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A Study on the Identification of Shear Branches Based on the TBM Model

Biao Huang[1,*], Jiaguo Mo[1], Shiping Zou[2]
[1]College of Mechanical Engineering, Guizhou Institute of Technology, Guiyang, Guizhou, China
[2]College of Food and Pharmaceutical Engineering, Guizhou Institute of Technology, Guiyang, Guizhou, China
*Corresponding Author.

Abstract:

Automated shearing is one of the main means of improving fruit production in fruit trees. However, current shearing methods are still dominated by manual shearing, resulting in low shearing efficiency and high shearing costs. To address this problem, this paper takes peach trees as an example and conducts a study on the nutrient distribution of fruit tree organs such as branches, trunks, leaves and fruits, and proposes a Trunk-branch Mathematical model (TBM) based on the structural relationship between branches and trunks of fruit trees. Based on the TBM model, we propose a shear branch identification method. Experiments show that the average relative error between the data calculated using the TBM model and the actual data is only 1.96%, and the average correctness and accuracy of the identified shear branches are 92% and 91% respectively. Therefore, the shear branch identification method and model described in this paper have certain feasibility and practical value, and they can be used as the theoretical basis for automated shearing.

Keywords: *TBM,Shear branches, Identification techniques, Fruit trees.*

I. INTRODUCTION

Automatic shearing is an inevitable trend in the development of intelligent fruit tree cultivation. Among them, the pruning of the main and senescent branches of fruit trees has become one of the key tasks of current fruit tree management. At present, fruit tree pruning is mainly manual, with the number of branches to be pruned, which branches to be pruned and the pruning points of the branches being determined subjectively by hand. As this judgement is usually based on experience, it is difficult to standardise, making it impossible to achieve automated or intelligent operation. In order to advance the development of automated shearing technology, we carried out a study on the structure of the branch model based on the growth principle using peach trees as an example, and proposed a Trunk-branch Mathematical model (TBM), and based on this model we proposed an algorithm for shearing point recognition in peach tree branch images.

Few studies have been reported on the shear points of fruit tree branches, but research on plant models has received some attention. For example, Paine CET proposed various non-linear models suitable for plant growth modelling and proposed a method for calculating function-derived growth rates [1]. Houska T combines catchment modelling framework (CMF) and plant growth modelling framework (PMF) to predict plant growth [2]. Fan Xing Rong proposed a new knowledge-and-data-driven modeling (KDDM) approach

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to predict plant growth. The model is used to simulate plant growth and consists of two sub-models. One sub-model is derived from all available domain knowledge, including all known relationships from physical or mechanistic models; the other sub-model is constructed entirely from data [3]. BozorgBehruz has developed a growth model based on a continuum equation that can employ mechanical signals [4]. Zhang Yajie gave a presentation on the application of the DNDC model to assist in forecasting[5]. KellnerJuliane combined plant growth and soil hydrology models to determine soil and plant growth models [6]. Thomas FM modelling plant growth using a hierarchical multi-species model [7]. Kiniry JR developed a bimodal growth model based on tall fescue in the USA. The model simulates well the yield of tall fescue at each site [8]. Lionheart Gemma conducted a study on simulated microgravity in plants [9]. Sridhar SL introduced a statistical method to describe the behaviour of populations with elastic properties to simulate the cell wall during expansive growth [10]. Attorre F proposes models that are blocky, steady-state and fully deterministic, allowing the calculation of primary productivity [11].Sari BG used an adapted growth model to describe the production behaviour of salad tomato genotypes and argued that the use of growth models could increase inferences about the production behaviour of other crops in multiple harvests [12].Smithers ET argued that plant growth is a highly mechanistic process and that mathematics can be used to provide a basic framework for exploring its underlying uncovered mechanisms. The breadth of the rich mathematical problems in plant science is demonstrated through the biological insights provided by mathematical modelling, thereby facilitating mutual understanding across disciplines[13]. Weise LD proposed a discrete mechanical model to study plant development [14]. El-HussienyHaitham proposes a Nonlinear Model Predictive Control (NMPC) scheme to guarantee stable robot performance while respecting the constraints imposed by the growth process and control limits[15]. Letort Veronique has developed a stochastic GreenLab model of plant growth (GL4). The model has a feedback effect of internal nutrient competition [16]. XieWenpeng proposed a scheme for calculating water temperature dynamics in paddy fields [17].

