et al., 2023). They may also strengthen students' applied competencies in surveying and mapping for construction and spatial planning practice (Hickman, 2023; Megahed et al., 2020; Obi et al., 2024). However, GNSS does not eliminate the need for terrestrial methods. In environments affected by obstruction, signal interference, or difficult access, resection using total stations remains a stable and reliable alternative (Hussein & Abdulla, 2021; Orbán, 2025; Qiao et al., 2023). Consequently, understanding when and why resection produces more accurate results remains a relevant technical and educational problem.

Although resection has long been recognized as a fundamental surveying method, important gaps remain in the literature. First, much of the existing research has focused on the computational principles or general applications of resection, while empirical analysis of how geometric distributions and reference-point spacing jointly influence coordinate accuracy remains limited. Second, previous educational studies in surveying have often emphasized procedural execution, whereas the accuracy implications of geometric configuration have received less explicit analytical attention. Third, although GNSS-based positioning is increasingly available in educational and professional contexts, fewer studies have examined resection accuracy in relation to GNSS-referenced measurement environments, especially in student calculation settings. These gaps are important because students may be able to complete resection computations correctly in a procedural sense while still working with geometrically weak setups that produce unstable or less accurate results.

This study addresses these gaps by examining the influence of geometric configuration and reference-point distance on resection accuracy in student surveying calculations. The study contributes in three main ways. First, it moves beyond a purely procedural treatment of resection by evaluating the geometric determinants of accuracy. Second, it analyzes the combined influence of control-point distribution and reference-point distance rather than treating resection as a uniform calculation. Third, it situates the analysis within a contemporary surveying context by relating resection outcomes to GNSS-based measurement logic as an accuracy benchmark. Accordingly, this study is guided by the following research questions:

RQ1. How does geometric configuration influence resection accuracy in student surveying calculations?
RQ2. How does reference-point distance influence resection accuracy?
RQ3. How do resection-based coordinate results compare with GNSS-referenced measurements?

In theoretical terms, the study extends the discussion of resection from a classical geometric method to an empirical accuracy problem that is highly relevant to surveying education. In practical terms, it provides evidence that may help identify more stable and accurate reference-point configurations for student fieldwork and instructional design. By clarifying how geometry and distance affect resection outcomes, the study contributes to more reliable surveying practice and to more analytically grounded surveying education.

2. Methods

2.1 Study design and research workflow

This study employed an empirical accuracy-assessment design to examine how geometric configuration and reference-point distance influence the accuracy of resection results in student surveying calculations (Huang et al., 2017; Pattanasethanon et al., 2008; Stehman, 2009). The analysis was based on field-practicum data generated by student teams and reference coordinates obtained through RTK GNSS measurements. In this design, resection-derived coordinates were treated as the observed survey outputs, whereas RTK GNSS coordinates were used as the benchmark for evaluating positional accuracy. Such a design is appropriate when the objective is not only to perform resection computations, but also to assess how different field configurations affect the quality of the resulting coordinates (Osman et al., 2021; Ventura et al., 2024).

The overall workflow comprised four stages: data acquisition, data validation, resection computation, and comparative accuracy analysis. First, field observations were collected from student surveying practice using total station measurements. Second, RTK GNSS data were used to establish reference coordinates for the control points and evaluation stations. Third, the resection coordinates were computed for each student configuration. Finally, the resulting coordinates were compared with the RTK reference coordinates to quantify positional discrepancies and evaluate the effects of geometry and reference-point spacing. The complete workflow of the study is illustrated in Figure 1.

