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MEASURING FOREST TREES HEIGHT USING DIFFERENT METHODS: A CASE STUDY ON CHINAR TREES (*Platanus Orientalis*) IN DUHOK PROVINCE

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ABSTRACT

In this study, forty *Platanus orientalis* trees located in Duhok-Kurdistan Region of Iraq were selected to measure tree height using two different methods: UAV-Terra and Terra software, and Total station (TS), then the results were compared with that measured by tape-mounted drone when wind speed is less than 5km/hour. Results showed the tree heights measured using the TS closely aligned with those obtained from the tape-mounted drone and Terra software method demonstrating high accuracy (R^2 was 98.51%). Among the thirty-nine observations, a strong correlation was also found between tape-mounted drone and UAV-Terra with an R^2 value of 90.89%. This study implies that integrating TS, UAV-Terra, and tape-mounted drone methods provides a reliable framework for accurate tree height measurement, which can be extended to broader forest monitoring and sustainable management in the Kurdistan region.

1.Introduction

Duhok is settled in the northern part of the KRI, characterized by mountainous terrain, fertile valleys, and river basins that support diverse forms of vegetation (Khwarahm, 2020). The city was selected for this study because there is a rare occurrence of clustered Chinar (*Platanus orientalis*) trees in the same location, which is better suited for objective measurement and analysis.

The forest of Kurdistan region of Iraq (KRI) is overwhelmingly by oak species with *Quercus ageilops* alone making up about 70% of the total forest cover followed by *Q. libani*, *Q. infectoria*, and *Q. macranthera* (Khwarahm, 2020). Predictive mapping studies also indicate that oak species well define their ecological niches for their presence in the area; further trends of climate scenarios suggest shifts in potential geographic ranges (HamadAmin and Khwarahm, 2023). Other modelling exercises including trees such as *Crataegus azarolus*, *C. monogyny*, and *Prunus macrocarpa* will highlight the ecological diversity of KRI and the susceptibility of its forest to both land use pressure and climate change (Radha and Khwarahm., 2022, Qadir and Khwarahm., 2025). Since these forests have been dominated comparatively extensively and homogeneously with oak stands, using as demonstrated in this study accurate tree height measurement techniques to scale are well justified. Such techniques give essential tools for inventory, long term monitoring and sustainable management on-the-ground practices for the oak dominated landscapes of the KRI.

Tree height measurement is an important part of forest science, being one of the most fundamental variables in the discipline. The height of a tree is associated with its growth, stand dynamics, and even where it lives, and acts as a fundamental input into most estimates of timber volume, biomass, and carbon storage. In this context, an error in height measurement necessarily affects the accuracy of related estimates. It also represents a number of ecological functions such as canopy structure, competition, and potential habitat. and the purpose may be as a standardized and useful parameter for method testing, validation of

remote sensing data, and support for sustainable forest management (Hartley *et al.*, 2020, White *et al.*, 2024, De Petris, Sarvia and Borgogno-Mondino.,2022). The measurement of tree height benefits forest managers, protectionists, researchers, decision makers and local communities by supporting permanent forest management, carbon assessment and organic protection.

There are indirect and direct techniques for measuring tree heights (Hartley *et al.*, 2020).

Direct methods of measuring tree height can be employed by taking the actual height of trees on the ground using instruments such as ladders, labeled poles, and tapes, for under-10-meter trees(Hansen, 2021).Instrumentation measurement techniques include traditional ones that use forester's sticks (Gyawali *et al.*, 2022). But most importantly, the latest includes measuring using TS mapping cameras for very high accuracy (Yao *et al.*, 2022).

Some traditional devices, like the Abney level and Clinometer, use trigonometry to find tree height by measuring the angle subtended at the top of the tree over a known distance; these techniques may suffer from low accuracy in denser stands due to obstruction of lines of sight (De Petris, Sarvia and Borgogno-Mondino, 2022).On the other hand, they are sometimes difficult and require great effort for direct in-situ steering and often involve multiple translations to find a good vantage point for observation (Capalb *et al.*, 2024).