Based on current research on plant models, we have not found a plant structure model for fruit tree shearing. In order to further improve the scientific and rational nature of automated fruit tree shearing decisions, we proposed the Trunk-branch Mathematical model (TBM) based on fruit tree growth theory. The model is used as a basis for branch structure optimisation and is mainly applied to the objective judgement of fruit tree branch shearing, including the judgement of the branch to be sheared, the number of branches to be sheared, the diameter to be sheared and the position to be sheared.

II. MATERIALS AND METHODS

2.1 Presentation of the TAW Model

2.1.1 Conjectures on the structural relationships of branches and trunks

In the process of fruit growth, branches need to be pruned every year, with the aim of balancing the distribution of nutrients. If the trunk is not sheared, the branches grow freely. The crown in this state is too dense and does not distinguish between priorities, resulting in a failure to properly distribute nutrients to the fruit tree, affecting fruit growth and thus leading to a reduction in fruit quality and yield. The main trunk of a fruit tree is the weight-bearing part of the entire canopy and the nutrient channel connecting the

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root system. The height of the trunk determines the size of the canopy and affects the ease of management of the fruit tree. A proper cut can regulate the reasonable distribution of branch gaps and allow the leaves to receive sufficient sunlight and a better distribution of nutrients. Shearing not only regulates growth and fruiting, but also making fruit trees less likely to fail to flower or bear fruit.The aim of regulating the nutritional relationship between the trunk and branches of fruit trees is therefore not only to make them flourish, but also, and more importantly, to make them flower and bear fruit. This is why a proper supply of nutrients is necessary to obtain a good harvest. From the nutrient supply relationship between fruit, branches and the main trunk we guess that there is an intrinsic link between the branches and the trunk of the fruit tree, which is an important basis for our TAW model.

Pruning of fruit trees has an important impact on the growth and development of fruit trees and flowering and fruiting, and its main control includes three aspects: control, regulation and transformation. The essence of this control is to maintain the balance between the tree potential (the overall growth momentum of the trunk) and the branch potential (the local growth momentum of the branch). We believe that the length and thickness of the trunk or branches at the same level should be approximately the same as each other, and on this basis we conjecture that there is a relationship between the trunk of a fruit tree and the first, second and third levels of branching. We then proposed the conjecture that:

Conjecture 1: There is a relationship among the trunk circumference and the primary branch circumference, secondary branch circumference and tertiary branch circumference.

Conjecture 2: There is a relationship among the cross-sectional area of the trunk and the total cross-sectional area of the primary branches,the total cross-sectional area of the secondary and the total cross-sectional area of the tertiary branches.

Conjecture3: There is a relationship between the squared diameter of the trunk and the sum of the squared diameter of the primary branches, the sum of the squared diameter of the secondary branches and the sum of the squared diameter of the tertiary branches.

2.1.2Mathematical Model for Branch Structure Optimization

Based on the above conjecture, we took the peach tree as an example and made a lot of actual measurements on its main trunk and branches, and found that conjecture 1 basically matched the actual situation, and 1established the relationship between the main trunk and branches based on the conjecture, as shown in the following equation.

$$D = K_1 \sum_{i=1}^{n_i} D_i + K_2 \sum_{j=1}^{n_j} D_j + K_3 \sum_{k=1}^{n_k} D_k \quad (1)$$

In the above equation, the parameters are explained as follows:
D: is the diameter of the main trunk of the peach tree

K_1, K_2, K_3: model coefficients for primary, secondary and tertiary branches of peach trees, respectively.

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n_i, n_j, n_k: Total number of branches for primary, secondary and tertiary branches, respectively.

D_i, D_j, D_k: are the branch diameters of the primary, secondary and tertiary branches corresponding to the number (i,j,k), respectively.

Based on the above mathematical model, we can use it to determine the optimal branch structure for the growth of fruit trees. TheK_1, K_2, K_3 parameters are influenced by the type of fruit tree, planting management and other factors. However, for the same species (e.g. peach tree), under the same growing environment, management and variety, K_1, K_2, K_3 the parameter values are the same. Therefore, under certain conditions, the model is general and can be used as an important basis for shearing.

2.2 Proposed Algorithm for Shear Branch Recognition

Based on the above mathematical model, for a particular peach tree, we can determine whether the branching of the peach tree is reasonable based on the known diameters of the primary, secondary and tertiary branches and the main trunk of the peach tree, and use this to determine which branches need to be sheared.