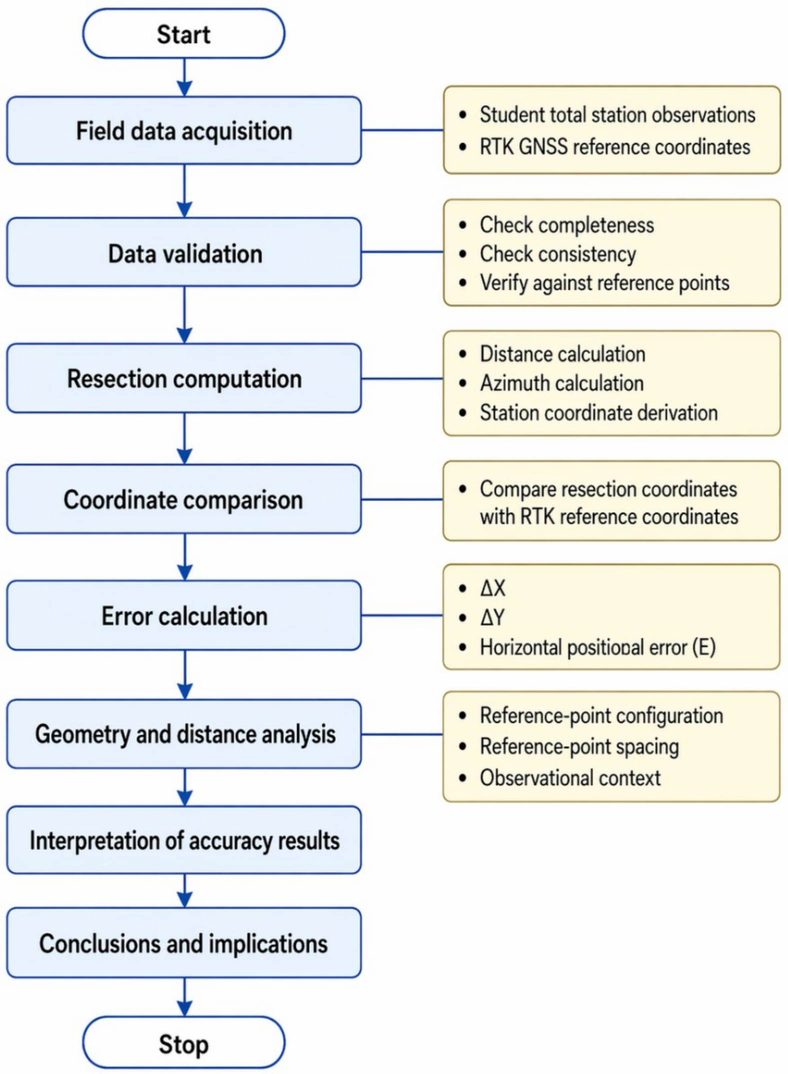

Figure 1. Research workflow of the study

2.2 Study area, control network, and data sources

The data used in this study were obtained from practical surveying and mapping exercises conducted by student teams in a campus-based survey environment. Each team established observations using different geometric configurations of reference points and different distances between the instrument station and the control points. This variation enabled examination of how configuration quality and reference-point spacing were associated with the accuracy of the resection solution.

The dataset consisted of two main sources. The first source was terrestrial survey data collected by the student teams, including angular and distance observations required for resection calculations. The second source was RTK GNSS coordinate data, which served as the reference dataset for accuracy assessment. RTK GNSS was selected as the benchmark because it is widely recognized as an efficient and high-precision positioning technique for control-point establishment and coordinate verification (Cho et al., 2024; Trong & Dung, 2024).

The spatial distribution of the student teams' survey area and the placement of the reference points are presented in Figure 2. To support reproducibility and transparency, the RTK-derived reference coordinates are reported in Table 1.