In contrast to the more direct methods of measuring tree height, indirect methods involve deriving the actual height without climbing the tree or physically arriving at its top. Though indirect measurements generally involve mathematical or technological means for such measurements, the first type includes instrument principles together with distance measurements with Clinometers and others based on trigonometric principles (Pariyar and Mandal, 2019) allometric equations which define height based on another diameter at breast height (Barbosa *et al.*, 2019). And further applications using remote sensing (RS) data with shadow length and trigonometry involving applications

(Safonova *et al.*, 2021). Mostly, indirect measurement methods are invoked when direct measuring is impossible, but their careful validation is always needed to ensure accuracy across a range of forest conditions.

Unmanned aerial vehicles (UAV) have been rather famous for some time lately and are expected to revolutionize RS within the natural sciences (Lagogiannis and Dimitriou, 2021). Small-scale technologies have developed so that UAVs are capable of carrying lightweight standalone lidar systems, thereby creating a feasible RS application (Dalla Corte *et al.*, 2020). The use of UAV-lidar is becoming more prevalent for forest structure health assessments, which can yield data on populations at a fine scale (Silva *et al.*, 2018). Drones became a household name after their introduction into commercial markets in the early 20s and very much into the 1950s. In the last ten years, their applicability for various civilian purposes, ranging from precision agriculture to forestry to biodiversity monitoring to meteorology to emergencies has contributed to their rapid increase in popularity due to different sizes, shapes, and capabilities (Vélez-Nicolás *et al.*, 2021).

Yousif and Ibrahim, (2023) measured tree heights from two selected locations. One was a pure *Pinus brutia* forest in Geverke, while the other was a mixed conifer-broadleaf forest in Babilo. Both sites are situated in the Duhok province of the KRI. The author generated a point cloud from a UAV 1" CMOS digital camera and compared the results against traditional methods.

1.1 The study aims

- 1- The study aimed to measure the single tree height of Chinar (*platanus orientalis*) by using different methods: TS, UAV equipped with an RGB (Red, Green, Blue) camera, and Tape-mounted drone.
- 2- To measure the tree height from drone points cloud by using software like DJI Terra.
3. To determine the most accurate method for measuring tree height.

2. Materials and methods

2.1 Description of the study area:

The site is located in Duhok province - KRI. The location has an average altitude of 472 meters. The latitude was 36.864832° N, and the longitude was 42.975675° E. The total area of the study site is 7.72 Donum. We select about forty *platanus orientalis* trees with a height between 5-15m figure 1. Chinar (*Platanus orientalis* L.) is a member of the Platanaceae family. Its natural distribution is southeast Europe and southwest Asia (Sabr, 2021). Oriental plane (*Platanus orientalis*) is included in one genus only along with (6-10) species of tall trees (Khalid, 2024). It is a large deciduous tree, which grows very fast and develops a very strong and extensive root system. Unlike other riparian species, it is quite tolerant to soil conditions and grows on a very limited range of soil types and on gravel along the rivers. It developed a height of 30m and stem diameter of 5m.

