

# TREE CANOPY HEIGHT ESTIMATION AND ACCURACY ANALYSIS BASED ON UAV REMOTE SENSING IMAGES

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## ABSTRACT:

The development of unmanned aerial vehicle (UAV) technology makes the traditional method of danger tree monitoring more digital and convenient. In order to explore the accuracy of tree height measurement by general consumer UAV, this paper takes a campus of University as the research area. The high-resolution images acquired by UAV were processed and compared the accuracy of extracting tree height based on the digital canopy height model (CHM) and point cloud information, respectively. The experimental results show that the mean absolute error of tree height based on point cloud extraction is 10.28cm, which is better than that based on CHM. The tree height extracted from CHM will be less than the measured height. In addition, the accuracy of extracting the height of round crown is better than that of cone crown. The correlation between the measured and true values of the two methods was 0.987 and 0.994, respectively, which indicates that the method of danger tree monitoring by UAV is feasible.

## 1. INTRODUCTION

The height of the vegetation canopy is an important indicator both in ecological terms and in terms of the safe operation of the transmission line. The height of trees will threaten the safe operation of power grids and cause accidents such as tripping and short circuits. Fast and accurate estimation of the height of trees in the transmission line can enable early detection of tree hazards, which is of great significance to ensure power supply (Zhou et al. 2019; Zeng et al. 2020).

At present, the methods of measuring tree height are mainly divided into traditional measurement and remote sensing inversion. Traditional methods mainly rely on altimeters or laser rangefinders to measure the height of trees. The working efficiency is low, and the quality of the instrument and human factors can affect the measurement accuracy (Xie et al. 2011; Huang et al. 2015; Yu et al. 2016). At this stage, there are several remote sensing techniques to invert the height of trees. Polarized interferometric synthetic aperture radar inversion technique (Pol-InSAR) is able to obtain vegetation canopy height over a large area, but it is still in the experimental stage, and the accuracy is not high in practical applications (Clould et al. 2017; Xie et al. 2017; Wu et al. 2016). Airborne lidar and the ground-based radar (GBR) can accurately extract the tree height, but the cost is high, and it will cost a lot in large-scale measurement (Vega et al. 2016; Sun et al. 2019). UAV have the advantages of low cost, easy operation and flexible acquisition cycle, and can acquire high-resolution images when equipped with optical sensors. It has been widely used in topographic mapping, agricultural production and other fields.

Many scholars have studied the use of UAV to measure tree height. Some scholars used UAV high-resolution images and ground data as the basis to build a canopy-tree height model to extract tree height (Liu et al. 2017; Li et al. 2009). He and others obtained forest resource information such as tree height,

3D coordinates, crown width and area by using UAV stereo photography technology (He et al. 2020). At present, tree height extraction using UAV is mainly divided into two methods: based on CHM model and point cloud extraction. Wang et al. used CHM to extract forest parameters such as number of trees, single tree height and canopy density, which shows that this method can replace manual measurement (Wang et al. 2019). The resolution of CHM and the size of the sliding window can affect the accuracy of tree height extraction (Liu et al. 2019). Some scholars use the maximum interclass variance method to split the tree point cloud into two parts, tree point cloud and ground point cloud, to obtain the tree height (Yang et al. 2017). It is difficult to obtain ground point cloud data in densely forested areas, but using total station to measure terrain data can effectively improve this problem and finally obtain more accurate tree height under high canopy density (Li et al. 2019).

In this paper, we used a general consumer-grade UAV to acquire high-resolution optical images of the forest area near a Campus of University. Based on the digital canopy height model and point cloud data, we calculated the height of some trees in the study area. We compared the tree height accuracy obtained by different methods, and analyzed the difference of extraction accuracy between different tree species.

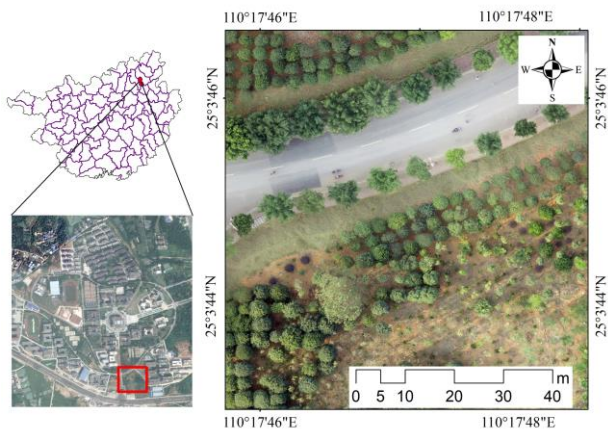
## 2. STUDY AREA AND DATA PREPARATION

### 2.1 Study Area

The study area is located near a Campus of University, which is situated in the northeastern part of Guangxi Zhuang Autonomous Region. It is in a low latitude (between 24°59' 52" and 25°14' 17" north latitude and 110°14' 46.31" and 110°29' 13.96" east longitude). It has a subtropical monsoon climate with abundant rainfall and mild climate. The vegetation

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in the study area is mainly planted with *Osmanthus fragrans* and *Ficus*.