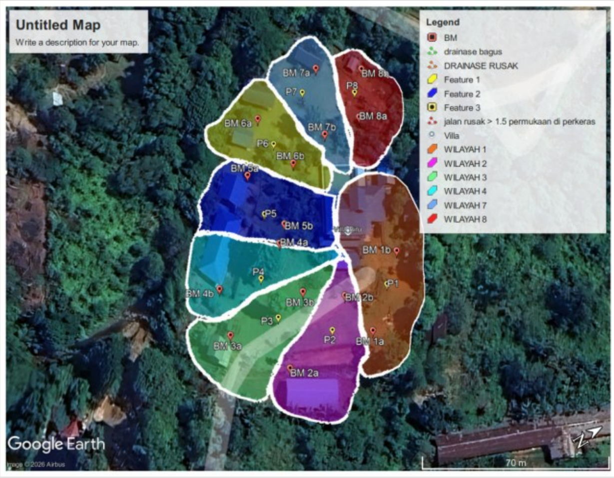

Figure 2. Distribution map of the student teams' survey area

Table 1. RTK reference coordinates

No	ID	Easting (m)	Northing (m)
1	BM1a	656069.4	9910139
2	BM1b	656046.8	9910164
3	BM2a	656061.4	9910109
4	BM2b	656043.7	9910149
5	BM3a	656041.6	9910103
6	BM3b	656042.8	9910141
7	BM4a	656029	9910138
8	BM4b	656025.3	9910105
9	BM5a	655990.9	9910135
10	BM5b	656023	9910144
11	BM6a	655980.9	9910149
12	BM6b	656005.9	9910157
13	BM7a	655971.7	9910166
14	BM7b	656001	9910167
15	BM8a	656006.6	9910184
16	BM8b	655983.6	9910188
17	P1	656061.4	9910157
18	P2	656058.9	9910134
19	P3	656037.3	9910132
20	P4	656031.9	9910123
21	P5	656015.3	9910139
22	P6	655997.3	9910151
23	P7	655980.4	9910173
24	P8	655994.9	9910181

2.3 Resection computation and coordinate derivation

The resection method was used to determine the coordinates of an unknown instrument station from observations to reference points with known coordinates. In practical total station surveying, this method enables the instrument to be set up at a convenient location rather than directly over an existing control point, while still allowing the station coordinates to be computed from the observed geometric relationships (Osman et al., 2021; Sestras, 2021; Zou et al., 2026). In this study, resection calculations were based on known benchmark coordinates and field observations collected during student practice. The distance between two known control points was first determined using the Euclidean distance equation:

$$d = \sqrt{(\Delta X)^2 + (\Delta Y)^2} \tag{1}$$

Where: $\Delta X = X_2 - X_1$ and $\Delta Y = Y_2 - Y_1$.
The azimuth between the known points was then derived as:

$$\alpha = tan^{-1}\,(\Delta X / \Delta Y) \tag{2}$$

These geometric relationships provided the basis for triangulation between the unknown station and the known reference points, allowing the station coordinates to be determined from observed angular and distance data (Basuki, 2006; Ghilani & Wolf, 2006).

2.4 Accuracy assessment

To evaluate the horizontal accuracy of the resection method, the coordinates derived from resection were compared with the RTK GNSS reference coordinates for each observation point. The coordinate differences were calculated separately for the easting and northing components as follows:

$$\Delta X = X_{resection} - X_{RTK} \tag{3}$$

$$\Delta Y = Y_{resection} - Y_{RTK} \tag{4}$$

where ΔX denotes the difference in easting coordinates and ΔY\Delta YΔY denotes the difference in northing coordinates. These component-wise differences were then combined to obtain the horizontal positional error:

$$E = \sqrt{(X_{resection} - X_{RTK})^2 + (Y_{resection} - Y_{RTK})^2} \tag{5}$$

A smaller value of E indicates a closer agreement between the resection result and the RTK reference coordinate, and therefore a higher level of positional accuracy (Kim et al., 2025; Nguyen et al., 2021; Nguyen & Cho, 2023; Qi et al., 2025). The accuracy evaluation framework applied in the study is summarized in Table 2.

Table 2. Analytical components used in the accuracy assessment

Component	Description	Analytical purpose
Geometric configuration	Spatial arrangement of reference points relative to the instrument station	To assess whether balanced or unfavorable point distribution affects resection accuracy
Reference-point distance	Distance between the instrument station and the selected control points	To examine whether shorter or longer baselines are associated with different accuracy levels
Coordinate difference (ΔX, ΔY)	Difference between resection coordinates and RTK reference coordinates	To quantify the discrepancy in each coordinate component
Horizontal positional error (E)	Combined error derived from (ΔX, ΔY)	To evaluate the overall positional accuracy of the resection result

