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Optimization of LAI estimation method based on smartphones with fisheye lens

Lichen Zhu, Peng Guan, Weiping Liu, Yili Zheng*
School of Technology, Beijing Forestry University,
Beijing 100083, P.R. China,
*corresponding author's email: zhengyili@bjfu.edu.cn

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Abstract—Leaf area index (LAI) is an important biological factor reflecting vegetation growth and forest ecosystem. LAI can be used to obtain plant health status, carbon cycle, and surrounding ecological environment effectively. In this study, the smartphone was equipped with a fisheye lens, and the optimization method was used to estimate LAI, which was compared with digital hemispherical photography (DHP) to investigate the possibility of the new method for LAI estimation. The hemispherical image was divided into blocks, and the optimized Otsu method was used for algorithm segmentation, which can effectively distinguish vegetation from the sky. Concurrently, when the gap fraction inversion LAI was performed, the linear inversion algorithm was improved based on single-angle inversion, and the LAI was obtained by inversion through the linear fitting of the mul-tiangle gap fraction. The experimental sample was located in Olympic National Forest Park in Beijing. Three coniferous mixed forests and three broadleaved forests were selected from the experimental sample. LAI measurements from smartphones were compared with those from DHP. In the samples for mixed coniferous forests, the values for coefficients of determination R^2 were 0.835, 0.802, and 0.809, and root mean square errors (REMS) were 0.137, 0.120, and 0.147. For the broadleaf forest samples, the values for R^2 were 0.629, 0.679, and 0.758, and REMS were 0.144, 0.135, and 0.137. The R^2 and RMES for the overall data was 0.810 and 0.134, respectively, and a good agreement between the LAI measurements from the proposed method and those from the DHP supports an accurate estimation. The results show that the use of a fisheye lens on a smartphone can effectively and accurately obtain tree canopy LAI. This provides a fast and effective new method to measure LAI of forest vegetation near the ground, which is of great significance for studying the interaction between plant growth status, ecological environment, and phenological changes.

Keywords—leaf area index; fisheye lens; Otsu; vegetation; Image processing; mixed coniferous forests; broadleaved forests

I. Introduction

In the context of global warming, the study of tree canopy is of great significance in understanding the changes in the forest ecological environment. The leaf area index (LAI) is an indispensable and important parameter in the tree canopy study, and hence an important factor in the model and function of forest ecological environment change. Measuring LAI can effectively calculate forest carbon sequestration efficiency, oxygen release rate, and the ability to conserve forest soil and water. Therefore, accurate and rapid measurement of LAI is of great significance for the study of the interaction between plants, the growth environment, and the global carbon cycle[1-3].

Currently, LAI measurement technologies can be divided into direct and indirect measurement methods. Direct measurement methods are difficult to apply to large-scale measurements because they require complicated manual operations and cause serious damage to vegetation; however, indirect measurement methods are estimated by measuring other variables, such as canopy clearance or transmitted radiation intensity, and have been widely developed because of its convenience, automation, and non-destructiveness[4,5]. Indirect measurement methods include a variety of methods, such as remote sensing and optical rituals. In the optical instrument method, digital hemispherical photography (DHP) uses a digital camera to take vertical images of the tree canopy, classify both the vegetation and the background (sky or soil) pixels in the image, and employ the gap ratio to estimate the LAI. With the reduction in the price of cameras, convenience, speed of operation, and increase in the number of DHP image processing software, which includes commercial software (such as HemiView and WinScanopy) and free software (such as CSN-EYE, CIMES, and GLA), DHP is widely used in LAI measurements of various vegetation types. However, when using DHP measurements, it is necessary to capture canopy images in the field and use a computer software for calculation. Thus, the LAI cannot be quickly obtained in the field, which limits the development of field measurement activity. Most equipment for measuring tree canopy parameters comes with high prices and complex operations. The relevant equipment technology is immature, and the few available technologies cannot meet the needs of the current situation of large-scale forest ecological samples[6-8].

With the development of smartphones, replacing cameras with portable LAI measuring instruments has gradually become an important supplement and aalternativetool for commercial instruments. In recent years, many scholars have researched the measurement of LAI using smartphones. In 2013 Confalonieri et al. proposed an application to measure LAI using two methods to measure tree canopy LAI from a smartphone[9]. In 2015, Patrignani et al. designed an application to obtain tree ccanopygap fraction on smartphones, and users can then obtain LAI through gap fraction inversion[10]. In 2016 De et al. studied the estimation of vine canopy LAI through smartphones or tablet computers. Bauer et al. proposed a method to measure LAI through smartphones[11]. In 2018, Wang et al. used a smartphone with a fisheye lens to capture tree canopy images and analyzed the data indoors through a computer to obtain the LAI[12]. In 2020 Qu et al. designed a new LAI measurement program for smartphones[13]. At present, the shooting and computing of smartphones are mostly separated from each other, and the original smartphone lens is used to obtain images simultaneously, so this study uses a fisheye lens with a smartphone to capture images and improve the algorithm to achieve a fast and accurate calculation of LAI.

In this study, to overcome the limitations of field measurement and obtain the LAI of the forest canopy quickly and accurately, the traditional leaf area index measurement method was further improved, and a smartphone was used to measure LAI, which provides a new method to obtain near-ground tree canopy LAI by simultaneously taking photos and processing images; this is considering that the method of measuring LAI by DHP is similar to the method of obtaining LAI by a fisheye lens on smartphones. Through quantitative analysis and comparison of the difference between the LAI obtained using DHP and a smartphone, we investigated whether the LAI obtained by the smartphone could be used to replace the DHP. This study provides a strong basis for the study of ecological indicators in the ecological environment and has important research significance for the development of all-round and multi-angle protection of forest resources.