2.2.1 Determining the model parameters

The determination of the model parameters is a prerequisite for sheardetermination and branch determination. The model parameters are mainly obtained from a database of models built under the same conditions. In the case of peach trees, for example, the relevant conditions such as the variety and environment of the peach tree plantation need to be combined and the data model based on the same conditions to determine the values of parameters such as K_1, K_2, K_3.

2.2.2 Shear judgement

The parameters obtained are used to build a mathematical model from which the shearing judgement of fruit trees is made. For example, when judging the shearing of a peach tree, the actual data (e.g. diameter of each branch, diameter of the main trunk, etc.) of the peach tree needs to be entered into the mathematical model. If the trunk diameter value is less than or equal to the model value, as shown in equation (2), then the judgement result is that no shearing is required. If the trunk diameter value is greater than the model value, as shown in equation (3), then the result is that shearing treatment is required.

$$D \leq K_1 \sum_{i=1}^{n_i} D_i + K_2 \sum_{j=1}^{n_j} D_j + K_3 \sum_{k=1}^{n_k} D_k \quad (2)$$

$$D > K_1 \sum_{i=1}^{n_i} D_i + K_2 \sum_{j=1}^{n_j} D_j + K_3 \sum_{k=1}^{n_k} D_k \quad (3)$$

2.2.3Identification of cut branches

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Based on the results of the shearing judgement, it is determined whether the fruit tree requires a shearing treatment. If no shearing is required, no identification of sheared branches is required. If shearing is required, then shear branch identification is required. In the identification of sheared branches, the image processing technique is first used to obtain the branch structure image, referring to the branch image extraction technique [18]. Afterwards, the branches are arranged in order from smallest to largest diameter at all three levels and the smallest diameter branch is selected as the cut branch. Finally, the model is used to determine whether the branch needs to be sheared or not. If the result is still in need of shearing, the smallest diameter branch is again selected from the remaining three levels of branches as the shearing branch, until the model's judgment is that no shearing is needed.

2.3 Experimental Verification

2.3.1 Mathematical model validation

Twelve peach trees were selected that had been reasonably standardized and were representative of the area, and each had a similar tree-age, tree vigor, number of branches and number of leaves. Information on the peach trees was collected in the field to obtain data on branch diameter and main trunk diameter. By comparison, the main trunk diameter was found to be positively correlated with the sum of all branch diameters of primary branches, the sum of all branch diameters of secondary branches and the sum of all branch diameters of tertiary branches, as shown in Fig 1. In the figure, DT indicates the diameter of the main trunk, SDP indicates the sum of all branch diameters of primary branches, SDS indicates the sum of all branch diameters of secondary branches, and SDT indicates the sum of all branch diameters of tertiary branches.

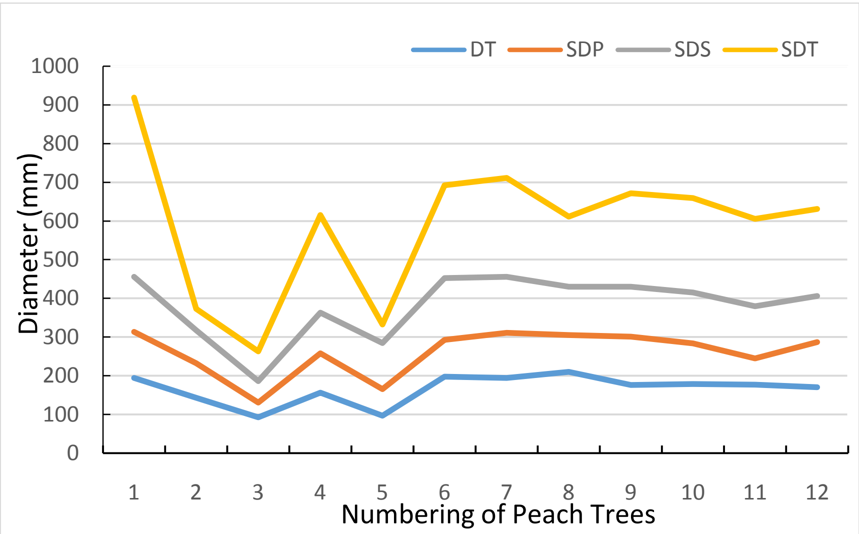

Fig 1: Folding diagram of branch and main trunk diameters

Based on the mathematical model proposed in this paper, the trunk diameters obtained from the simulations have been more consistent with the actual trunk diameters, with a maximum absolute error of 7.11 cm and a maximum relative error of 4.25%, as shown in TABLE I. The average absolute error is 3.52 cm and the average relative error is 1.96%.