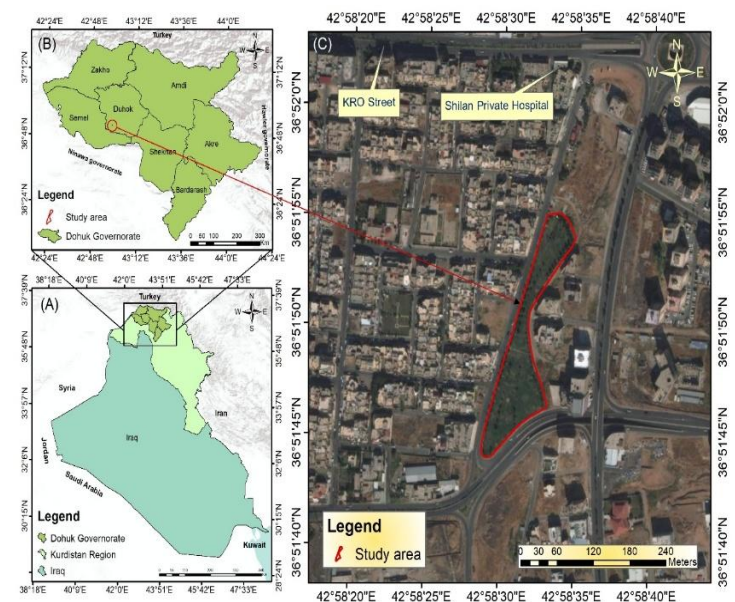


Figure 1: study area

2.2 materials

2.2.1 The Unmanned aerial vehicle (UAV) and its RGB camera:

The DJI Phantom 4 Pro is the drone that was used for this study. It weighs 1.38 kg and is able to take images as far away as 5 km from its position. It has a maximum flying period of 30 minutes per battery charge. This quadcopter is the favorite tool of agricultural professionals, breeders, agronomists, and researchers (Guan SenLin *et al.*, 2019). The RGB camera, which

has a 20-megapixel resolution and can capture both photos and videos, has been mounted on the drone. It comprises three visible spectral bands (Blue, Green, and Red) with a focal length of 8.8 mm. While the camera has a 45° field of view, it was operated from a flying height of approximately 60m. The sensor (FC6310) made it possible to develop 3D reconstruction models of the study area.

2.2.2 The differential GPS

Differential GPS (Global Positioning System) operates using a one-way ranging technique, where GPS satellites transmit signals along with their estimated positions (Parkinson and Spilker, 1996). For this study, we used a Marvel laser GNSS receiver (INTEC) as show in figure 2. The instrument was used to measure and georeferenced the coordinates of the eight-ground control points (GCPs) in the study site.



Figure 2: The Marvel laser GNSS receiver (INTEC)

2.2.3 The Total station instrument

The TS is an instrument used in surveying to measure positions in three dimensions and built-in calculations to calculate vertical and horizontal distance, slopes, and elevation differences between locations. For our project, we used the Leica TS03 (2024) Model Pinpoint R500 with an accuracy of 5. The main parts of the TS are the tripod, telescope and optics(theodolite), EDM, and an electronic control unit Figure 3.



Figure 3: The Total station main parts.

2.2.4 Measuring tape

It is a flexible device used to measure lengths or distances. It usually has a strip made of cloth, plastic, fiberglass, or metal, with measurements marked down in line (Zhou, He and Chen, 2019).

2.2.5 software

1. DJI Terra

Essentially, photogrammetry is part of the whole 3D model reconstruction program, DJI Terra, and this technology is capable of processing visual data collected with DJI LiDAR, as well as various elaborate and high-precision visible-light reconstruction techniques, both 2D and 3D. In addition, the DJI Terra program is used in conjunction with DJI Enterprise drones and payloads and enables complete application solutions for vertical applications such as emergency services, power transmission, and land surveying and mapping, as well as construction, transportation, and agriculture (Tan *et al.*, 2024).

2.3 Methods

2.3.1 Fieldwork:

2.3.1.1 Locating (GCPs)and photo acquisition

The base GNSS receiver was first configured to capture GPS signals and then connected to the radio for transmitting data to the Rover. Upon receiving the signal, the Rover verified the location readings for accuracy, with the radio capable of transmitting up to 15km. After confirming signal accuracy, the Rover was used to mark points, measure, and store coordinates. At the same time the drone was launched from

the starting point and captured images in two directions, west to east and south to north at a constant flight altitude. After completing the mission, the drone returned and landed at the starting point.

2.3.1.2 Innovative method of measuring tree height

The researcher introduced an innovative method for measuring tree height by combining a measuring tape with a simple UAV. In this approach a measuring tape was mounted onto the UAV, with a vertical turbine attached to ensure the tape remained straight during flight. The UAV was then flown to the top of the tree and tape reading from tress’s base to the top was recorded.