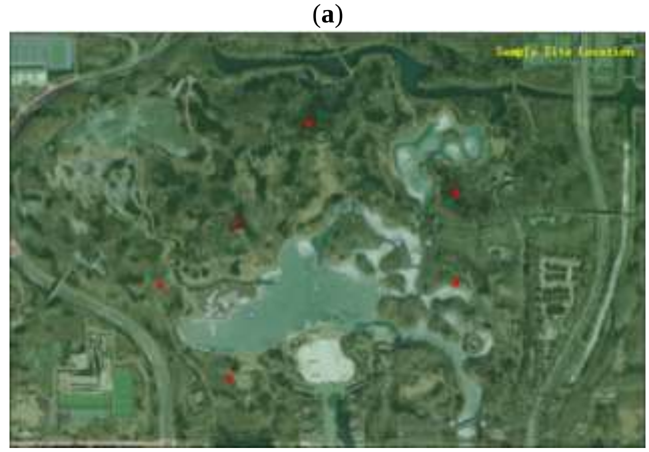
II. Materials and Methods

A. Profile of the Study Area

Olympic National Forest Park is located in Beijing, China(116°23 '2.98 "E, 40°01' 3.00" N) and covers an area of 380 hectares with rich tree resources, including mixed coniferous and broad-leaved forests, and the site is open and well-lit. The field is a temperate continental subhumid monsoon climate, with four distinct seasons, and precipitation concentration. The average annual temperature is 10-12 degrees Celsius, with July being the hottest with an average temperature of 27.5 degrees Celsius and average annual precipitation of 600 millimeters in figure 1.

After on-site inspection and analysis, 6 sample plots were selected as the experi-mental shooting sampling area and divided into 3 coniferous and broad-leaved mixed forests and 3 broad-leaved forests according to classification as table 1. Randomly se-lected 25 ideal plots in different areas as measurement areas, used a single-lens reflex camera to capture digital images of tree canopies for DHP analysis in each plot, and used smartphones with fisheye lenses to capture tree canopy images.

(**a**)



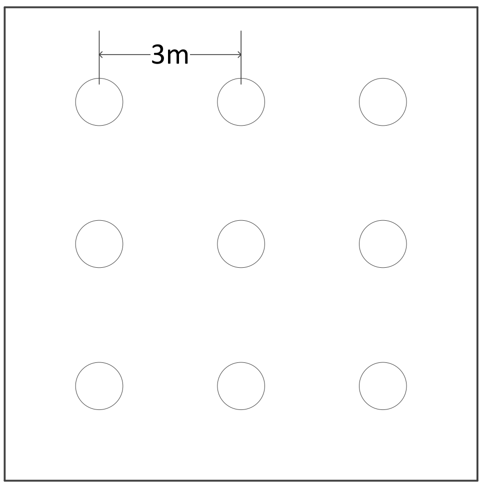
(**b**)

Fig. 1 Satellite photos of the study location and Forest

B. data source

When using a smartphone with a fisheye lens to measure LAI, use the selfie stick to extend the smartphone horizontally to ensure that the front camera is up and vertical to shoot, and keep the measurement heights as about 1 meter, and at the same time to prevent the horizontal plane of the smartphone from being too low to cause the portrait to enter the picture, as shown in Figure 2a. The fisheye lens used the Yum Wind Proud, with a 180° viewing angle and a double-layer coating. When taking photos, chose between 10:00 a.m. and 2:00 p.m. for measurement to avoid measurement errors caused by insufficient light. During shooting, avoided direct sunlight to reduce the light spot on the image caused by sunlight to affect the measurement results. After taking the image, run the program to calculate LAI, and saved the measurement results locally on the smartphone for subsequent calculation and processing. When shooting in each plot, nine locations 3 meters apart were selected as the shooting sites, and each plot was measured 9 times, and the average value was selected as the final measurement result, as shown in Figure 2b.

(**a**)



(**b**)

Fig. 2 Schematic diagram of the sampling method within the quadrat and Physical display

When using a camera to measure LAI, it should be ensured that the synchronous measurement, point position and the measurement heights of the DHP and smartphone measurements are consistent. The selected camera model is Canon EOS Kiss X3, the image saving format is JPG, and the image size is 3456 pixels × 2302 pixels. To ensure that the image is not distorted, the lens should be shot vertically upwards when shooting and paid attention to avoid direct sunlight on the lens causing light spots to affect the measurement results.

Used the CAN-EYE V6.4.91 software to process the acquired DHP images, set the analysis parameters according to the software documentation, set the resolution of the zenith angle and azimuth angle to 2.5°, and set the image size and other related parameters[6]. Run the software to batch calculate the pictures, got the LAI, and stored them locally on the computer.

C. Image segmentation

The effective area of the image captured by the fisheye lens is a circle. To calculate LAI, it is necessary to extract the effective area of the image to perform the next calculation. Therefore, obtaining the effective area in a circular image is the primary premise for calculating and studying the LAI[14,15].

The commonly used methods for obtaining circular regions are area statistics, scan-line approximation, and boundary fitting. Among them, the area statistics method is suitable for situations in which the gray values inside and outside the area have a large difference; therefore, there are more restrictions in use. The scanning line approximation method scans from the four directions of up, down, left, and right to the center and determines the boundaries in the four directions through the threshold value. Ideally, a circumscribed square is obtained from which the center and radius are obtained. Practically, it is often impossible to obtain a standard square, and the size of the threshold has a certain influence on the result; in the case of a large image, this will lead to a large amount of calculation. The boundary fitting method uses the Hough transform to solve the coordinates of the center of the circle, and the duality of points and lines to linearly transform the image space into the parameter space. The clustered points in the parameter space correspond to the center of the circle in the image space, thereby solving the circular area. The circular area solved by the Hough transform has high accuracy but takes more time to calculate. Comparing the method and the current application scenario, the circular area can be quickly obtained on the premise of maintaining accuracy, and the scan line approximation method is suitable for outdoor measurement using smartphones[16,17].

