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Key Technologies of Forest Resource Examination System Development in China

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1. Introduction

As an important resource, forests not only provide irreplaceable economic benefits, but also yield ecological benefits that maintain the balance of terrestrial ecosystems. In addition, forests are an energy base of the biosphere. With the development of information-based technologies and globalization, accurate information regarding individual trees and standing forests in forest resource investigations is increasingly needed in order to achieve sustainable development of forestry [1–6]. As an important means of obtaining information, unmanned aerial vehicles (UAVs) are becoming increasingly popular in a wide range of fields, given their developmental trends of miniaturization and diversification [7–9]. Moreover, geographic information system (GIS) technology, as another type of core technology in the digital world, is undergoing rapid development. With the development of relevant components and Internet technologies, GIS has been applied to componentization and networking, and its conventional function has been greatly improved. For example, technological developments in data editing, querying and calculating, spatial analysis, and spatial data engines provide a solid foundation for GIS applications in various fields, and offer both technological and theoretical support [10].

As an indicator of biodiversity, the term *forest resources* is an umbrella term for the lands and organic body of forests that provide the necessary material bases for human beings' productive activities and lives. Therefore, the question of how to efficiently, accurately, and rapidly obtain forest resource information is a hot topic. Forest examination is a type of observational analysis and evaluation of forest resources in terms of quantity, quality, spatial distribution, and utilization, which is performed at regular periods and regular positions. The aim of forest examination is to keep abreast of the status quo of forest resources and the dynamics of changes (growth and decline), as well as to predict the developmental tendency of forest resources while serving forestry management and scientific decision-making. China's first forest resources investigation was performed in 1950, in the Yaohe Forest, Gansu Province, and was organized by the Ministry of Forestry and Land Reclamation (now Ministry of Natural Resources of the People's Republic of China) [11]. Since the 1960s, new techniques such as sampling survey theory technology and remote sensing (RS), GISs, and positioning and navigation system technologies have been applied to forestry surveys [12]; these technologies have promoted the development of forest resource survey technology and form a basic model of China's forest resource survey technology.

By the 1980s, the basic framework of China's forest resource surveying had been established. It was officially proposed that the national forest resource survey be divided into three categories: ① a continuous inventory of national forest resources—namely, Category I investigation, which takes the forests all across the country as its research objects, with the aims of thoroughly determining the status quo and dynamics of forest resources in a broader sense and offering support for forestry principles, plans, layouts, and designs; ② a forest resource planning and design investigation—namely, Category II investigation, which is based on sub-compartment units of the national forests, and which aims to obtain a good knowledge of the status quo of country-level forestry organizations and to offer support for analyzing and examining the management results of forest activities and designing sustainable management plans; and ③ a forest operating investigation—namely, Category III investigation, which is basically designed for corporations to carry out productive activities. Since the beginning of the 21st century, which is guided by information technology, the focus of forest resources investigations has no longer been limited to the acquisition of single-tree measuring factors. Instead, forest knowledge exploration and accurate forest resources measurement, as well as annual data acquisition and examination, have gradually become the focus of modern investigation and of the examination of forest resources [13,14].

Chinese management of forest resources still needs improvement in terms of integrity and maturity, as several practical problems are still encountered in the investigation of China's forest resources. To be specific, an examination system that is relevant to forest investigation has not been extensively applied. In comparison with forest resource measurement in developed countries, there is still considerable room for China's national standard to develop. This state of affairs is reflected not only in the establishment of the system for the dynamic of forest resource changes, but also in data-renewal technologies. In other words, China's dynamic forest resource assessment has not been sufficiently modernized. In addition, it is quite clear that neither Category I investigation data

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(which is collected every five years) nor Category II investigation data (collected every ten years) can fully cover the overall status of China's forest resources or their dynamic changes [15]. Consequently, a prediction model that can be used to deduce annual forest data is greatly required. Earlier investigations have mostly involved manual practices, in which researchers performed a field investigation and manually calculated the data. A forest investigation performed in this manner is costly as well as being less efficient and accurate. With today's scientific and technological developments, China's forest investigation technology can transition from purely manual work to being assisted by RS, which will dramatically increase the investigation efficiency. However, this shift will not improve the field investigation model in essence, as it still has high energy and material costs. Therefore, a dynamic simulation model of a forest resource ecosystem is desperately needed in order to save costs and realize more precise management and calculation of forest ecosystems. A flow chart of systems for investigation and examination of China's forest resources show in Fig. 1.