2.3.1.3 Measuring tree height by Total station

were entered. The telescope was then directed toward the target points on the tree focusing first on the highest and lowest positions. In this process when the TS is aimed at the highest and lowest points of the tree the instrument measures the distance between itself and the selected point, along with the corresponding angle. These First, the tripod was firmly set up on solid ground, after which the TS was mounted and carefully leveled. Once the instrument was switched on the required settings were entered. After which the TS was mounted and carefully leveled. Once the instrument was switched on the required settings

2.3.2.2 Image processing and tree height measuring:

The images were acquired on March 9 and processed using DJI Terra V4.2.5 with a total processing time of approximately 1 hour and 13 minutes. During the flight the drone maintained an average altitude of 54.61 meters, resulting in a ground sampling distance (GSD) of 2.386cm/pixel. Image processing involved the use of three natural bands (unit8) to generate a True Digital Orthophoto map (TDOM), covering an area of about 0.098182km². A full 3D reconstruction was then performed which required approximately 1 hour and 9 minutes. The output imagery was color-adjusted to

measurements from a triangle in which two parameters are known the slope distance and the angle. Using these values, the vertical height of the tree can then be determined through the application of appropriate trigonometric calculations.

2.3.2 Office work:

2.3.2.1 Flight plan design: Depending on the arrangement from west-to-east, and south-to-north, the images were captured, on March 9th, with the details shown in table 1.

Table 1: The flight information

NO.	Details	Values
1	Drone height	60m
2	Front overlap	80%
3	Side overlap	80%
4	Photos number	252
5	Ground resolution	2.31cm/pixel
6	Coverage area	0.098182 km ²
7	Camera angle	45°

emulate natural tone enhancing visual interpretation. Tree height was subsequently measured using the software’s measurement tool which calculated the vertical distance from the top of each tree to its base through the 3D point cloud.

3. Result and Discussion

Table 2 shows the forty trees' height data measured by TS, Tape-mounted drone, and UAV-Terra

Table 2: Tree height measurements by different methods

No. Trees	TS	Tape-mounted drone	UAV-Terra	No. Trees	TS	Tape-mounted drone	UAV-Terra
1	13.43	13.42	12.92	21	6.55	6.56	6.13
2	9.46	9.48	9.6	22	8.81	8.75	8.31
3	9.19	9.18	9.33	23	9.45	9.40	8.62
4	12.93	12.95	12.83	24	11.18	11.20	11.01
5	7.02	7.05	6.86	25	9.05	9.03	7.89
6	11.69	11.70	11.38	26	9.56	9.54	8.0
7	9.36	9.40	8.49	27	7.91	9.30	8.89
8	12.82	12.80	11.44	28	6.95	6.99	5.76
9	7.11	7.09	6.24	29	6.50	6.55	4.49
10	6.10	6.17	5.95	30	10.12	10.12	8.19
11	5.23	5.29	4.17	31	9.40	9.25	9.06
12	8.90	8.70	6.69	32	8.75	8.97	7.02
13	6.93	6.95	5.02	33	9.12	9.10	7.24
14	10.03	10.04	7.17	34	11.30	11.34	9.8
15	7.66	7.66	7.46	35	8.66	8.80	6.87
16	6.91	7.44	6.88	36	6.12	6.17	3.65
17	8.91	8.89	8.25	37	8.15	8.17	6.0
18	5.60	5.57	4.13	38	8.63	8.65	7.48
19	7.15	7.15	6.84	39	10.03	10.03	9.03
20	7.17	7.05	6.98	40	8.69	8.70	7.25

3.1 Statistical analysis results between the tape-mounted drone and the TS method

The results indicate that the model fitted explains 98.5196% of the variability in Tape-mounted drone, as indicated by R². The correlation coefficient thus obtained is equal to 0.99257 indicating a relatively strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals is 0.242679.

This value can be used to predict and set the limit of prediction for new observations from the Forecasts option in the text menu. Figure 4 describes the linear relationship between the tape-mounted drone and TS measurement values. Table 3 shows the results of fitting a linear model to describe the relationship between them. The equation of the fitted model is:

$$\text{Tape- mounted drone} = 0.1997 + 0.98302 \cdot \text{TS}$$

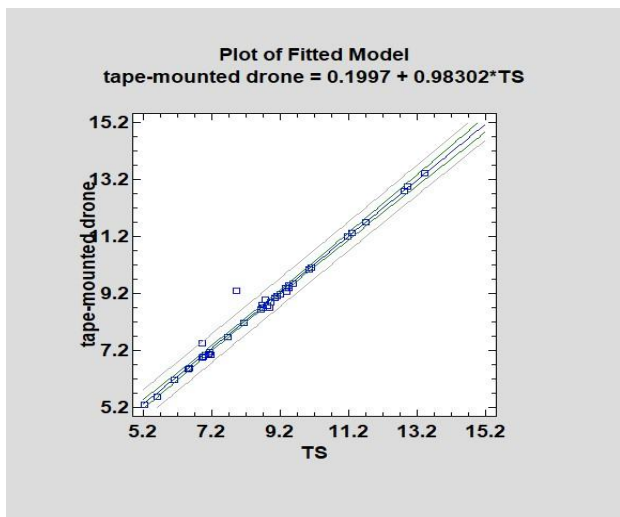


Figure 4: The linear relationship between TS & tape-mounted drone values

Table 3: Coefficients of tree height

Parameter	Least Squares Estimate	Standard Error	T Statistic	P-Value
Intercept	0.1997	0.174596	1.14378	0.2599
Slope	0.98302	0.0195481	50.2872	0.0000

Table 4 depicts the analysis of variance. Since the P-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between the Tape-mounted drone and TS at the 95.0% confidence level.

Table 4: Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	148.929	1	148.929	2528.80	0.0000
Residual	2.23794	38	0.0588932		
Total (Corr.)	151.167	39			

The mean absolute error (MAE) of 0.106888 it represents the average of the absolute values of the residuals. The average of raw residuals is always close to zero by definition figure 5. The Durbin-Watson (DW) statistic evaluates the

residuals to check for any significant correlation based on the sequence in which they appear in your data file. Since the P-value exceeds 0.05, there is no evidence of serial autocorrelation in the residuals at the 95.0% confidence level. The mean absolute error F-ratio compares the variance between groups to the variance within groups. The F-ratio is employed in an ANOVA, offering a deeper understanding of the data than simply relying on the mean or median. The F-ratio equation is as follows:

$$F = MSB / MSW$$

MSB= Mean of Squares Between

MSW= Mean of Squares Within

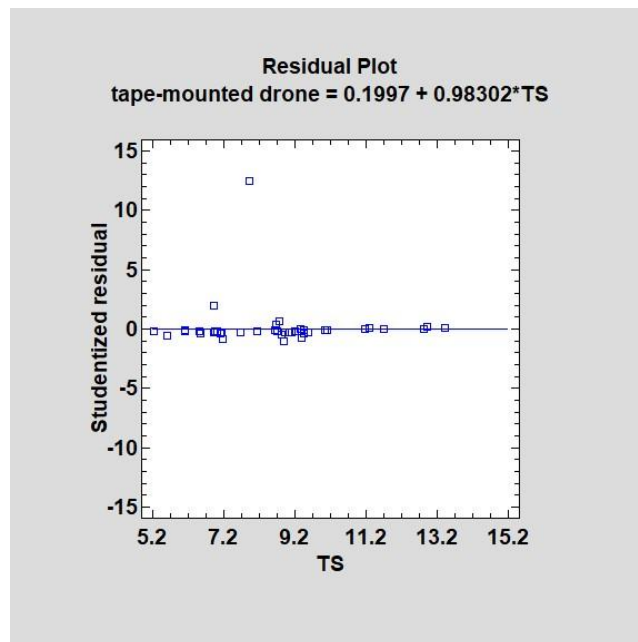


Figure 5: Residual plot of TS & tape-mounted drone values

3.2 Statistical analysis results between Tape-mounted drone and the UAV-Terra values

Table 5 shows the R2, Standard error, y-intercept values, slope, and the equation of the Double-squared model which explains the relationship between the two measured tree heights (using a Tape-mounted drone and UAV-Terra), signifies that 90.8923% of the variability observed in the fitted model with respect to Tape-mounted drone data is explained by the R² statistic. The correlation coefficient equals 0.953375, indicating a relatively strong

association between the two variables. The standard error of the estimate implies that the standard deviation of the residuals is equal to 11.314, which can be applied in generating prediction limits for new observations from the Forecasts option of the text menu. Figure 6 show the Double-squared model relationship between the tape-mounted drone and UAV-Terra measurement values. Table 6 shows the results of fitting a Double-squared model to describe the relationship between them. The equation of the fitted model is:

$$\text{Tape-mounted drone} = \text{sqrt} (18.6982 + 0.946374*\text{UAV-Terra}^2)$$