D. Binary image

Image binarization refers to dividing the obtained circular-effective area into the foreground and background vegetation and the background sky, and then calculating the proportion of the foreground and background to obtain the gap fraction of the tree canopy. Reasonable and correct division of foreground and background is the key to accurately obtaining gap fraction values[18,19].

Considering the time cost, this study used the threshold segmentation method to quickly measure and obtain the final result. First, the circular effective area was sepa-rated by R, G, and B channels, and the blue channel which is sensitive to green vegeta-tion and blue sky was selected as the target[20]. The threshold segmentation method was used to segment the foreground and background. Commonly used threshold seg-mentation methods include the fixed threshold algorithm, Otsu, and adaptive thresh-old methods. Among them, the fixed threshold is subject to a large difference in subjec-tive influence. The Otsu method, also known as the maximum interclass variance method, was first proposed by the Japanese scholar Otsu in 1979[21]. Using the histo-gram of the image, the optimal threshold is calculated to maximize the inter-class variance to segment the foreground and background of the image. The interclass variance is defined as follows:

$$\sigma_B^2 = \omega_0\omega_1(u_0 - u_1)^2 \tag{1}$$

where $\omega_0$is the proportion of pixels contained in the first category under threshold T segmentation, ω_1 is the proportion of pixels contained in the second category, u_0 is the average gray value of the pixels of the first type, and u_1 is the average gray value of the pixels of the second type. When T traverses all grayscale values from zero to 255, the interclass variance σ^2 can reach the maximum value, and the threshold T at this time is the best threshold for segmentation. The adaptive thresholding method requires dividing the image into many small areas and then performing threshold segmentation in each area. This method requires a lot of computation, is time-consuming, and hence is unsuitable for quickly obtaining tree canopy LAI outdoors[22,23].

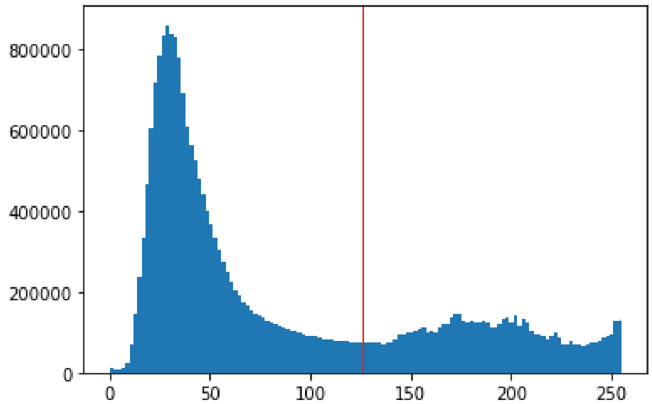


Fig. 3 Histogram of the effective region

Considering several algorithms and their actual effects, this algorithm was improved based on the Otsu method. Tree canopy images are mainly divided into a blue-sky background and green-vegetation foreground. There were two peaks before and after the histogram, and the threshold calculated by the Otsu method was between the two peaks. Therefore, when performing the optimal threshold iteration, iterating from the foreground to the background wave peaks could be considered, thereby reducing the amount of computation.

Gap fraction is the proportion of bright voids in the middle of the tree to the total area. The hemispherical image under the fisheye lens is expressed as the ratio of the background image pixels to the pixels in the circular effective area[24]:

$$P(\theta) = \frac{C_0(\theta)}{C_0(\theta)+C_1(\theta)} \tag{2}$$

where P(θ) represents the canopy gap fraction when the zenith angle is θ, $C_0(\theta)$ and$C_1(\theta)$ represent the number of pixels in the background and foreground, respectively, when the zenith angle is θ[25].

E. Leaf area index inversion

The Beer–Lambert law can describe the relationship of light absorption with material concentration and thickness [26], When the inter-canopy medium is uni-formly chaotic, its mathematical model is:

$$\frac{I_t}{I_0} = e^{-K \cdot LAI} \tag{3}$$

where I_0 and I_t are the light radiation intensity above and below the canopy, respectively, and I_t/I_0 is the canopy gap fraction P, LAI is the leaf area index of the plant canopy, and K is the extinction coefficient related to the incident light angle, that is, the zenith angle θ and leaf inclination angle α.

The relationship between the extinction coefficient and zenith angle leaf inclination is as follows [27,28]:

$$K(\theta,\varphi) = G(\theta,\varphi)/cos\theta \tag{4}$$

where G(θ,φ)is the blade projection function, and φ represents the azimuth angle. If the distribution of the leaves is assumed to be an elliptical random distribution, the leaf projection function G(θ,φ) can be expressed by the following formula:

$$G(\theta) = \frac{(x^2+tan^2\theta)^{1/2}cos\theta}{x+(sin^{-1}\varepsilon_1)\varepsilon_1}, x \le 1$$
$$G(\theta) = \frac{(x^2+tan^2\theta)^{1/2}cos\theta}{x+\frac{1}{2\varepsilon_2 x}\ln[(1+\varepsilon_2)/(1-\varepsilon_2)]}, x > 1 \tag{5}$$

Where $\varepsilon_1 = (1-x^2)^{1/2}$, $\varepsilon_2 = (1-x^{-2})^{1/2}$, and x represents the ratio of the major axis to the minor axis of the ellipse model x represents the ratio of b to the area of the ellipse model, which reflects the change in the average blade inclination angle of the blade, expressed as follows[29]:

$$x = -3 + (\overline{\alpha}/9.65)^{-0.6061} \tag{6}$$

Combined with Equations 3 and 4, it is assumed that the leaves are randomly distributed and the optical medium is uniformly distributed in the canopy. According to Miller's research, the relationship between the leaf area index and gap fraction is:

$$LAI = 2\int_0^{\pi/2} ln\frac{1c}{P(\theta)} cos\theta csin\theta d\theta \tag{7}$$

Rewrite the expression in differential form

$$LAI = 2\sum_{i=0}^{n} ln\frac{1}{P(\theta_i)} cos\theta_i sin\theta_i \, \Delta\theta \tag{8}$$

where n is the number of divided concentric circles and each variable corresponds to the corresponding concentric circle, where Δθ=π/2n.