2. Development of a forest resource examination system

2.1. System development based on the Internet+

As mentioned earlier, China's forest resource investigation is divided into three categories. A Category I investigation focuses on the diameters of each individual tree in fixed forest sample plots. A Category II investigation is mainly conducted based on sub-compartment units of the national forests; it records the area in square meters of the sublot, along with the accumulation volume, average height, canopy density, and site conditions of standing forests. Finally, a Category III investigation is applied to logged forests, and is used for final felling and forest planting operations.

2.2. Development of a Category I "continuous examination of growth" model in sample plots

To achieve precise management of China's forest resources, it is necessary to have a good knowledge of forest status information and, in particular, of the dynamic changes and relationships between trees' growth and standing environments. To be specific, the standing environments integrate various environmental factors that affect the trees' growth, including topographical terrain, temperature, rainfall, soil, and planting density [16]. In addition, the standing environments are directly related to multiple aspects of forest management such as productivity, economic benefits, logging harvest, forest cultivation direction, and growing speed. China's forest growth prediction model has great practical significance for the precise management and planning management of forests. Quantitative management of forest resources and prediction of forest growth volume can well assist in the realization of cultivation, intermittent logging, and rotational logging, in addition to the re-planting, transplanting, and management of forest resources in different standing environments [17]. It can also accelerate the sustainable development of forest resources while achieving great economic benefits. Therefore, this study analyzes Category I (over multiple periods) investigation data, which includes the longitudes and altitudes, height, temperature, rainfall, slope gradient, direction, position, and soil thickness of continuous examination sample plots in Fujian Province. The prediction model of China's forests' growth, including the growth pattern (standing environment) index and growth structure (site class) index, is shown in Eq. (1),

$$\Delta Y^{j}_{t+\Delta t} = A_j \cdot Y_t^{j^2} \cdot \mathrm{e}^{-b_j \cdot Y^j_t} \cdot X^i_{\mathrm{p}} \cdot X^k_{\mathrm{s}} \tag{1}$$

