Evaluation of UAV Flight Altitude for Accurate Mangrove Canopy Height Estimation: A Case Study from Melgonze, Persian Gulf, Iran

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ABSTRACT:

Unmanned Aerial Vehicles (UAVs) have become valuable tools for high-resolution ecological monitoring, particularly in complex environments such as mangrove forests. This study investigates the impact of flight altitude on the accuracy of tree height estimation in the Melgonze mangrove forest, in southern Iran. Two UAV flights were conducted at altitudes of 100 meters and 150 meters using a DJI Phantom 4 Pro, and photogrammetric processing was performed using Agisoft Metashape. A total of 16 mangrove trees were measured in the field to provide ground-truth reference data. Canopy height models (CHMs) were generated from both UAV datasets and compared to the field measurements. Preliminary results indicate that the 100-meter flight achieved higher accuracy, with a lower root mean square error (RMSE =21.2 cm), Mean Absolute Error (18.94 cm), and a higher coefficient of determination (R^2 = 0.97) compared to the 150-meter flight (43.3 cm, 35 cm, and 0.92, respectively). These findings underscore the significance of flight altitude in UAV-based assessments of forest structure and offer practical guidelines for optimizing data acquisition in future mangrove mapping applications.

1. INTRODUCTION

Mangrove forests are among the most productive and ecologically valuable coastal ecosystems (Odum and Heald, 1975). In southern Iran, these forests, dominated by *Avicennia marina*, play a crucial role in shoreline stabilization, carbon sequestration, and supporting biodiversity. Accurate mapping and monitoring of mangrove canopy structure, particularly tree height, is essential for understanding forest dynamics, estimating biomass, and evaluating restoration efforts (Karimi et al., 2025).

Recent advancements in Unmanned Aerial Vehicles (UAVs) have enabled high-resolution, low-cost, and repeatable remote sensing of vegetation (Kabiri, 2020). UAV-based photogrammetry provides detailed 3D reconstructions of forest canopies, which can be used to estimate tree heights with considerable accuracy (Dandois and Ellis, 2010; Puliti et al, 2019). However, the accuracy of derived canopy height models (CHMs) depends on various factors, one of the most critical of which is the flight altitude (Sadeghi and Sohrabi, 2019).

This study investigates the effect of UAV flight altitude on the accuracy of mangrove tree height estimation in the Melgonze forest of southern Iran. Two UAV missions were conducted over the mangrove forest of Melgonze, southern Iran, at flight altitudes of 100 meters and 150 meters, respectively. A set of ground-based tree height measurements was collected for validation purposes. By quantitatively comparing the photogrammetrically derived tree heights with field measurements, this research aims to identify the optimal flight altitude for precise mangrove canopy mapping and provide practical guidelines for future UAV-based ecological studies. The location of the study area is shown in Figure 1.

2. DATA AND METHODS

2.1 Study Area

The study was conducted in the mangrove forest of Melgonze, located along the northern coast of the Persian Gulf in southern Iran (Figure 1). The region is characterized by dense stands of *Avicennia marina*, with tree heights typically ranging from 2 to 5 meters (Kabiri and Abedi, 2025; Karimi et al., 2025). The site is ecologically significant due to its biodiversity and its role in coastal protection and carbon cycling. The sea surface temperature around the study area in the Persian Gulf fluctuates between approximately 15 °C during winter and 36 °C in summer (Kabiri et al., 2012).

Over recent decades, it has shown a gradual increasing trend, primarily attributed to global warming and broader climate change effects that are intensifying thermal stress in the region's coastal and marine ecosystems (Shabani et al., 2025).