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TABLE I. Comparison of model results with actual data

Number of the tree	Actual diameter of trunk	Trunk diameter obtained based on the model	Absolute error	Relative error
1	194.27	191.13	3.14	1.62%
2	143.31	137.4	5.91	4.12%
3	156.05	153.98	2.07	1.33%
4	197.45	195.38	2.07	1.05%
5	194.27	195.42	1.15	0.59%
6	176.43	183.92	7.49	4.25%
7	178.34	178.03	0.31	0.17%
8	170.06	173.2	3.14	1.85%
9	214.77	207.66	7.11	3.31%
10	178.22	173.46	4.76	2.67%
11	176.80	175.35	1.45	0.82%
12	202.25	198.65	3.60	1.78%

Based on the experimental results we believe that the optimal branch structure is determined using the mathematical model proposed in this paper and can be used as a basis for shear judgement.

2.3.2 Identification verification of cut branches

Based on the mathematical model proposed in this paper, the main steps to complete the identification of shear branches include the following.

Firstly, determine the age, species and growing environment of the fruit tree to be identified. The purpose of fruit tree shearing is to regulate the rational distribution of branches and leaves and to regulate growth and fruiting. In addition, it is also important to avoid the canopy of fruit trees expanding with age and having too many branches and leaves, which can lead to a reduction in fruit yield and quality. Fruit trees of different species, ages and growing environments have different shearing requirements and therefore different corresponding model parameters. Therefore, the actual condition of the fruit tree must be determined before the model parameters can be determined.

Secondly, the corresponding model parameters in the parameter library are determined according to the actual condition of the fruit trees.

Thirdly, using image processing, the branch images were extracted and the main trunk and branch diameters were obtained, which can be found in the literature [18].
Fourthly, the data for the model parameters, main trunk and branches are entered into the model and the shear branches are determined according to the methods proposed in sections 2.3.2 and 2.3.3 of this paper.

The branches identified for validation in this paper are peach tree branches, which are five years old and there are 30 peach trees involved in the identification. Based on the actual situation of the identified peach

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trees, the values of model parameters K_1, K_2 and K_3 were chosen to be -2.6,2.6, -0.2 respectively. In order to better verify the feasibility of the shear branch algorithm proposed in this paper, a recognition comparison was carried out. The branches to be sheared were first identified using mathematical models and image techniques. Then, the branches to be sheared were identified by a manual based method. Finally, the two methods were compared using the shear branches identified by the manual method as the standard. The parameters used for comparison include: the number of branches to be sheared (N_M) determined based on the manual method, the number of branches to be sheared (N_C) deduced using the mathematical model, the percentage of branches cut correctly (P_1), the number of branches cut correctly N_R (the number of branches cut deduced by the mathematical model and the number of branches cut using the manual determination as the same branch), and the accuracy of the branches cut (P_2). Where $P_1$and P_2 are obtained from the following equations.

$$P_1 = \left(1 - \frac{|N_M - N_C|}{N_M}\right) \times 100\% \tag{4}$$

$$P_2 = \frac{N_R}{N_M} \times 100\% \tag{5}$$

Experimentally, it was found that the number of branches to be sheared N_C deduced by the mathematical model agreed well with the number of branches to be sheared N_M determined by the manual method, and that the number of correctly cut branches N_R also agreed well with the branches determined by the manual method, as shown in Fig 2, where NM denotes the number of branches to be sheared N_M determined based on the manual method, NC denotes the number of branches to be sheared N_C deduced using the mathematical model, and NR denotes the number of correctly cut Number of branches N_R.