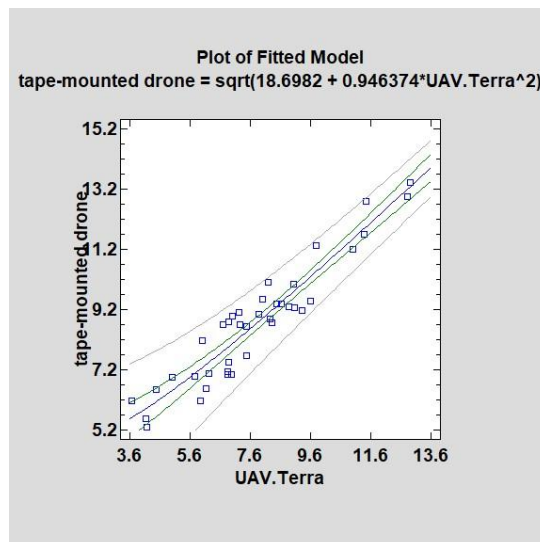


Figure 6: Double-squared relationship between Tape-mounted drone & UAV-Terra

Table 5: Mathematical models that fit the relationship between the tape-mounted drone and the UAV-Terra

No.	Model type	R ²	SE. (standard error)	Equation
1	Linear	89.0241	0.665947	Y = 2.22963 + 0.839333*X.....1
2	Recp-y	79.7319	0.0124278	Y = 1/(0.205246 - 0.0110454*X)....2
3	Log-y sqrt-x	87.292	0.0816535	Y = exp(0.693382 + 0.525879*sqrt(X))....3
4	Double-squared	90.8923	11.314	Y= sqrt(18.6982 + 0.946374*X^2)....4
5	Multip	87.5795	0.0781711	Y = exp(0.668615 + 0.734191*ln(X))....5
6	Recp-y log-x	85.0035	0.0107548	Y = 1/(0.290361 - 0.0847664*ln(X))....6

Recp: Reciprocal.
 Sqrt: square root. Multip: multiplicative

The best model that can describe the relationship was: Y= sqrt(18.6982 + 0.946374*X^2)....4

Table 6: Coefficients of tree height

Parameter	Least Squares Estimate	Standard Error	T Statistic	P-Value
Intercept	18.6982	3.67261	5.09124	0.0000
Slope	0.946374	0.0492496	19.2159	0.0000

Table 7 The analysis of variance indicates that there is a statistically significant relation at the 95.0% confidence level between the Tape-mounted drone and UAV-Terra due to a P-value that is less than 0.05 in the ANOVA table.

Table 7: Analysis of Variance.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	47266.1	1	47266.1	369.25	0.0000
Residual	4736.21	37	128.006		
Total (Corr.)	52002.3	38			

MAE of 9.54869 represents the average of the residuals as show in figure 7. The DW statistic considers the residuals with respect to whether any significant correlation exists among the order in which they occur in your data file. Because the P-value is below 0.05, it indicates a possible serial correlation at a 95.0% confidence level.