Based on Equations 5 and 6, the projection relationship between the blade projection function and zenith angle under different blade inclination angles is obtained, as shown in Figure 4.

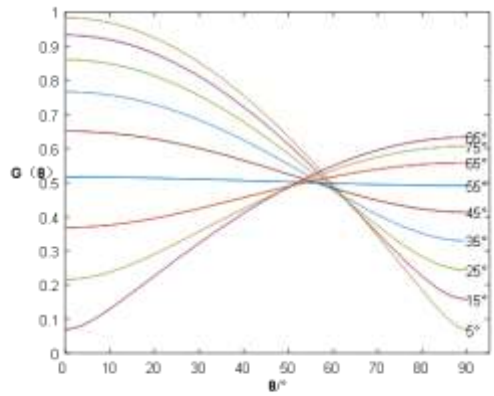


Fig. 4 Relationship between blade projection function and blade inclination angle

The single-angle inversion method was used to obtain the LAI according to the characteristics of the image [30,31]. Observing the image curve, it is found that when the sun angle, that is, the zenith angle, is 57.5°, the projection function values under different leaf inclination angles converge at 0.5, and the following formula is obtained:

$$\mathrm{LAI} = \frac{-\ln P(57.5°)\cos(57.5°)}{0.5} \tag{9}$$

Based on the single-angle inversion, it can be found that the function curve approximates a straight line when the top angle of the sun is between 20° and 60°, and different blade inclination angles correspond to different straight line slopes. Therefore, the relationship between the average leaf inclination angle $\overline{\alpha}$ and slope S of the fitted straight line can be calculated by the fitting function as follows:

$$\overline{\alpha} = 56.63 + 2.52 \times 10^3 S - 141.47 \times 10^{-3} S^2 \tag{10}$$

The corresponding G(θ) was obtained from the gap fraction between 20° and 60° of the zenith angle, and the corresponding slope of the straight line was obtained by fitting a straight line using the least-squares method to obtain the average leaf inclination angle of the plot. Using the functional relationship between the blade projection function and the blade inclination angle, the LAI was obtained by inversion.

Compared with the single-angle inversion method, which only inverts the LAI through a single angle, the improved line fitting algorithm uses more information elements in the image. Further, it avoids the over-bright area in the center of the image and the dark area at the edge of the image, making the obtained data more ready and reliable. Based on the LAI obtained by inversion, the linear fitting method obtained the average leaf inclination angle of the plot through the simultaneous linear fitting.

F. data analysis method

The data obtained by using DHP and the LAI method are compared point-to-point, and the scatter plot can effectively and intuitively reflect whether there is good consistency between the two. A linear regression model was used to quantitatively compare the differences and correlations between the two, and the closer the fitting result was to a 1:1 straight line, the higher the consistency between the two. The reliability of the linear simulation results is expressed by calculating the coefficient of determination (R^2) of the scatter plot data, and the root mean squared error (RMES) indicates the degree of deviation between DPH and LAI. The formula for calculating R^2 and RMES is:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \overline{y})^2} \tag{11}$$

$$\mathrm{RMES} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}} \tag{12}$$

where $\hat{y}_i$ and y_i represent the measured values using LAI and DHP, respectively, $\overline{y}$ represents the average value of DHP measured values, and n represents the overall number of measured data[32].

III. Results

A. Threshold segmentation method

The traditional Otsu method threshold segmentation segmented the entire target circular area as a whole, but in the canopy image captured by the actual fisheye lens, the zenith angle of 0° meant that the center of the image was located in the central ar-ea of the field of view, and the illumination the brightness was strong, while at the edge of the fisheye image when the zenith angle is large, the image was darker. There-fore, thresholding the entire image would cause errors. According to the requirements of LAI inversion, the corresponding gap fraction needed to be obtained according to different zenith angles. The circular effective area could be divided into rings, and threshold segmentation was performed in each ring area to perform image binariza-tion. It should be noted that at different azimuths, the distribution of the canopy might not be uniform, and there was an uneven distribution of sky pixels at different azimuth angles under the same ring. the segmentation of different azimuth angles was per-formed in the same ring to further ensure the reliability of the threshold segmentation. Considering that the algorithm should be able to perform a fast calculation on the smartphone, the zenith angle and azimuth angle step size of the segmentation should not be too small, which will lead to a long calculation time. The final segmented block is shown in Figure5.