**Figure 1.** The location of the study area. The red rectangle illustrates the coverage of study area.

## 2.2 Datasets

We measured the height of 50 trees in the study area in May 2021, mainly *Osmanthus fragrans* and *Ficus*. We measured the height of the trees using the remote elevation measurement (REM). We estimated the height of each tree by taking the mean of three height measurements using a total station. The measuring instrument was a Nikon total station ( $\pm(2+2\text{ppm}\times D)$  mm).

An off-the-shelf micro-quadcopter is chosen for this study, and the UAV model is DJI PHANTOM 4RTK. It is equipped with an RGB camera, and the main parameters are shown in Table 1. The weather conditions at the time of image acquisition were sunny and breezy. In order to generate sufficient point cloud density to improve the accuracy of tree height extraction, the flight height of the UAV was set to 80m, the heading overlap rate was 85%, and the side overlap rate was 75%. In addition, we used RTK to measure control point coordinates, which were used to improve the accuracy of post-processing of aerial survey data. A total of 378 images were taken for this experiment, with an aerial survey area of 0.062 square kilometers, and the image acquisition process took a total of 24 min.

| Parameter               | Value               |
|-------------------------|---------------------|
| Maximum flight speed    | 72km/h              |
| PTZ range               | -90° to +30°        |
| Camera lens             | FOV94°f/2.8         |
| Equivalent focal length | 20mm                |
| Effective pixel         | 12.4 million pixels |

**Table 1.** Detailed parameters of UAV.

## 3. METHODOLOGY

### 3.1 Data processing

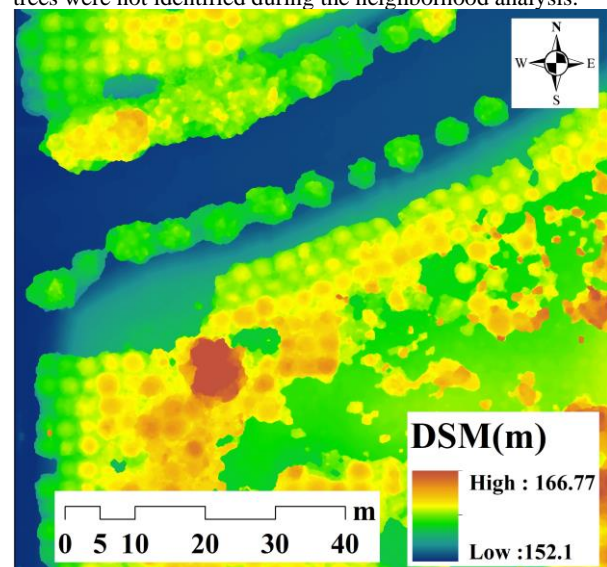
Due to the lack of information and geometric distortion of the image caused by factors such as light, wind deleted direction and air flow, we first checked the image and the unqualified image. We use Pix4D software to process the image. Firstly, we carry out matching correction and image correlation (called stabbing points) based on the coordinates of image control points. Next, aerial triangulation is carried out to finally obtain the 3D point cloud and 3D model with coordinates. In addition, the results of Pix4D processing include some 2D products, such

as digital surface model (DSM), digital elevation model (DEM) and orthophoto.

### 3.2 Extraction of tree height

**3.2.1 Tree height extraction based on CHM:** The extraction of tree height using CHM is mainly divided into two steps: the first step is to build the model, and the second step is to extract the height of tree vertices. CHM records information such as tree height and crown size. We obtained CHM by DSM (representing the change in tree surface height) from DEM (representing the change in ground height) in the study area. The resolution of CHM is 0.03cm/pix, and the model is shown in the figure below.