2.5 Geometry and distance analysis

The study treated geometric configuration and reference-point distance as the two main analytical factors. The geometric configuration was examined from the spatial distribution of the reference points around each instrument station, with particular attention to whether the control points were well distributed, unevenly clustered, or nearly collinear. In surveying theory, such geometric properties affect the strength of the observation network and the stability of the resulting coordinate solution (Cho et al., 2024; Plesník et al., 2023; S. Sharma et al., 2023). Reference-point distance was examined because baseline length influences the propagation of measurement error. Shorter observation distances are generally expected to yield more stable results, whereas longer distances may amplify the effects of angle uncertainty, atmospheric conditions, and instrumental limitations (Rivera et al., 2024). In addition, the study considered local environmental conditions, such as openness of the survey area and the presence of physical obstructions, because these may affect both terrestrial visibility and GNSS signal quality (Hussain et al., 2022; Park et al., 2025; Vélez et al., 2024; Yuwono & Prasetyo, 2019). The analysis, therefore, did not evaluate resection as a purely computational process, but as a field-based positioning method whose accuracy depends on both network geometry and observational context.

2.6 Data processing and comparative analysis

After collection and validation, the resection results and RTK reference coordinates were compiled into a common dataset for analysis. For each observation point, the dataset included the point identifier, the easting and northing coordinates derived from resection, the corresponding RTK coordinates, and the resulting coordinate differences and horizontal positional error. This organization enabled a direct comparison between the two methods for every observed station. The analysis was descriptive and comparative. First, the positional discrepancies between resection and RTK were calculated for each observation point. Second, these discrepancies were interpreted in relation to the geometric distribution of the reference points and the distances between the station and the control points. Third, the results were synthesized to identify which geometric patterns and distance conditions were associated with higher or lower resection accuracy. The outputs were then presented in tables and supported by spatial figures to facilitate the interpretation of the relationship between field configuration and computational accuracy.

3. Results

3.1 Comparison of Resection and RTK Coordinates

The first stage of the analysis examined the agreement between coordinates derived from the resection method and the RTK GNSS reference coordinates. This comparison was used to identify the magnitude and direction of positional discrepancies at each observation point before interpreting positional error. As presented in Table 3, the comparison includes the resection-derived coordinates, the corresponding RTK reference coordinates, and the coordinate differences in the easting and northing components.

Table 3. Coordinate comparison between resection and RTK reference coordinates

Area	Team	Resection easting (m)	Resection northing (m)	RTK easting (m)	RTK northing (m)	ΔX (m)	ΔY (m)
2	36	656058.8	9910134	656058.9	9910134	0.097	-0.107
4	7	656031.5	9910123	656031.9	9910123	0.356	-0.044
6	13	655997.2	9910151	655997.3	9910151	0.004	0.216
6	39	655997.9	9910152	655997.3	9910151	-0.612	-0.897
7	29	655980.3	9910173	655980.5	9910173	0.158	-0.099
8	26	655994.9	9910182	655994.9	9910182	-0.008	0.383

Across the six observed configurations, the discrepancies between resection and RTK coordinates were generally small to moderate, although their magnitudes varied considerably across teams. In several cases, the easting difference remained close to zero, whereas the northing difference was more pronounced. As shown in Table 3, this pattern indicates that disagreement between the two methods was not uniform across coordinate components and suggests that positional quality should be interpreted in terms of the combined horizontal error rather than a single coordinate difference alone. At a descriptive level, most resection results were relatively close to the RTK benchmark, indicating that the method could produce acceptable station coordinates across several student survey configurations. However, one configuration produced substantially larger deviations than the others, indicating that resection accuracy was sensitive to the specific observational setup. This variation is consistent with the principle that resection solutions are not determined solely by the computational formula, but also by the geometric strength of the reference-point arrangement and the quality of field observation.

3.2 Horizontal positional error

To evaluate the overall positional accuracy of the resection method, the coordinate differences were combined into a horizontal positional error for each observation point. This metric provides a more direct measure of the distance between the resection-derived position and the RTK reference position. The resulting error values are summarized in Table 4.