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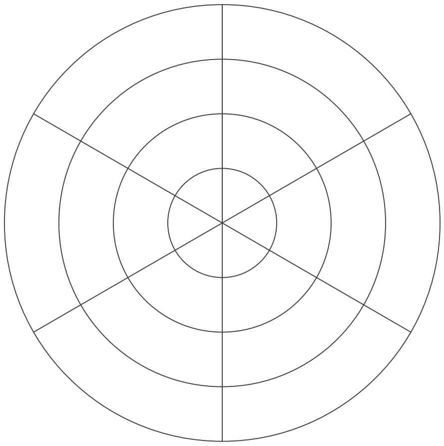
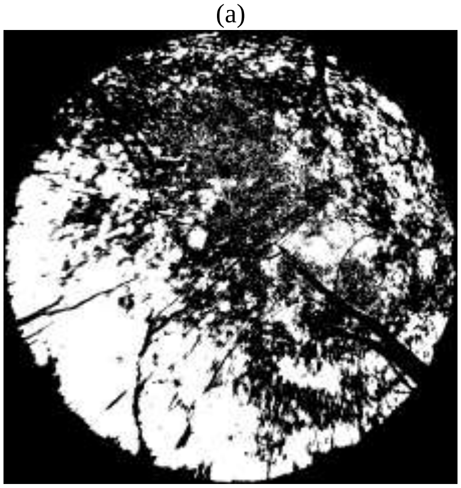


Fig. 5 Schematic diagram of the division of the graphics area

The effect of the optimized Otsu method is shown in Figure 6, in which Figure 6-a is the original image, Figure 6-b is the effect after segmentation using the traditional Otsu method, and Figure 6-c is the optimized Otsu method. It can be seen that after the algorithm's improvement and recalculation, many vegetation pixels that were mistakenly classified as sky pixels were correctly identified again. It shows that the improved algorithm is superior to the traditional Otsu method, which can ensure the acquisition of more accurate canopy gap fraction and provide reliable data for the next inversion.

(a)



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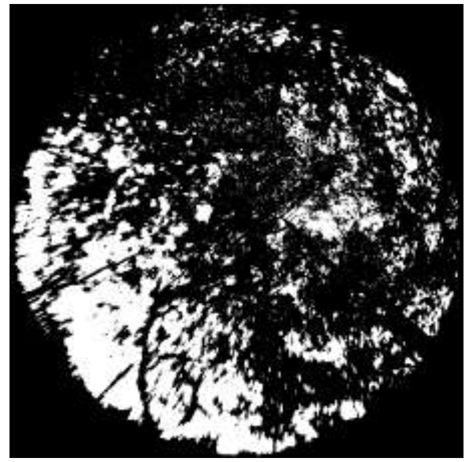
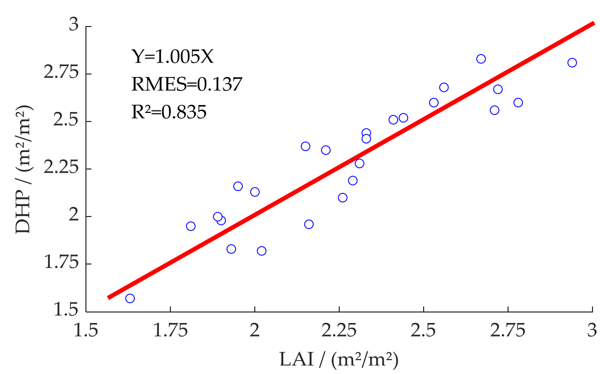


(c)

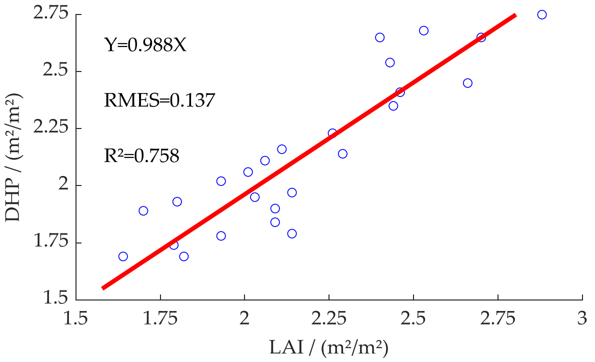
Fig. 6 Schematic diagram of the division of the graphics area, (a) Original Image, (b) Traditional Otsu method segmentation map, (c) Optimized Otsu method segmentation map

B. data analysis

The relationship between DHP and smartphone LAI measurement values was represented by a scatter plot. Figure 7-a, Figure 7-b, and Figure 7-c showed the meas-ured data and linear regression line at the mixed coniferous forests sites, Fig. 7-d, Fig. 7-e, Fig. 7-f were the data and linear regression line obtained by photographing the broadleaf forests sites. The scatter data of mixed coniferous forests and broadleaf for-ests were mostly evenly distributed around the 1:1 line, which indicates that there is no significant difference between the measurements obtained by DHP calculation and those obtained by using a smartphone with a fisheye lens. In the regression index, the REMS are both about 0.13m²/m², which indicates that the DHP and the optimized Otsu straight-line inversion method have good consistency in the statistical relationship, The R^2 were 0.835, 0.802 and 0.809 in the three groups of mixed coniferous forests data, and 0.629, 0.679 and 0.758 in the three groups of broadleaf forests, which is consistent with other experimental results obtained by indirect methods to obtain LAI.



