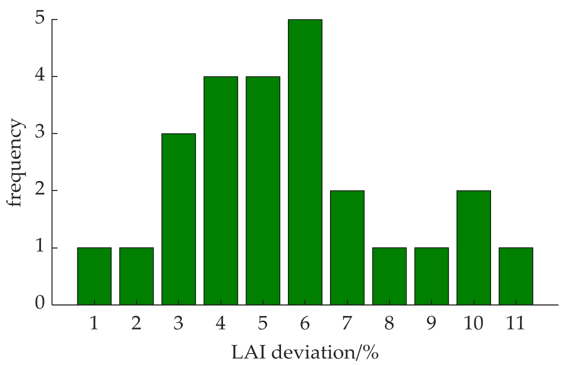
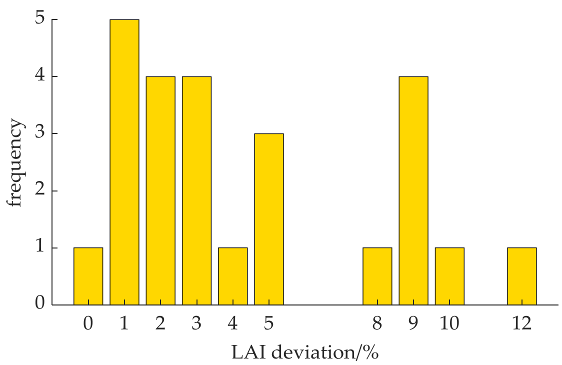
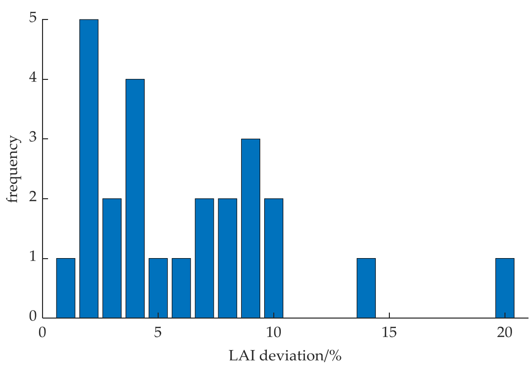


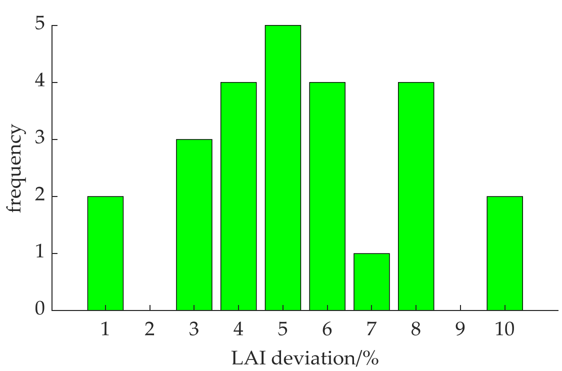
(a)



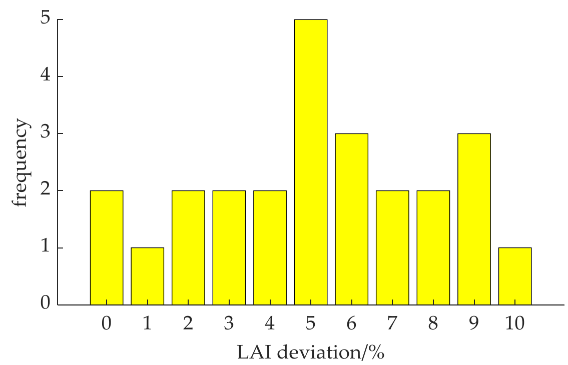
(b)



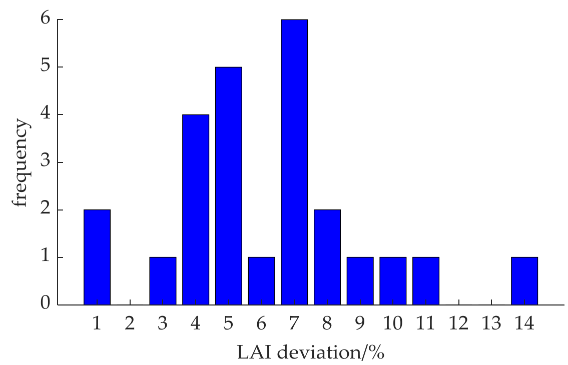
(c)



(d)



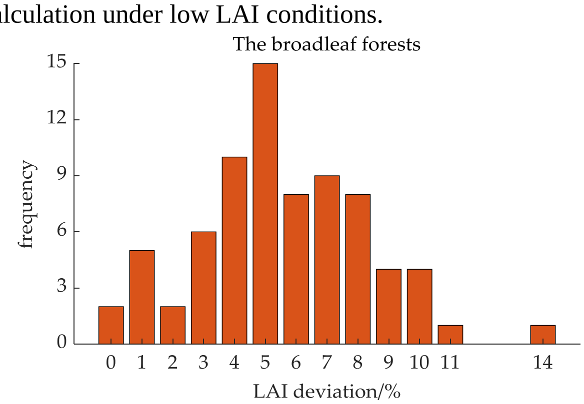
(e)



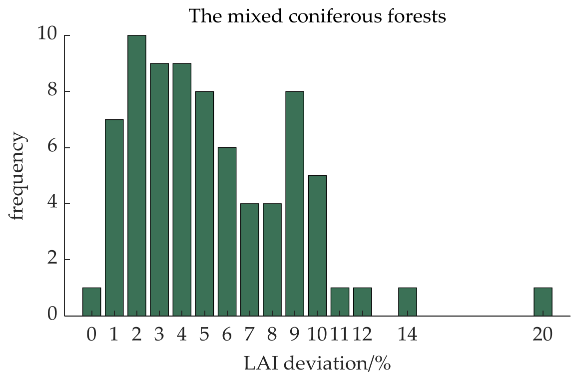
(f)

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

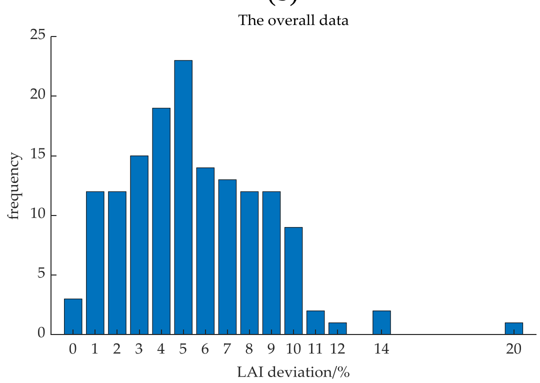
In figure 10, where 10-a is the frequency of the LAI deviation rate of the broadleaf forests, 10 -b is the frequency of the LAI deviation rate of the mixed coniferous forests, and 10-c is the frequency of the LAI deviation rate of overall data. In the broadleaf forests, the LAI deviation rate was concentrated 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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