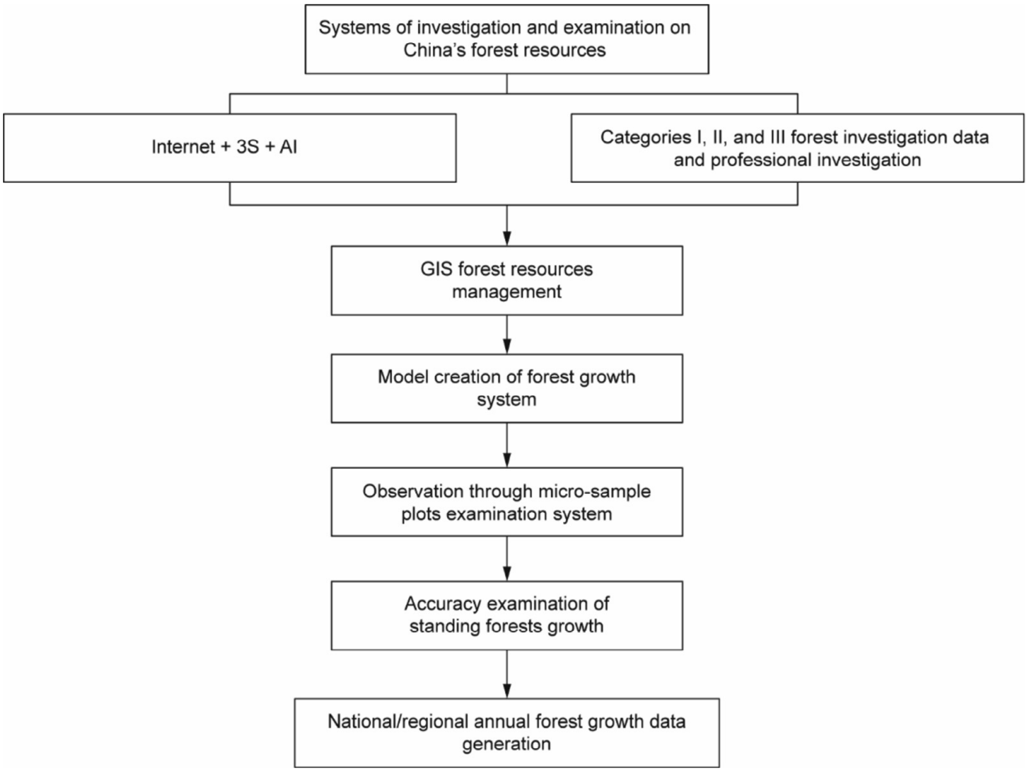

Fig. 1. Flow chart of systems for investigation and examination of China's forest resources. 3S: remote sensing, global positioning system, and geographic information system; AI: artificial intelligence.

where j refers to China's major arbor species, Y_t is the information for the examined tree, $\Delta Y_{t+\Delta t}$ is the forests' growth after Δt years, A_j is the growth speed index (for tree species j), b_j is the growth acceleration index (for tree species j), X_{p}^{i} is the growth pattern (standing environment) index for category i, t is age of the tree, and X_{s}^{k} is the growth structure (site class) index for category k.

3. Observation of the micro-sample plot examination system

With the assistance of the Internet+, all forests on a country level can be categorized into 100–300 independent heterogeneous sub-compartments according to the investigation factors. The overall picture can then be observed through accurate investigation of these 100–300 sub-compartments [12]. For the examination of individual forest sub-compartments, we applied a methodology of accurate examination—that is, standing forest examinations on micro-sample plots (5–9 trees). Micro-sample plot observation is a highly effective, low-error, and standardized sampling survey method derived from the polygon sample plot method. The basic method of micro-sample plot observation is to select five or nine observation trees around one observation tree, determine the diameter at breast height (DBH) value of all of the trees, the height of the center tree, and the sample plot radius, and calculate the stand parameters, such as the average DBH, stand density, and volume. The layout principle of a sample plot in the micro-sample plot observation method is as follows: ① Each sample point is evenly distributed, and is established on different topography. The distance between the sample plots is at least 10 km. ② Representative sample plots are chosen to reflect the distribution of tree species in the area. ③ Convenient transportation, which is conducive to monitoring and is convenient for continuous observation, is selected. ④ Forest margins, roadsides, and areas with serious human interference are avoided; otherwise, these will result in greater data errors. Fig. 2 shows a diagram of the nine-tree micro-sampling plot observation method.

The calculations of the stand density, average stand DBH, and stand volume are as follows:

Stand density, $\bar{N}$, typically refers to the density of trees in the fixed area of each plot. The formula is as follows:

$$\bar{N} = \frac{n - 0.5}{\partial R_{n-1}^{2}} \times 10^{4} \tag{2}$$

where n is the number of trees and R_{n-1} (m) is the distance from the center tree to the farthest $(n-1)$th tree.

The average stand DBH, $\bar{D}$, refers to the general stand DBH value of the whole stand tree; the formula is as follows:

$$\bar{D} = \frac{\sum_{i=1}^{n-2} D_i + D_n + 0.5D_{n-1}}{n - 0.5} \tag{3}$$

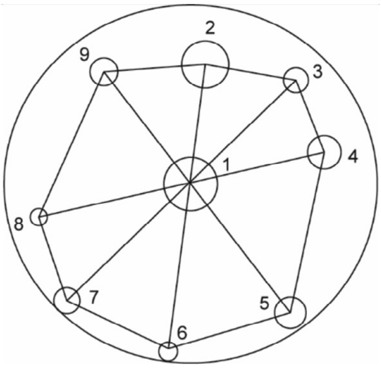

Fig. 2. Diagram of the nine-tree micro-sampling plot observation method.

where D_i (cm), D_n (cm), and D_{n-1} (cm) is the breast diameter of the ith, nth, and $(n-1)$th tree.