(a)



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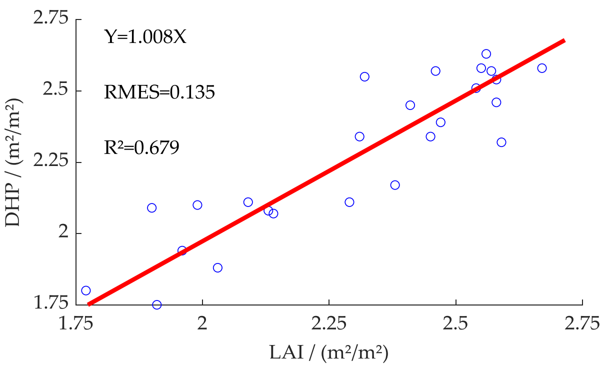

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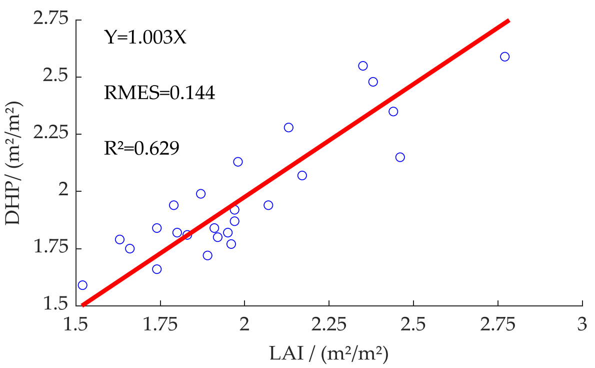
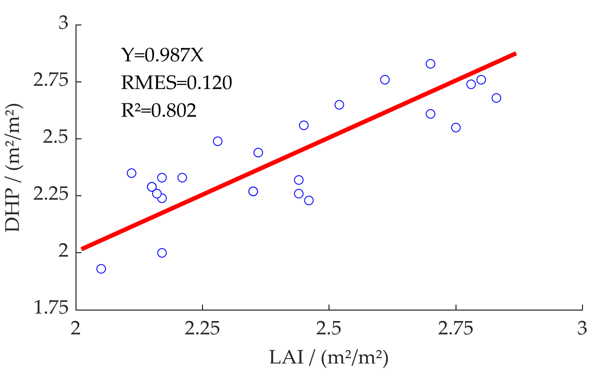


(d)



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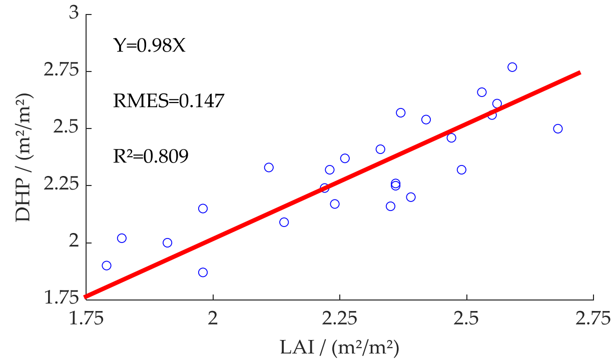


(f)

Fig. 7 LAI Scatter Comparison Chart, (a, b, c) Coniferous and broad-leaved mixed forest plot, (d, e, f) Broadleaf forest plot

The overall data is shown in Figure 8, the slope of the fitted line is close to 1.0, the RMES is 0.134, and the R^2 is 0.810. The measurement results of DHP are almost the same as those of the optimized Otsu method and the straight-line inversion method.

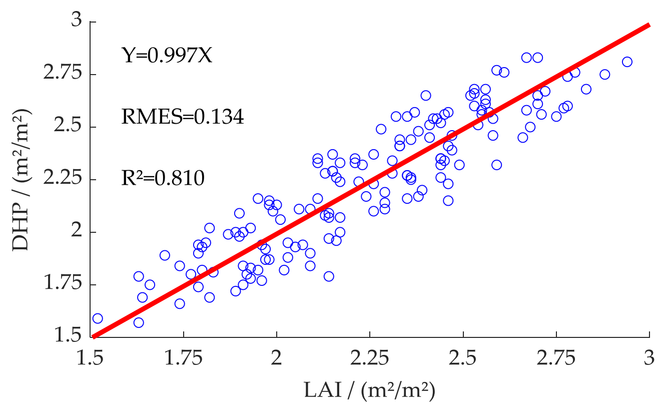
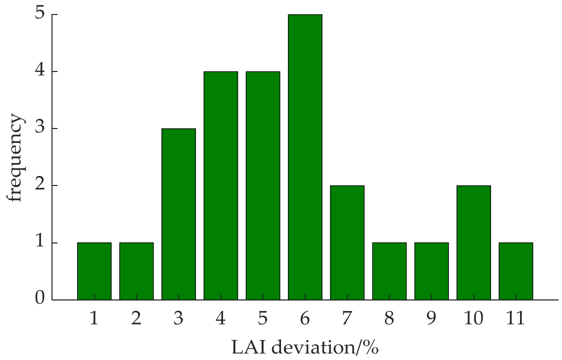
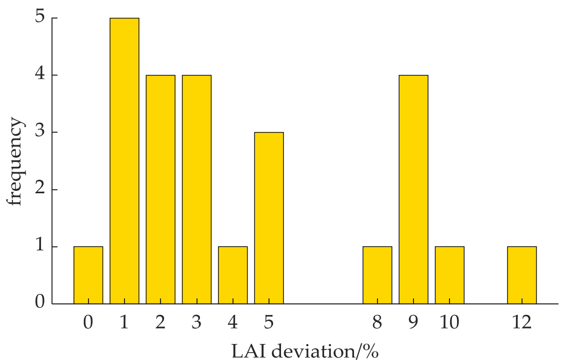


Fig. 8 Overall data comparison chart

In figure9, a, b and c represent sample 1, 2, and 3 respectively, and d, e, and f rep-resent sample 4, 5, and 6. The first three of them are mixed coniferous forest plots, and the last three are broadleaf forest plots. The data obtained through DHP is seen as the true value of LAI, and the deviation rate between LAI, which is obtained by using a smartphone with a fish eye, and the true value of LAI is calculated. It can be known that there are differences in the deviation distribution of different plots under different vegetation types, but the overall deviation rate is distributed below 10%. The data showed that there is little difference between the LAI obtained by the improved meth-od with a fisheye lens on the smartphone and the LAI obtained by DHP.