Table 4. Horizontal positional error of resection results

Area	Team	ΔX (m)	ΔY (m)	Horizontal Error, E (m)
2	36	0.097	-0.107	0.144
4	7	0.356	-0.044	0.359
6	13	0.004	0.216	0.216
6	39	-0.612	-0.897	1.086
7	29	0.158	-0.099	0.186
8	26	-0.008	0.383	0.383

The error pattern shows substantial variation across the observed cases. As reported in Table 4, the smallest horizontal error was recorded for Area 2 Team 36 at 0.144 m, followed by Area 7 Team 29 at 0.186 m and Area 6 Team 13 at 0.216 m. By contrast, the largest error was found for Area 6 Team 39, which reached 1.086 m. Overall, five of the six configurations produced errors below 0.40 m, suggesting that the resection method was reasonably accurate in most cases, although its performance was not uniformly stable across all student setups.

This spread of error values indicates that resection accuracy in student calculations was condition-dependent rather than constant. The presence of one markedly larger error also suggests that the quality of the result may degrade sharply under less favorable field conditions or weaker observational execution. In accuracy analysis, such variation is not unusual because positional error is influenced by the combined effects of network geometry, distance relationships, and measurement quality rather than by a single factor in isolation. For easier visual comparison, the distribution of horizontal positional error across areas and teams is plotted in Figure 3. The figure makes the overall pattern clearer by showing that most configurations cluster at relatively low error levels, while Area 6 Team 39 stands out as a distinct outlier.

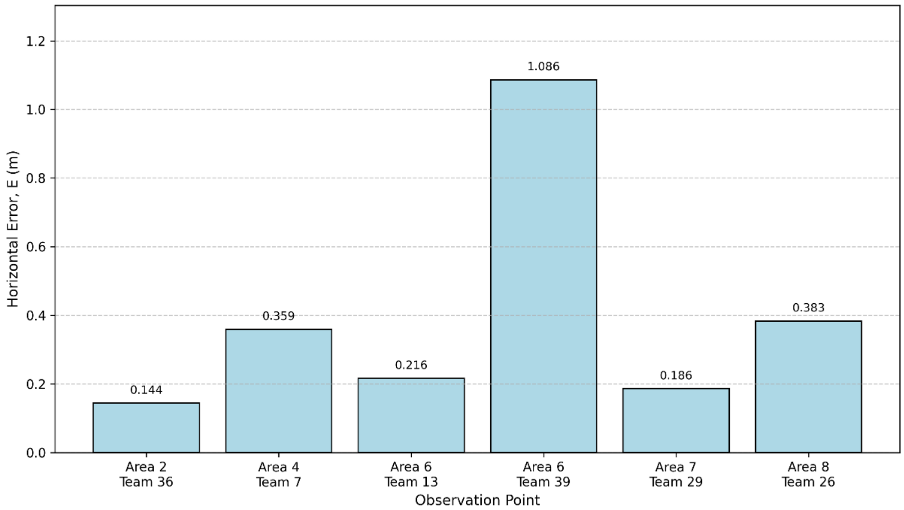

Figure 3. Horizontal positional error by area and team

The graphical pattern shown in Figure 3 reinforces the numerical results in Table 4. Most teams produced relatively small horizontal errors, whereas one case exhibited a much larger error than the rest. This visible contrast provides an important basis for the next stage of the analysis: interpreting whether geometric configuration and reference-point distance help explain the observed differences in accuracy.

3.3 Influence of Geometry and Reference-Point Distance

To explain why positional error varied across teams, the study examined the geometric characteristics of each configuration, including distances from the station to the reference points and the angular relationships in the resection triangle. These geometric attributes are summarized numerically in Table 5.

Table 5. Geometric characteristics of the observed resection configurations

Area / Team	P–BM1 (m)	P–BM2 (m)	BM1–BM2 (m)	Angle at P	Angle at BM1	Angle at BM2	Horizontal error (m)
Area 2 / Team 36	11.8	21.4	27.446	107°54'17"	47°53'45"	24°08'54"	0.144
Area 4 / Team 7	19	15	32.687	147°48'00"	18°02'38"	14°09'15.85"	0.359
Area 6 / Team 13	16.306	16.368	16.792	59°13'25"	59°09'45"	59°43'53.11"	0.216
Area 6 / Team 39	16.699	16.62	16.792	59°16'15"	55°59'48"	61°38'22"	1.086
Area 7 / Team 29	23.9	11	19.576	53°48'05"	99°50'00.3"	26°57'54.7"	0.186
Area 8 / Team 26	12.3	28	39.491	160°15'00"	13°51'25.51"	6°02'19.28"	0.383