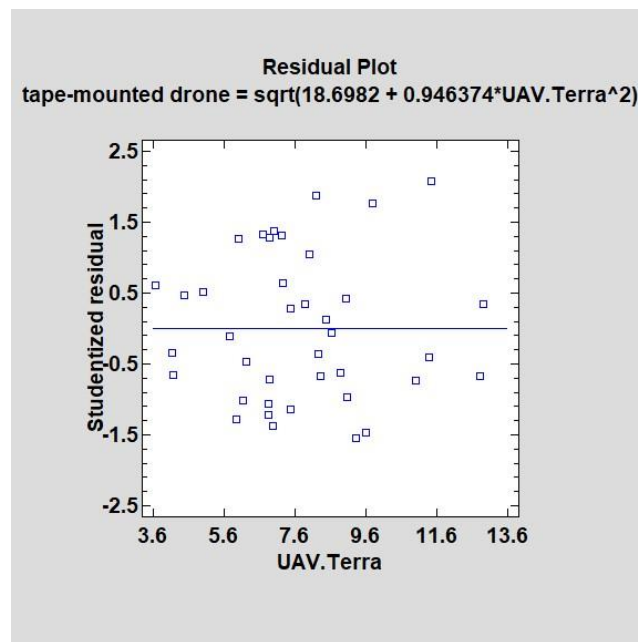


Figure 7: Residual plot of tape-mounted drone & UAV-Terra

3.3 comparison of the current study R² result with other studies

Some studies depended on indirect field tree height measurements when comparing their results with other measuring methods, and other methods depend on direct measuring methods. In the current study, the researcher compared his measuring results with those obtained from the tape-mounted drone method which is considered to be a direct method. The TS results depicted an R²=98.51% which coincides with those found by Liyan et al., (2018) who used an integrated TS with a CCD (charge-coupled device) camera to measure the height of 160 standing timber. The results depicted an accuracy of 98.41%, and Yao et al., (2022) who used an electronic theodolite for measuring tree height compared the results with measurements obtained from felled wood in Beijing (China), and found an R² value of 99.23% which both coincide with those found by the researcher.

In other field measurements, Ganz et al., (2019) compared tree height measurements obtained by direct field (by using a measuring tape) methods with those obtained by indirect field methods. The indirect methods followed were the Vertex clinometer, based photogrammetry and LIDAR. The R^2 values obtained were 92%, 99%, and 99% respectively which also agreed with what the researcher obtained.

Besides that, the result found by this study using the UAV and Terra software against the tape-mounted drone method, has an R^2 of 90.89% which is approved by (Martin, 2022) who also used a tape-mounted drone against clinometer, laser rangefinder, and stick methods, and he registered an R^2 of 98.3%, 98.7%, and 94.5% alternatively. Belmonte et al., (2020) recorded the cumulative tree height of the mixed forest of Coconino at the San Francisco Peaks. Measurements of R^2 between heights derived in the field and individual tree heights derived in UAV images showed a very strong agreement ($R^2= 95\%$) which is close to the researcher's result. Yousif and Ibrahim, (2023) studied sixty-one *pinus brutia* trees in Geverke Duhok province/Kurdistan Region of Iraq to compare tree height measurements with field measurements, the comparison achieved an R^2 of 84.03% which is less than the researcher found.

Zhao et al., (2014) conducted tree height and volume measurements under TS survey conditions. New methods for estimating tree height and volume through TS have been developed even when part of the crown is shaded. Three approaches were applied-mathematics: use of similar triangles, empirical equation methods for single tree growth, and Kunze, M. Stem Curve Method, which yielded a height and volume estimate from their results. The increased accuracy of height and volume forecasting with TS -assisted measurement through mathematical modeling has already made up to 90% accuracy for Kunze, M. Stem Curve Method.

Krautz, (2019) compared the measuring accuracy of TS and Terrestrial Laser Scanners (TLS) in measuring tree heights and Diameters

at Breast Height (DBH), for biomass estimations. A dual TS arrangement enhanced the height measuring precision by up to 0.052 m.

Ramli and Tahar, (2020) tree heights were calculated by using Least Seeded Region Growing (SRG) segmentation to detect tree crowns. Tree heights were measured with the TS and prism with an accuracy of 57.7 cm according to actual measurements.

3.4 discussion

This study highlights the importance of indirect tree height measurement, as they offer practical solution in areas where direct methods are limited by canopy density or terrain. While the TS ensures high precision, it is time saving but sensitive to wind speed and weather, UAV-Terra provides wider coverage but depends on flight design and processing quality, tape-mounted drone is simple and practical but sensitive to weather. These benefits and limitations show that the applied techniques can complement each other and hold strong potential for improving forest monitoring and sustainable management in the diverse forests of the Kurdistan region.

4. Conclusion

According to the current results, the tree heights measured using the TS method are closely aligned with those obtained from the tape-mounted drone method demonstrating high accuracy when wind speed is less than 5km/hour. The UAV-Terra method also provided a very high accuracy but stands in the second order. These findings imply that the applied techniques can be extended to other species and larger forest areas, offering practical tools for improving forest monitoring and forest management.

5. Recommendations

1. Applying the TS method for measuring the height of other tree types.
2. Applying the tape-mounted drone under different wind speeds to measure tree height and assess its accuracy.

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