(a)



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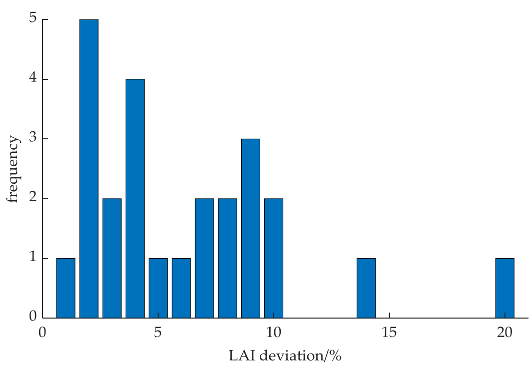

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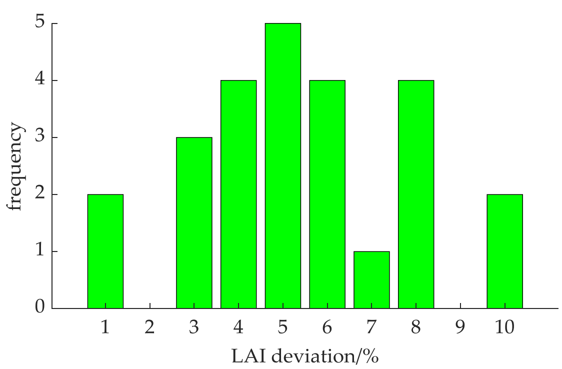

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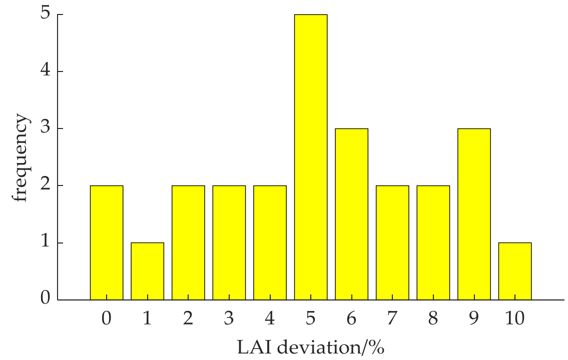

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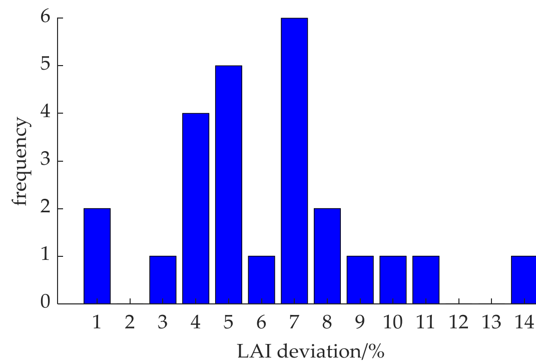
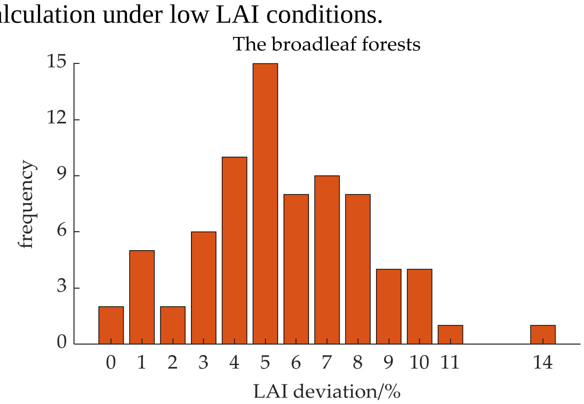


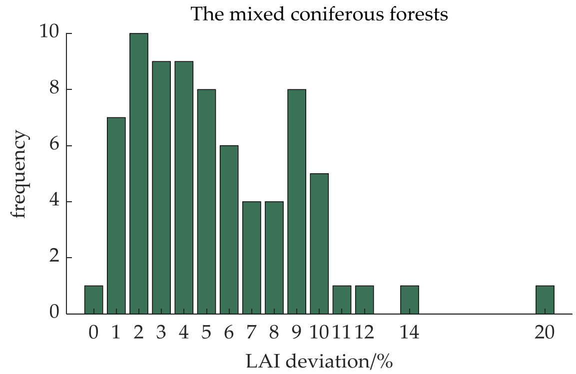
(f)

Fig. 9 Frequency of LAI deviation rate. (a)sample1; (b)sample2;; (c)sample3; (d)sample4; (e)sample5; (f)sample6

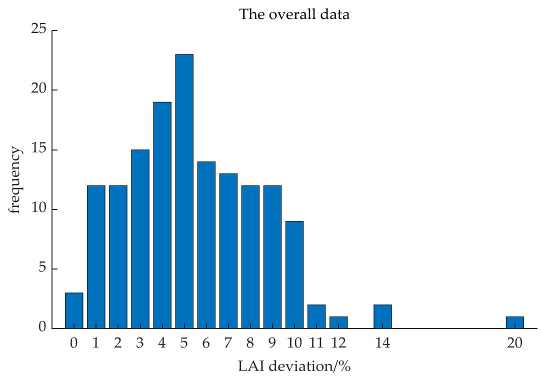
In figure 10, where 10-a is the frequency of the LAI deviation rate of the broadleaf forests, 10 -b is the frequency of the LAI deviation rate of the mixed coniferous forests, and 10-c is the frequency of the LAI deviation rate of overall data. In the broadleaf forests, the LAI deviation rate was concentrated around 5%, and in the mixed conifer-ous forests, the LAI deviation rate was uniformly distributed below 10%. By comparing the LAI deviation rates of mixed coniferous forests and broadleaf forests, it can be con-cluded that the LAI deviation of mixed coniferous forests is less than that of broadleaf forests on the whole. The LAI value obtained in broadleaf forests is larger than that obtained in mixed coniferous forests. Therefore, when the LAI value is larger, the LAI deviation rate is higher. The improved algorithm by using a smartphone with a fisheye lens is more suitable for LAI calculation under low LAI conditions.