We use the neighborhood analysis tool in ArcMap software to analyze the neighborhood of CHM and get the tree vertices. Based on the characteristics of the tree canopy, we use a circular window for neighborhood analysis, and the window radius is determined after several tests based on the size of the tree canopy and the resolution of the CHM. We set the neighborhood radius size to 150 pixels and use the focus statistics tool to extract the maximum value in the neighborhood as the undetermined tree vertices. Next, we combine the orthophotos to remove the wrong "tree vertices" located on roads or buildings to get the tree height information in the study area. The extraction results are shown in Figure 5, where the red points are the tree vertices of the trees in the study area. Due to the different canopy sizes, the vertices of a small number of trees were not identified during the neighborhood analysis.



**Figure 2.** Digital surface model.



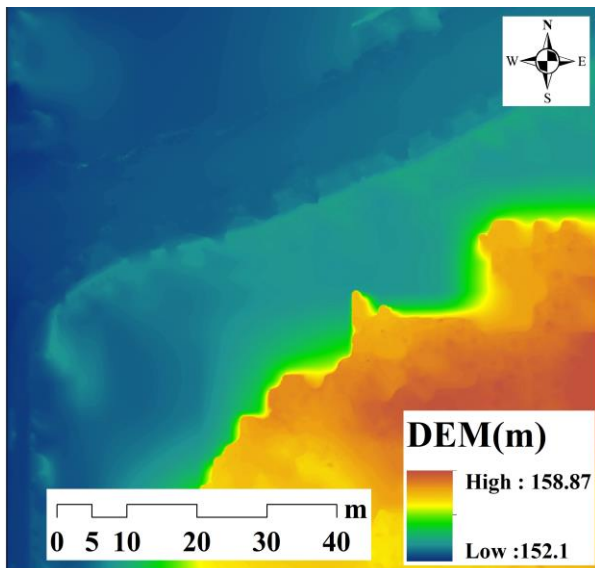


Figure 3. Digital elevation model.

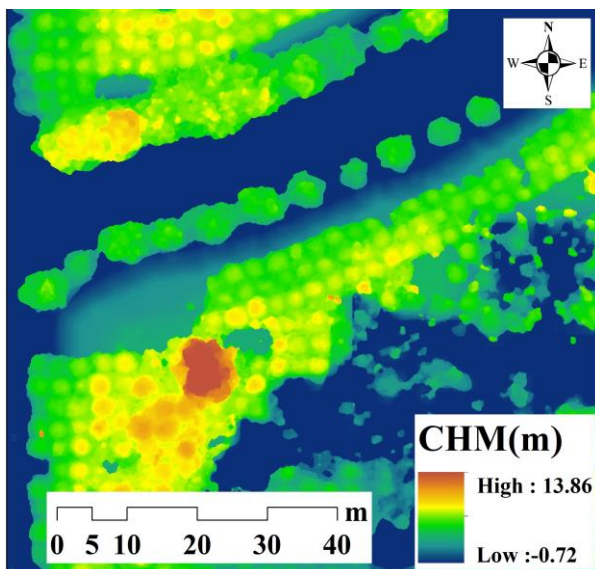


Figure 4. Digital canopy height model.

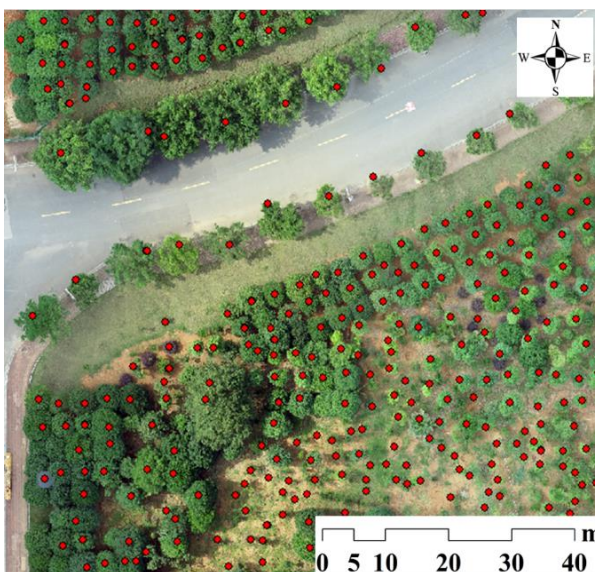


Figure 5. Extraction results of tree vertices.

**3.2.2 Tree height extraction based on point cloud:** After processing the images, we obtained about 47.36 million points in the study area, with a density of about 248.02 points/m<sup>3</sup>. The point clouds are of high quality and can be used as data for tree height extraction.