As shown in Table 5, the observed cases differed not only in reference-point distance but also in angular structure. Some configurations formed relatively balanced triangles with moderate interior angles, whereas others formed stretched or nearly collinear shapes. To support visual interpretation of these differences, the corresponding resection triangle geometries are illustrated schematically in Figure 4.

Area 2: Team 36

Area 4: Team 7

ID	Distance (m)	ID	Horizontal Angle
P-BM1	11.8	P	107^{0}54'17"
P-BM2	21.4	BM1	47^{0}53'45"
BM1-BM2	27.446	BM2	24^{0}8'54"

ID	Distance (m)	ID	Horizontal Angle
P-BM1	19	P	147^{0}480
P-BM2	15	BM1	18^{0}2'38.01"
BM1-BM2	32.687	BM2	14^{0}9'15.85"

Area 6: Team 13

Area 6: Team 39

ID	Distance (m)	ID	Horizontal Angle
P-BM1	16.306	P	59^{0}13'25"
P-BM2	16.368	BM1	59^{0}9'45"
BM1-BM2	16.792	BM2	59^{0}43'53.11"

ID	Distance (m)	ID	Horizontal Angle
P-BM1	16.699	P	59^{0}16'15"
P-BM2	16.62	BM1	55^{0}59'48"
BM1-BM2	16.792	BM2	61^{0}38'22"

Area 7: Team 29

Area 8: Team 26

ID	Distance (m)	ID	Horizontal Angle
P-BM1	23.9	P	53^{0}48'05"
P-BM2	11	BM1	99^{0}50'0.3"
BM1-BM2	19.576	BM2	26^{0}57'54.7"

ID	Distance (m)	ID	Horizontal Angle
P-BM1	12.3	P	160^{0}15'0"
P-BM2	28	BM1	13^{0}51'25.51"
BM1-BM2	39.491	BM2	6^{0}2'19.28"

Figure 4. Geometric configurations of the observed resection setups by area and team

Taken together, Table 5 and Figure 4 indicate that geometry and reference-point distance influenced resection accuracy, although their effects were not purely linear. Configurations with more balanced distances and stronger angular geometry tended to produce smaller errors. A clear example is Area 6 Team 13, where the distances from the instrument station to the two benchmarks were nearly equal, and the internal angles were close to 60°, creating a geometrically strong triangle. As reported in Table 5 and illustrated in Figure 4, this configuration produced a relatively low positional error of 0.216 m. Such a result is consistent with surveying theory, which holds that well-balanced observation geometry strengthens the stability of coordinate solutions.

By contrast, weaker angular configurations were associated with larger errors. Area 4 Team 7 and Area 8 Team 26 provide important examples. In both cases, the triangular geometry was less favorable because one angle was very large while the other two were small, resulting in a stretched, unstable configuration. This is particularly evident in Figure 4, especially for Area 8 Team 26, where the 160° angle at the station and the very small angle at one benchmark reflect a nearly collinear arrangement. Under such conditions, small observational errors can propagate more strongly into the final coordinate solution, which helps explain the higher positional error of 0.383 m.

The relationship between distance and accuracy also appeared meaningful. In general, shorter and more balanced distances were associated with better agreement between resection and RTK coordinates, whereas longer or more uneven baselines tended to coincide with larger discrepancies. However, the findings also show that distance alone did not determine accuracy. Area 6 Team 39 is particularly noteworthy because its geometric dimensions were similar to those of Team 13, yet it produced the largest error in the dataset. This pattern, evident in Table 5 and shown in Figure 4, indicates that favorable geometric design does not guarantee accuracy in the presence of other field-related influences, such as targeting inaccuracy, angle-reading error, instrument setup instability, or computational errors. In other words, the results suggest that resection accuracy emerged from the interaction between geometric strength and measurement execution rather than from geometry alone.