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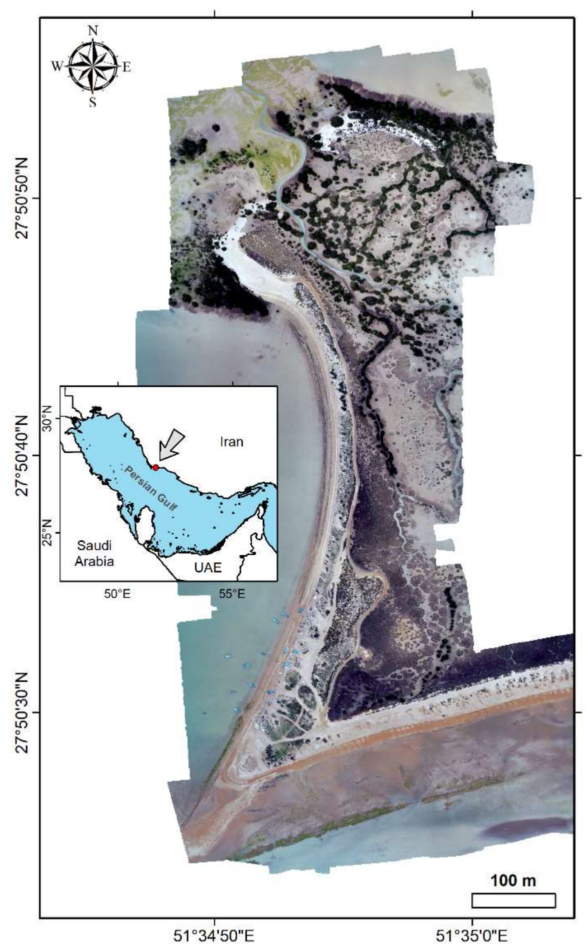


Figure 1. Location of the study area in the Melgonze mangrove forest, situated along the northern coast of the Persian Gulf in southern Iran. The map shows the extent of the UAV survey zone over *Avicennia marina* stands, overlaid on a high-resolution ortho-mosaic generated from drone imagery.

2.2 Research Workflow

A comprehensive flowchart depicting the entire methodological framework of this study is presented in Figure 2. The research was structured into three primary phases. The first phase involved field data collection, during which 16 representative mangrove trees were selected and their heights were measured to establish a ground truth dataset. The second phase encompassed UAV data acquisition and processing, where two separate flights were conducted at 100 meters and 150 meters altitudes following a standardized flight plan. The imagery from each flight was independently processed using Agisoft Metashape to generate Digital Surface Models (DSMs) and Digital Terrain Models (DTMs), from which Canopy Height Models (CHMs) were derived. In the final, integrative phase, the UAV-derived tree heights from both CHMs were extracted at the corresponding ground truth locations and compared against the field measurements. This comparison, quantified using Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and the coefficient of determination (R^2), formed the basis for identifying the optimal flight altitude for accurate mangrove canopy height estimation.

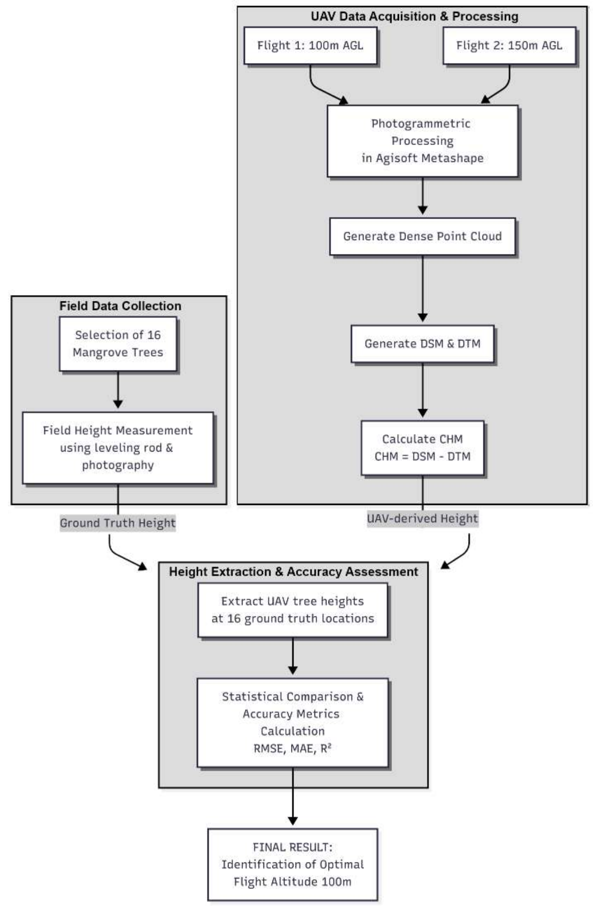


Figure 2. Flowchart of the methodology for evaluating UAV flight altitude effects on mangrove canopy height estimation. The process integrates field-based ground truthing with parallel photogrammetric processing of data from two flight altitudes (100 meters and 150 meters).