Firstly, we filter the 3D point cloud to prevent isolated noise points from affecting the extraction results. Next, we extract single wood point clouds, mainly including ground point clouds and vegetation point clouds, and exclude the interference of other trees as much as possible to prepare for the extraction of tree height. The point cloud extraction results for a single tree are shown in Figure 6 and Figure 7.

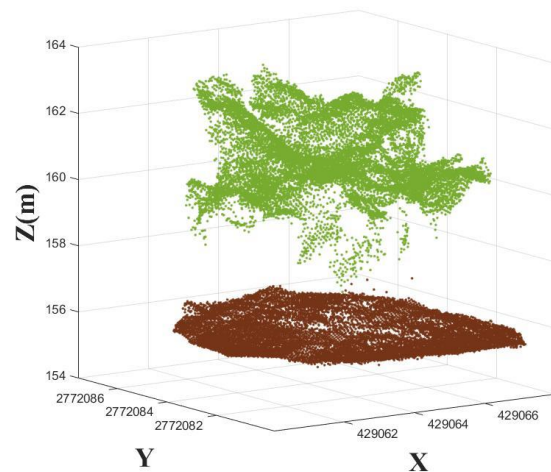


Figure 6. The results of point cloud



Figure 7. Ficus.

Based on the distribution of the number of point cloud height values, it is easy to divide the single wood point cloud into ground point cloud and vegetation point cloud. Because the terrain under the tree is relatively flat, we take the average elevation of the ground point cloud as the ground elevation, and then take the maximum elevation in the vegetation point cloud as the tree vertex. Finally, the subtraction of the two is the height of the target tree.

## 4. RESULT ANALYSIS

### 4.1 Extraction results based on CHM

We compare the tree height extracted by CHM with the tree height measured by total station, and calculate the correlation and mean absolute error between them. The calculation results are shown in Figure 8.

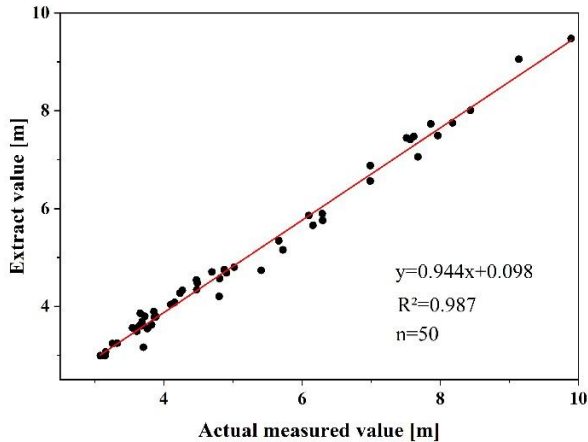


Figure 8. Correlation based on CHM.

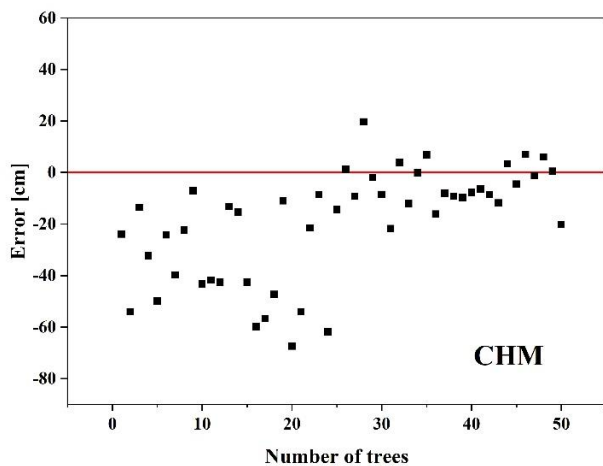


Figure 9. MAE of CHM.

The correlation between the tree height extracted based on CHM method and the actual measured tree height is 0.987, and the absolute value of the error between them is less than 80cm, of which the maximum absolute value of the error is 67.4cm and the minimum value is 0.1cm. The mean absolute error is 21.49cm, which shows that the height information of trees can be extracted well based on CHM.

By observing the distribution of absolute errors, it can be found that most of the measurement errors of trees are below 50cm, and the errors of only a few trees are above 60cm. The trees with the largest absolute errors are ficus. It is speculated that the main reason is that some points at the top of the tree are discarded in the process of generating DSM from point cloud, while the generated DEMs are large due to the large roots of ficus. Two reasons lead to the final tree height is lower than the real height.