Collectively, these findings support the argument that geometrically strong and operationally well-executed resection setups are more likely to produce accurate station coordinates. Balanced point distribution, moderate station angles, and proportionate reference-point distances generally corresponded to better results, whereas stretched or near-collinear configurations were associated with reduced accuracy. The comparison with RTK coordinates, therefore, confirms that both geometry and distance matter in student surveying calculations, while also showing that non-geometric measurement factors can still substantially affect the final result.

4. Discussion

This study examined how geometric configuration and reference-point distance influenced the accuracy of resection results in student surveying calculations by comparing resection-derived coordinates with RTK GNSS reference coordinates. Overall, the findings show that most student configurations produced relatively small horizontal errors, indicating that the resection method can generate acceptable station coordinates under several field setups. At the same time, the results reveal that resection accuracy was not uniform across cases, with one configuration producing a markedly larger error than the others. This pattern suggests that resection in educational practice should be understood not merely as a computational routine, but as a geometry-sensitive and execution-dependent positioning method.

The findings are consistent with previous surveying research showing that resection reliability depends strongly on the strength of the observation network and the spatial arrangement of reference points (Osman et al., 2021; Shahzad & Miao, 2025; Ventura et al., 2024). Configurations with more balanced distances and moderate internal angles tended to produce lower positional error, while stretched or near-collinear triangles were associated with weaker results. This was particularly evident in the contrast between Area 6 Team 13 and Area 8 Team 26. The former displayed a nearly ideal triangular form with angles close to 60°, whereas the latter showed a highly elongated configuration with one angle approaching 160°, which is theoretically less stable and more sensitive to error propagation. In this respect, the present findings support earlier discussions of geometric strength, instability, and the classical danger-circle problem in resection analysis (Cossarizza et al., 2021; Paliathanasis, 2021; Specht, 2021).

The role of reference-point distance was also meaningful, although it did not operate independently of geometry. In general, shorter and more proportionate distances were associated with better agreement between resection and RTK coordinates, which aligns with the geodetic principle that longer baselines can amplify the effects of angular uncertainty and measurement propagation (Cho et al., 2024; Rivera et al., 2024). However, the results also demonstrate that shorter or balanced distances alone do not guarantee higher accuracy. The clearest example is Area 6 Team 39, which had geometric dimensions similar to Team 13 but produced the largest horizontal error in the dataset. This discrepancy indicates that measurement quality, including instrument setup, angle reading, targeting precision, and computation handling, remained influential alongside geometry. Accordingly, the findings refine prior studies by showing that reference-point distance matters most when considered alongside network geometry and observational execution, rather than as an isolated factor.

An important strength of the study lies in the internal triangulation of evidence across several analytical layers. The coordinate comparison in Table 3 first showed that discrepancies between resection and RTK were not uniform across easting and northing components. Table 4 and Figure 3 then demonstrated that most configurations remained within a relatively low error range, while one case clearly emerged as an outlier. Finally, Table 5 and Figure 4 showed that this variation corresponded in meaningful ways to the geometric structure of each resection setup. This convergence across coordinate-component analysis, horizontal positional error, and geometric interpretation strengthens the credibility of the results, because the conclusions are supported not by a single statistic but by mutually reinforcing empirical patterns. In this sense, the study provides a coherent account of how geometry, distance, and execution jointly shape resection accuracy in student fieldwork (Kim et al., 2025; Nguyen et al., 2021; Qi et al., 2025).

From an educational perspective, the findings are especially important because they extend surveying instruction beyond procedural correctness toward analytical accuracy awareness. Students may complete resection calculations correctly in a formal sense, yet still obtain weak positional results if the selected reference-point arrangement is geometrically poor or operationally unstable. The study therefore supports the argument that surveying education should emphasize not only how to compute resection, but also how to evaluate geometric strength, distance balance, and field execution quality before and during measurement. In practice, the results suggest that student training should encourage the selection of balanced point distributions, moderate station angles, and proportionate reference-point spacing, wherever possible. Simultaneously, the outlier case reminds us that even favorable geometry does not eliminate the need for careful observation and instrument handling, thereby reinforcing the view that resection accuracy emerges from the interaction between geometric design and survey practice rather than from geometry alone.