2.3 UAV Data Collection

A DJI Phantom 4 Pro quadcopter UAV was used to acquire aerial imagery during two separate flights conducted in February 2020 under sunny conditions to ensure optimal lighting and shadow minimization. The UAV is equipped with a 1-inch 20 MP CMOS sensor capable of capturing high-resolution RGB imagery.

Two flights were planned over approximately the same area using Pix4Dcapture mobile application:

- Flight 1: Altitude 100 meters above ground level (AGL)
- Flight 2: Altitude 150 meters AGL

Both flights followed similar flight plans with a front overlap of 80% and side overlap of 70% to ensure sufficient image coverage and 3D reconstruction quality.

2.4 Ground Reference Data

To validate the UAV-derived canopy height models, 16 mangrove trees of varying sizes were selected randomly within the flight area. The height of each tree was measured using a surveying levelling rod (mire). An operator stood adjacent to each tree, holding the mire while ground-level photographs were taken. The apparent height of each tree was then estimated from these photos by referencing the scale of the mire. The distribution of these ground control points is shown in Figure 3.

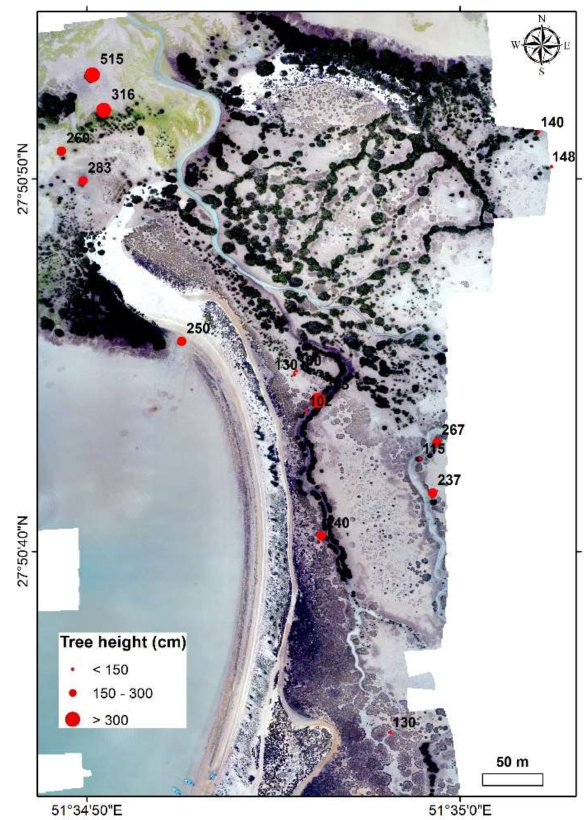


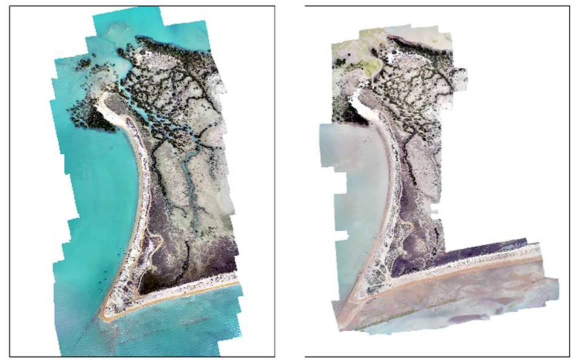
Figure 3. Spatial distribution of ground reference trees used for canopy height validation within the UAV survey area. Each point represents a tree for which height measurements were obtained using field-based methods