The stand volume M ($\mathrm{m^3 \cdot hm^{-2}}$) must be calculated according to the deduced form number; that is, the volume of each tree is calculated from the deduced form number, and the stand volume is calculated from the volume. The calculation formula is as follows:

$$M = \frac{\sum_{i=1}^{n-2} V_i + V_n + 0.5V_{n-1}}{\partial R_{n-1}^{2}} \times 10^{4} \tag{4}$$

where V_i ($\mathrm{m^3}$), V_n ($\mathrm{m^3}$), and V_{n-1} ($\mathrm{m^3}$) is the volume of the ith, nth, and $(n-1)$th tree.

4. Methodology of annual growth prediction

To maintain the fitness and accuracy of the model in practical applications, we analyzed the data obtained from the Fujian sample plots and applied the model solution in Statistical Product and Service Solutions (SPSS). The results are shown in Table 1, where the goodness of fit index (GFI) is applied to determine the fitting level between the estimated model and the observation values. (The model is shown to be better when the correlation coefficient, R, is closer to a value of 1.) In this model, R reached 0.98, and the reset R^2 was 0.98, which demonstrates that the independent variables can explain 98% of the changes in the dependent variables. Thus, this model is believed to fit well for growth prediction.

Analysis of variance (ANOVA) was applied to analyze the variance results. The ANOVA is represented by the F value, which is an overall verification of the regression equation, and which helps to determine whether there is a significant linear relationship between the independent variables and all the dependent variables in the model. As Table 2 shows, the independent degrees of freedom (DOF) in this model equals 52, and the sample size is 37 798; therefore, it can be calculated that the value of F at a significance level of 0.05 is far less than that of the model of this study. Consequently, it is believed that all the independent variables selected in this model can exert significant influence on diameter growth. In addition, the value of significance is 0, which is less than 0.05, signifying that the design and application of this model is quite feasible.

5. Verification of the accuracy of the micro-sample plot growth model

To verify the prediction accuracy of this model on forest growth volume, we selected data from 100 Fujian sample plots, in which the following factors are included: geographical factors such as longitude, latitude, height, slope gradient, slope direction, and slope position; meteorological factors such as rainfall and average temperature; soil factors such as soil thickness and soil categories; and information on tree species such as the density of standing

Table 1
Model-fitting results.

R	R^2	Reset R^2	Standard deviation
0.98	0.98	0.98	1.03

Table 2
ANOVA results.

Item	Sum of square	DOF	Mean square	F	Significance
Regression	1 647 900.435	52	34 190.314	29 693.399	0.000
Residual	40 284.562	37 746	1.067		
In total	1 688 184.997	37 798			

Table 3
Verification and analysis of DBH prediction accuracy.

Item	Bias (mm)	Relative bias (%)	RMSE (mm)	Relative RMSE (%)	R^2
Accuracy verification	–2.187	–1.235	14.154	7.993	0.941

forests and the RS index. Next, the bias, relative bias, root mean squared error (RMSE), relative RMSE, and R^2 were calculated based on 567 data values obtained from these 100 sample plots; in this way, an overall evaluation of this model was generated. The results are shown in Table 3, in which the value of the bias is –2.187 mm, that of the relative bias is –1.235%, that of the RMSE is 14.154 mm, that of the relative RMSE is 7.993%, and that of the R^2 is 0.941 (which is higher than 0.9). Therefore, it was determined that the model can effectively predict annual forest growth.

6. Conclusion

Focusing on Category I investigation data obtained from 37 798 plots in Fujian Province—including longitude, altitude, height, temperature, rainfall, slope gradient, direction, position, and soil thickness—we developed a prediction model of China's forest growth with a growth pattern (standing environment) index and growth structure (site class) index included. Taking the original diameter, longitude, altitude, height, temperature, rainfall, slope gradient, direction, position, and soil thickness as the independent variables, this model can accurately predict forest growth. It was found by model fitting of the Fujian districts that the prediction accuracy of annual growth was as high as 0.98, which demonstrates that the equation can be well applied for growth prediction. Furthermore, to verify the prediction accuracy, we selected 100 sample plots in Fujian Province, which were excluded from the development of this prediction model, and ensured that each dataset covered the information for all the tree species present. The resulting R^2 was higher than 0.9 on average after prediction verification on 567 data values, indicating that this model can effectively predict forest growth. Therefore, the proposed model can be widely promoted and applied in national forest investigation systems, in order to ensure data reliability and offer supporting data for forest carbon sink calculations, annual output, and quality evaluation of forests.

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