### 4.2 Extraction results based on point cloud

The following are the results of a comparison and analysis of the tree heights obtained by point cloud extraction and the measured tree height:

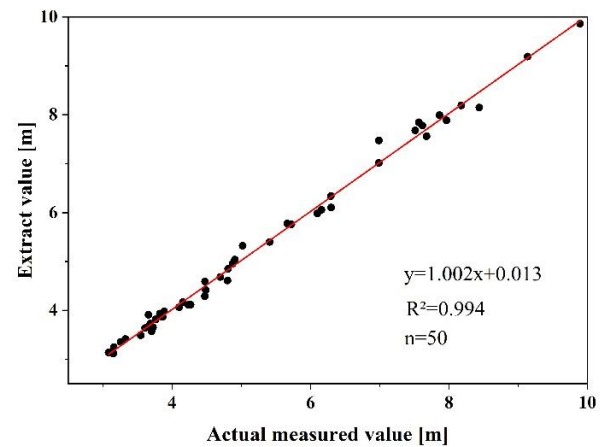


Figure 10. Correlation based on Point Cloud.

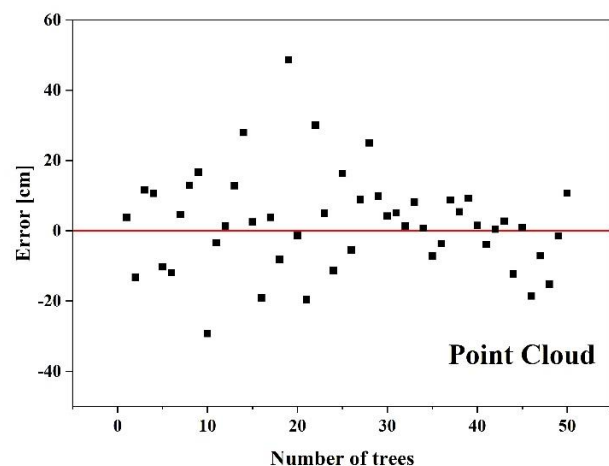


Figure 11. MAE of Point Cloud.

The correlation between the tree height extracted based on point cloud and the actual measured tree height is 0.994. The absolute error of tree height is less than 60cm, the maximum absolute error is 48.6cm, the minimum is 0.4cm, and the mean absolute error is 10.28cm. This result shows that the error of tree height based on point cloud extraction is smaller, which means it is better than the tree height obtained by CHM.

The analysis shows that the absolute errors based on point cloud extraction are less than 30cm, and only one tree has an error greater than 40cm. The reason may be that there are still isolated noise points in the point cloud after filtering.

### 4.3 Extraction results based on different tree species

In addition to the extraction method, the different types of trees will also affect the extraction accuracy. To verify the effect of tree type on the extraction results, we compared the extraction results of two major tree species in the study area, Osmanthus fragrans and Ficus, and calculated the correlation coefficients and mean absolute errors. The results are shown in Table 2.



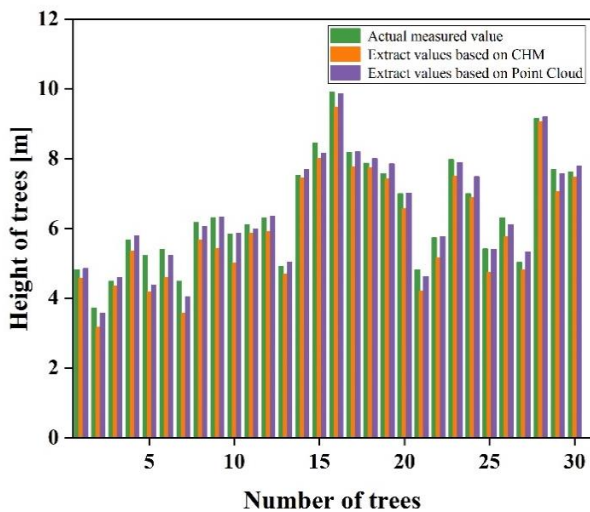


Figure 12. Comparison of Ficus height.