2.5 Image Processing and Canopy Height Estimation

Aerial images from both flights were processed using Agisoft Metashape Professional desktop software. The processing workflow included:

- Image alignment and sparse point cloud generation
- Dense point cloud creation
- Digital Surface Model (DSM) generation
- Ground classification and Digital Terrain Model (DTM) generation
- Canopy Height Model (CHM) = DSM – DTM

Two ortho-mosaics corresponding to each flight altitude were produced (Figure 4), along with their respective DSMs, DTMs, and CHMs (Figure 5). Tree heights at the 16 field-measured locations were extracted from the CHMs for both flights. The differences between estimated and actual heights were analysed using standard accuracy metrics including R^2, Mean Absolute Error (MAE), and Root Mean Square error (RMSE).



Orthomosaic 150m Orthomosaic 100m

Figure 4. Ortho-mosaic images generated from UAV flights at two altitudes (100 meters and 150 meters) over the Melgonze mangrove forest. The higher resolution of the 100-meter flight enhances canopy detail and feature clarity.

3. RESULTS

To evaluate the accuracy of UAV-derived tree height estimation, the results obtained from both flight altitudes (100 meters and 150 meters) were compared against field-measured tree heights across 16 reference points. Height values were extracted from the Canopy Height Models (CHMs) generated from each flight, and their correspondence with ground-truth measurements was statistically analysed.

Figure 4 shows the ortho-mosaics generated from the two flights, while Figure 5 presents the derived DSMs, DTMs, and CHMs. Visual inspection indicates that the dataset acquired at 100 meters yields finer texture and better canopy definition due to its smaller Ground Sampling Distance (GSD).

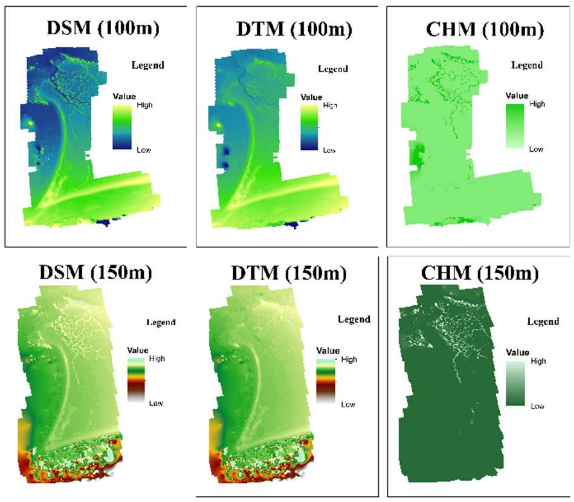


Figure 5. Digital Surface Models (DSMs), Digital Terrain Models (DTMs), and derived Canopy Height Models (CHMs) from UAV flights at 100 meters and 150 meters altitudes. The 100-meter data provide greater detail in canopy structure, reflecting the influence of flight altitude on 3D reconstruction quality.

The graphs depicting the differences between modelled and measured tree heights is shown in Figure 6, and the numerical accuracy metrics are summarized in Table 1.

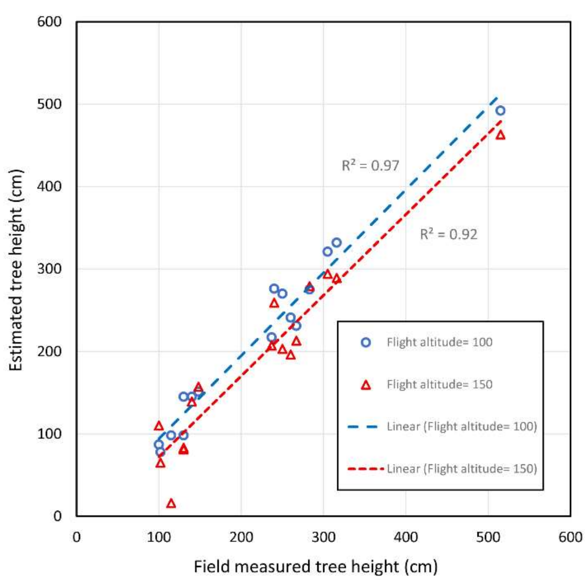


Figure 6. Comparison between field-measured and UAV-derived tree heights for two flight altitudes (100 meters and 150 meters). The graph illustrates the linear fit and correlation (R^2) for each dataset, highlighting higher accuracy in estimates from the 100-meter flight.