5. Limitations and Implications

This study has several limitations that should be considered when interpreting the findings. First, the analysis was based on a relatively small number of observed student survey configurations drawn from a single campus-based practicum context. Although this setting was appropriate for examining variation in resection accuracy under authentic educational conditions, it limits broader generalization to other surveying environments, institutional settings, or levels of measurement complexity. Second, the study adopted a descriptive and comparative accuracy-assessment design rather than an experimental design. As a result, the findings are well-suited to identifying patterns of accuracy and plausible geometric influences, but they do not permit stronger causal claims about the independent effect of any single factor. Third, while RTK GNSS was used as a high-precision benchmark, the study still focused on horizontal comparison at the level of student field calculations and did not model all possible sources of uncertainty in a fully statistical manner. In addition, non-geometric influences such as targeting precision, instrument setup quality, observer skill, and local field conditions were interpreted from the observed results rather than isolated through controlled testing. Future studies could therefore strengthen the evidence base by including more configurations, multiple field sites, repeated observations, controlled comparisons of geometric scenarios, and more formal statistical modeling of the contributions of geometry, distance, and operational error.

Despite these limitations, the study offers important implications for both surveying education and field practice. From a theoretical perspective, the findings reinforce the view that resection accuracy should not be understood solely as a matter of computational correctness, but as the outcome of an interaction among network geometry, reference-point distance, and field execution quality. This extends resection from a classical geometric procedure to an empirically grounded accuracy problem that is directly relevant to surveying instruction. From a practical perspective, the results suggest that surveying education should place greater emphasis on analytical accuracy awareness, especially in teaching students to evaluate the strength of point configurations before measurement is performed. In particular, balanced point distribution, moderate station angles, and proportionate reference-point spacing should be emphasized as desirable conditions in student fieldwork. At the same time, the outlier case in this study highlights that favorable geometry alone is insufficient without careful observation and instrument handling. Accordingly, surveying instruction and practicum design should integrate both geometric reasoning and operational discipline so that students can develop not only procedural ability, but also professional judgment regarding measurement reliability.

6. Conclusion

This study concludes that resection accuracy in student surveying calculations is influenced by both geometric configuration and reference-point distance, as evaluated through comparison with RTK GNSS reference coordinates. Most observed student configurations produced relatively small horizontal errors, indicating that resection can yield acceptable station coordinates across several field setups. However, the results also showed that accuracy was inconsistent across cases, with one configuration producing a markedly larger positional error than the others. This confirms that resection performance in educational practice is condition-dependent rather than uniform.

More specifically, the findings show that geometrically stronger configurations, characterized by more balanced point distribution, moderate internal angles, and proportionate distances to reference points, tended to produce more accurate results. Conversely, stretched or near-collinear configurations were associated with weaker positional accuracy. At the same time, comparing teams with similar geometric dimensions but different error outcomes shows that geometry and distance alone do not fully determine resection quality. Field execution factors, including targeting, instrument setup, and measurement handling, also remain influential. Overall, the study demonstrates that the accuracy of resection in student fieldwork emerges from the interaction between geometric design and observational quality. In this sense, the study contributes to surveying education by showing that students must learn not only how to compute resection solutions, but also how to judge the geometric and operational conditions under which those solutions are likely to be reliable.

Author's declaration

Author contribution

Elisa Maiyenti: Conceptualization, Methodology, Supervision, Writing – review & editing. **Khairul Hamdi:** Formal analysis, Validation, Writing – review & editing. **Annisa Irena Rahmatita:** Investigation, Data curation, Writing – original draft. Johan Ariyantoni: Formal analysis, Validation, Writing – review & editing. **Fani Keprila Prima:** Methodology, Validation, Writing – review & editing.

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Conflict of interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical clearance

Ethical approval for this study was obtained prior to data collection, and permission to conduct the research was granted by the relevant institutions.

AI statement

This article is the original work of the author without using AI tools for writing sentences and/or creating/editing tables and figures in this manuscript.

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