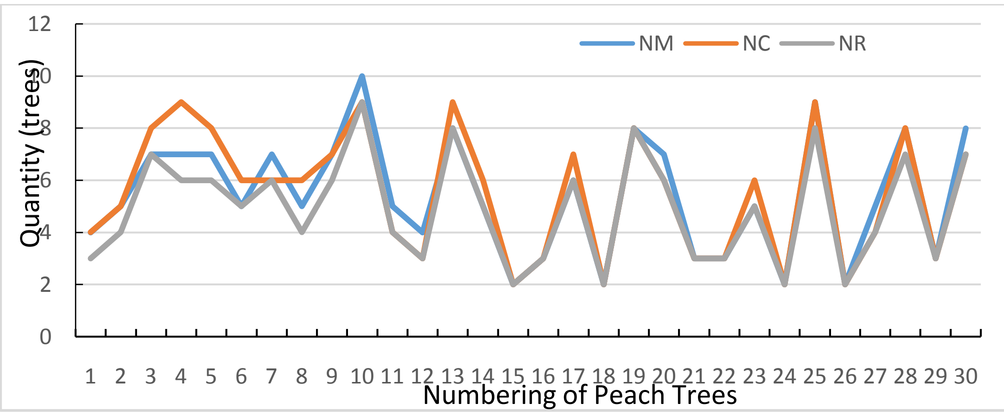

Fig 2: Comparison of cut branches

Based on the above experimental results, based on equations (4) and (5) we obtained the correct rate of cut branches P_1 and the accuracy rate of cut branches P_2. From the obtained results of $P_1$and P_2, it is not difficult and found that the mathematical model used to obtain cut branches has a high correct rate and accuracy rate, where the minimum correct rate, the maximum correct rate and the average correct rate of the branches of peach trees participating in the experiment are 75%, 100% and 29% respectively. Of these, 80% of all peach trees participating in the experiment had a correct rate of more than86 %. The minimum

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accuracy, maximum accuracy and average accuracy of the branches of the participating peach trees were 75%, 100% and 91% respectively, while more than 70% of all the peach trees participating in the experiment had a correct rate of more than 85%, as shown in Fig 3. This shows that the model and branch identification method proposed in this paper can be used to better complete the identification of shearing branches and can be used as a theoretical basis for automated shearing equipment such as branch shearing robots.

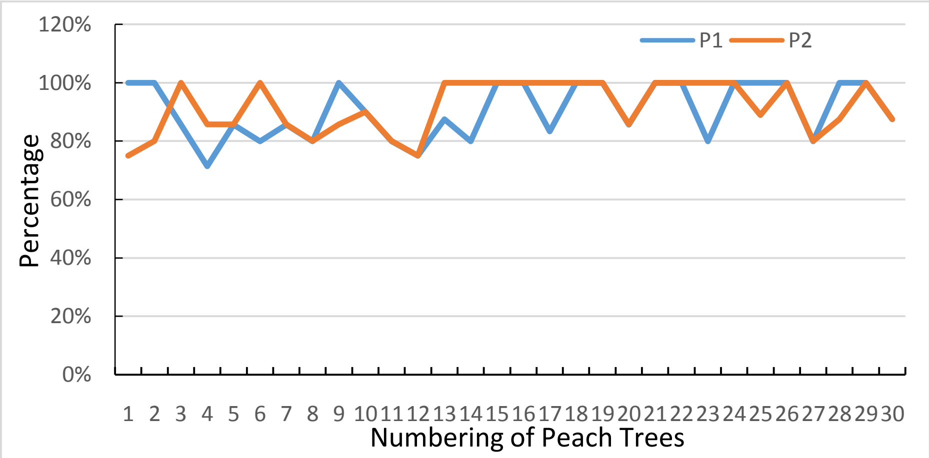

Fig3: Correctness and accuracy of cut branches

III. CONCLUSION

In this paper, a Trunk-branch Mathematical model (TBM) was established based on the relationship between trunk and branch growth and nutrient distribution in peach trees, and a shear branch identification method was proposed based on this model. The experimental results show that the average relative error of the trunk diameters inferred from the model described in the paper is only 1.96%, which fully meets the practical requirements. The average correctness and average accuracy of the shear branches obtained using this model are 92% and 91% respectively. Therefore, the shearing judgments made using the present model and recognition algorithm are basically consistent with the results of manual judgments, which can effectively break the bottleneck of branch recognition technology for automated shearing and advance the development of automated fruit tree branch shearing. However, due to the complexity of the fruit tree growing environment and the variability and adaptability of fruit tree growth, the established model database needs to be updated in real time. This is not conducive to the generalisation of the model and the pruning branch identification method, so in subsequent studies we will target the generalised database of the model for further research.

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