Flight Altitude (meters)	RMSE (cm)	MAE (cm)	R^2
100	21.2	18.94	0.97
150	43.3	35	0.92

Table 1. Summary of accuracy metrics for tree height estimation from UAV imagery at two flight altitudes.

The UAV data acquired at 100 meters underestimated tree heights across almost all samples, with the magnitude of underestimation being nearly equal to the MAE (21.2 cm). The results clearly indicate that the 100-meter flight altitude produced more accurate tree height estimates, with a lower RMSE (21.2 cm), a lower MAE (18.94 cm), and a higher R^2 value (0.97). In contrast, the dataset from the 150-meter flight exhibited larger deviations from ground truth, likely due to lower spatial resolution and reduced key-point density during photogrammetric processing. These findings support the hypothesis that lower flight altitudes enhance the reliability of UAV-based canopy height estimation in dense mangrove environments, albeit at the cost of increased flight time and data volume.

4. DISCUSSION

The results demonstrate a clear advantage of flying at lower altitudes for accurate mangrove canopy height estimation. The superior performance of the 100-meter flight can primarily be attributed to its higher image resolution and smaller Ground Sampling Distance (GSD), which enabled better feature extraction and more precise 3D reconstruction during photogrammetric processing.

In contrast, the dataset collected at 150 meters suffered from increased pixel size, which likely led to lower point cloud density and a reduced ability to capture fine-scale canopy structures. This reduction in detail contributes to underestimation or over-smoothing of tree tops, especially in dense or uneven mangrove stands.

The use of Structure-from-Motion (SfM) photogrammetry relies heavily on the detection and matching of distinct image features. At higher altitudes, image features become less distinct, resulting in fewer matched key-points and less reliable point clouds. This is particularly critical in mangrove environments, where overlapping canopies, shadows, and reflective water surfaces increase processing complexity.

Despite its advantages, the lower altitude flight at 100 meters also involves practical trade-offs. These include:

- Increased flight duration and number of images, leading to longer processing times
- Potential operational challenges in large or restricted areas
- Battery limitations, especially in humid and coastal climates

Nevertheless, the gains in vertical accuracy observed in this study support the use of lower altitude flights when the primary objective is the estimation of vegetation height. This finding is consistent with general recommendations in UAV-based forestry and ecological mapping, although the exact trade-offs may vary depending on site conditions, sensor characteristics, and required coverage area.

In future work, the findings of this study can be compared against similar studies conducted in other mangrove or forest environments, where varying flight altitudes have been tested. This will allow a broader generalization of optimal flight parameters for mangrove monitoring.

5. CONCLUSION

This study highlights the significance of UAV flight altitude in capturing accurate structural information from mangrove canopies. Our findings indicate that lower-altitude flights are more effective in generating detailed 3D representations of mangrove forests, resulting in more consistent and realistic height estimations. This improvement stems from enhanced image resolution and point-cloud density, which are crucial for resolving the complex textures and vertical variability typical of coastal vegetation.

Although lower-altitude flights may introduce logistical challenges—such as increased flight time, battery usage, and data volume—their advantages outweigh these constraints when the goal is to capture precise structural parameters. This is particularly relevant in mangrove environments, where subtle changes in canopy height can reflect ecological processes such as regeneration, degradation, or dieback.

From a practical perspective, these insights can inform the design of UAV surveys aimed at supporting coastal monitoring, blue carbon assessments, or habitat mapping. By prioritizing flight settings that maximize vertical accuracy, researchers and practitioners can improve the reliability of data products used in environmental decision-making.

Ultimately, this case study from the Melgonze mangrove forest underscores the importance of tailoring UAV mission parameters to the unique demands of ecological applications and reinforces the growing value of drone-based photogrammetry in the monitoring and management of sensitive coastal ecosystems.

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