(a)



(b)



(c)

Fig. 10 Frequency of LAI deviation rate for mixed forest, broadleaf forest and overall data

IV. Discussion

A. Comparison of estimated LAI methods

Estimating LAI first required obtaining the gap fraction of the tree canopy and obtaining LAI through gap fraction inversion. The commonly used method for obtaining gap fraction was to perform the calculation after the threshold segmentation of the image was performed. The Otsu method is a typical threshold segmentation method. By performing Otsu segmentation on the hemisphere image, the result obtained was the best threshold for the overall image, but at different zenith and azimuth angles, the distribution of the tree canopy might not be uniform, which might lead to different regions in the hemisphere image a segmentation error occurs, which meant that the segmentation threshold might be higher or lower. The Otsu method is further optimized in this study, and the optimal threshold is obtained by dividing different zenith angle and azimuth angle regions to calculate the optimal threshold, which ensures the accuracy of the segmentation results. Considering the method of estimating the LAI, which needs linear fitting of the gap fraction under different zenith angles, the optimized Otsu method can perfectly adapt to the subsequent calculation[33-35].

The method of inversion of LAI can obtain the method of single-angle inversion through the characteristics of the projection function G, which can be found in the projection function G converges to 0.5 when the apex angle of the sun is 57.5°. The straight-line fitting inversion method, which was based on the single-angle inversion method, uses the characteristic that the projection function G approximates a straight line when the zenith angle is between 20° and 60°, and the LAI is obtained by inversion through the slope of different straight lines corresponding to different average leaf inclination angles. Compared with the single-angle inversion method, the straight-line fitting method selects gap fraction data between 20° and 60°. On the one hand, this requires threshold segmentation under different zenith angles to achieve well results, on the other hand, more image information is used to make the obtained data results more reliable, and the average leaf inclination angle of the tree canopy is preliminarily predicted. Therefore, the straight-line fitting inversion method is better than the single-angle fitting method[36-39].

B. Choice of comparison equipment

Currently, the research on LAI generally chose the LAI-2000 measuring instrument as the comparison object but rarely chose DHP as the comparison object. The LAI-2000 measuring instrument measures LAI through radiation parameters. It is currently recognized as the most accurate instrument for measuring LAI. Therefore, many studies on LAI use LAI-2000 as the experimental comparison object. The DHP measurement method generally uses a camera to obtain the canopy image upward or downward and then uses the corresponding software to calculate the LAI. CAN_EYE is a software with high accuracy to obtain the LAI through the canopy image calculation. Compared with LAI-2000, the measurement method of DHP is similar to the principle of using a smartphone with a fisheye lens to measure LAI in this paper, while many current studies on LAI mostly use LAI-2000 as a comparison object, and rarely use DHP as a reference[40-43].

Compared with LAI-2000, it is simpler and faster to use DHP as the comparative experimental equipment for LAI measurement. As a professional LAI measurement tool, LAI-2000 has the problem of being expensive and inconvenient to carry. To measure LAI using DHP, it is only necessary to carry an SLR camera for shooting and ensure that the tree canopy is photographed vertically under sufficient light. A large number of images acquired by an SLR camera need to be calculated by computer soft-ware, commonly used software includes CAN_EYE, CIMES, and GLA. Different pack-ages containing different algorithms to estimate LAI, through contrast can be obtained using CAN_EYE is a good choice. The P57 algorithm in CAN_EYE was used for LAI estimation, and the obtained data were regarded as the real LAI data and the LAI data obtained by the improved algorithm using the smartphone with the fisheye lens in this study were compared and analyzed. By comparing LAI under different vegetation types, it was found that the correlation and consistency were high under mixed coniferous forest and broadleaf forest conditions. The experimental conclusion obtained proved the feasibility and accuracy of the improved algorithm on a smartphone with a fisheye len. The LAI data of the broadleaf forest is higher than that of the mixed coniferous forest, and the LAI deviation rate of the broadleaf forest is also higher than that of the mixed coniferous forest, indicating that the measurement error increases with the increase of LAI, which is consistent with LAI characteristics studied by other scholars. In the analysis of the deviation results, the LAI deviation rate of the broadleaf forest was higher than that of the mixed coniferous forest, but the overall LAI deviation rate was kept at a low level, indicating that the error of the improved algorithm when estimating LAI on a smartphone with a fisheye len was small[6,44-47]

V. Conclusion

In this study, a fast and convenient tree canopy LAI estimation method is developed by improving the existing algorithm and using a fisheye lens on a smartphone. Based on the Otsu method, multiregion segmentation and an improvement of reducing the number of traversals were adopted for threshold segmentation, which improves the accuracy and speed of the Otsu method. Simultaneously, the linear inversion method is improved according to the single-angle inversion method in leaf area inversion to improve accuracy. Three plots with mixed coniferous, broad-leaved, and broad-leaved forests were selected and divided into 25 quadrats for the experiments. The results show that the two have a strong correlation and low deviation value. The coefficient of determination R^2 of the overall data reached 8.10 and the RMSE was 1.34. This shows that, by improving the algorithm, it is possible to replace the DHP with a smartphone having a fisheye lens to obtain the LAI quickly and in real-time. Accurate and rapid measurement of LAI provides relevant technical support for the study of the interactions between plants and the growth environment, which has important theoretical significance and practical value.

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