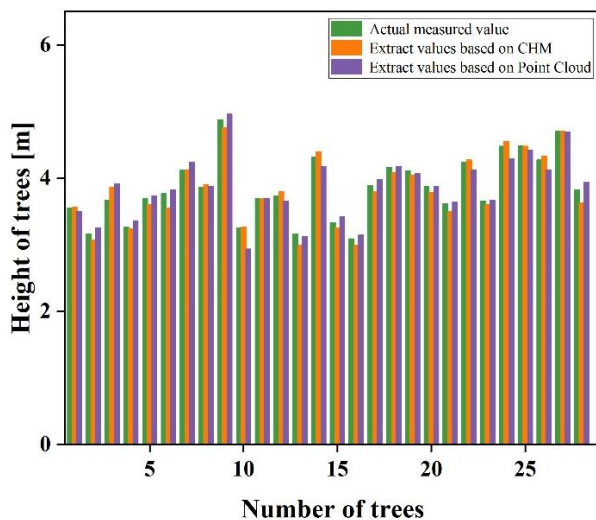


Figure 13. Comparison of Osmanthus fragrans height.

| Setting            |          | CHM            |      | Point cloud    |       |
|--------------------|----------|----------------|------|----------------|-------|
| Species            | Quantity | R <sup>2</sup> | MAE  | R <sup>2</sup> | MAE   |
| Ficus              | 25       | 0.986          | 34.7 | 0.987          | 13.45 |
| Osmanthus fragrans | 25       | 0.966          | 8.2  | 0.962          | 7.1   |

Table 2. Extraction results of different tree species.

The height value of ficus extracted based on CHM method is significantly lower than those obtained by point cloud extraction and the real tree height, and its mean absolute error is 34.7cm. The tree height extracted based on point cloud is close to the real tree height, with a mean absolute error of 13.45cm. There are two main reasons for the error. One is that the branches of the ficus are scattered and the crown is tapered, so some of the tree vertices are smoothed during the DSM generation resulting in a reduction of the extracted tree height values. On the other hand, the roots of some ficus grow on the ground, and the thick roots are mistakenly treated as the ground in the process of generating DEM, resulting in an increase in ground elevation. These two reasons lead to the low height values of trees extracted by CHM method.

Compared with ficus, the extracted tree height values of Osmanthus fragrans are significantly more accurate. The mean absolute error of tree height extracted by the two methods is

8.2cm and 7.1cm respectively. There is little difference between the height of Osmanthus fragrans extracted by the two methods and the real tree height. The crown of Osmanthus fragrans is relatively flat, so it is relatively easy to identify, while the crown of ficus grows around and the top is sharp and scattered, so it is not easy to identify. At the same time, some point clouds in the ficus are easy to be removed as isolated noise. The crown shape can affect the extraction of tree height. The extraction accuracy of tree height of tree species with flat and smooth crown is higher than that of tree species with sharp and scattered crown.

#### 4.4 Overall analysis

On the whole, both the CHM method and the point cloud method can extract the tree height accurately, and the latter has better extraction accuracy than the former. Different methods will affect the extraction results. The tree height extracted based on CHM method is slightly lower than the real value, which may be caused by the deletion of isolated tree vertices, and the tree height extracted based on point cloud is close to the real tree height. The extraction results of different tree species are also different. The extraction accuracy of tree height of flat crown is higher than that of conical crown. The correlation between the two methods is 0.987 and 0.994, indicating that using UAV for danger tree monitoring is feasible.

#### 5. CONCLUSIONS

In this paper, we extracted tree canopy heights using a general consumer UAV and analyzed the effects of tree species and different methods on the accuracy of tree height extraction. In general, the UAV can extract the tree height accurately, the maximum error of tree height in this experiment is 67.4cm, the minimum error value is 0.1cm, most of the error is less than 50cm. The tree height extracted from the point cloud is closest to the real value, and the mean absolute error is 10.28cm. The results show that it is feasible to use general consumer UAV for danger tree monitoring.

The crown shape can affect the extraction of tree height. The minimum mean absolute error of Osmanthus fragrans is 8.2cm, and the determination coefficient  $R^2$  between the extracted value and the real value is 0.966. The minimum mean absolute error of ficus is 13.45cm, and the determination coefficient  $R^2$  between the extracted value and the real value is 0.987. Compared with the tree species with sharp and scattered crown, the tree height extraction accuracy of tree species with flat and smooth crown is higher.

In addition to extracting tree height and canopy information, UAV can also establish a model to obtain tree characteristic factors such as canopy density, volume and density. Compared with traditional manual monitoring and lidar monitoring, UAV has the advantages of high speed and low cost, and can improve work efficiency. However, this technology still has disadvantages. Extracting the height of trees requires ground image information, but UAV can only collect the information of the top of trees in dense woods. Canopy occlusion will cause the loss of ground data and affect the extraction of tree height. In addition, UAV is dangerous to fly in the woods. As a result, more research is needed to determine how to better use UAV to monitor dangerous trees and improve measurement accuracy.

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