RESEARCH ON VISUAL NAVIGATION PATH DETECTION METHOD FOR DENSE PLUM GROVE
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密植李子树林视觉导航路径检测方法研究

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ABSTRACT
Aiming at the field management of plum grove in Inner Mongolia of China, taking the dense planting plum groves in Bikeqi town of Hohhot City as the research object, this paper proposed a visual navigation path detection algorithm for plum grove. By processing the video image information of plum grove, comparing RGB and HSV color space model, HSV color model was selected to separate the plant and background in V channel. Homomorphic filtering was used to highlight the region of interest in the image, Otsu was selected to segment the image, the intersection of plum trunk and ground was extracted as feature points, and the least square method was used to fit the navigation path. Through the comparative analysis of detection rate under different detection conditions in one day, the verification test of route accuracy was carried out. The experimental results show that: for dense planting plum grove, the average path detection accuracy of the algorithm is 70% and 73.3% under the condition of front light and weak light, respectively. The detection accuracy and real-time meet the requirements of plum grove field management, and the navigation baseline can be generated more accurately, which provides a preliminary basis for the realization of mechanical vision navigation in plum grove field management.

摘要
针对中国内蒙古地区李子园田间管理，以呼和浩特市毕克齐镇密植李子园为研究对象，该研究提出一种李子园行内做视觉导航路径检测算法。通过处理李子园图像信息，对比 RGB 和 HSV 颜色空间模型，确定选用 HSV 颜色模型，在 V 通道进行植株与背景分离。使用同态滤波将图像感兴趣区域凸显出来，选择 Otsu 对图像进行分割，并将李子树干与地面交点作为特征点进行提取，采用最小二乘法拟合导航路径。通过在一天内不同检测条件下检测率的对比分析，对路线精度进行验证试验。试验结果表明：对于密植李子园在顺光和弱光检测条件下，该算法的路径检测准确率平均值分别为 70%和 73.3%，检测准确性与实时性满足李子园田间管理要求，能够较准确生成导航基准线，为李子园田间管理机械视觉导航实现提供前期基础。

INTRODUCTION
Plum tree, also known as cherry plum, which can be planted in a variety of soil types because of its low requirements for climate and soil, is widely planted in Inner Mongolia of China. With the improvement of agricultural and forestry machinery, the planting and production efficiency of agricultural and forestry products has been greatly improved, and the agricultural and forestry products have been developed rapidly. However, for many reasons, most of the planting, management and harvesting operations in the dense plum grove were completed by manpower and a small part of machinery, which did not fully realize the mechanization of forestry equipment, which was time-consuming and laborious, and the cost was high. In the period of plum field management, the operators operated the machinery, which would expose them to dangerous pesticides, and their health was vulnerable to great threat. At the same time, working for a long time may reduce the operator's concentration, produce visual fatigue, and affect the observation and judgment.

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Visual navigation has been widely used in various fields because of its high precision, wide signal detection range, good autonomy and real-time. With the continuous development of visual navigation, some scholars have developed automatic navigation systems for Kiwi *(Li, 2017)*, citrus *(Liu, 2019)*, jujube *(Peng et al., 2018)* and other plants.

According to the characteristics of orchard standard specification row planting, *Zhang* used image processing methods such as threshold segmentation, edge detection and centroid extraction to identify fruit trees from aerial top view of orchard, extracted fruit tree coordinate information and created orchard feature map. Hough transform and random sampling consistency algorithm were used to extract the straight line features of tree line, and the feasibility of the design was verified by simulation and field experiments *(Zhang, 2016)*. *Ye et al*. used the offset algorithm to cluster the pixels of the original image to eliminate the diversity of pixels in the image, and then used the image segmentation algorithm based on graph theory to segment the processed image. On the basis of the binary image after edge detection, Hough transform was used to extract the boundary line between the tree and the ground, so as to obtain the robot's route *(Ye et al., 2017)*. Hou et al. put forward a robot navigation system based on VC + + in 2008, which can carry out weed recognition application software. Camera was installed on the robot, and the perspective transformation principle was used to make the weeding robot carry out different pose changes *(Hou et al., 2008)*. *An* took the lead in applying color constancy theory to machine vision navigation, so as to realize autonomous navigation of field agricultural robot *(An, 2008)*. Liu et al. designed a navigation path generation algorithm based on the machine in the fruit tree grove in winter, which had good anti-interference and high robustness *(Liu et al., 2019)*. Zhang et al. identified the tomato plants planted in the greenhouse from the complex background, extracted the navigation path feature points through the tomato position, and obtained the navigation path by using Hough transform, thus inventing a robot mainly used for timely image processing in the greenhouse *(Zhang et al., 2018)*. Peng et al. used MFC (Microsoft Foundation Classes) and Opencv to create a visual navigation path extraction software for dense jujube garden *(Peng et al., 2018)*. *Montalvo et al*. used the second Otsu method to segment images in high weed environment. Set the template in advance before the experiment, extracted the green pixels, separated the crops from the surrounding environment, and then compared it with the template to get the navigation center line after removing the noise *(Montalvo et al., 2012)*. *Gu* used the combination of linear transformation and least square method to detect the navigation path when extracting the visual navigation parameters. This method can fuse the set of near distance points detected by the transform to fit the navigation path. The experiment showed that the false detection rate of this method was about 30% lower than that of using only transformation to detect the navigation path *(Gu, 2012)*. According to the complex orchard navigation environment, Feng proposed an orchard navigation baseline generation algorithm based on image processing, which used two-dimensional Otsu algorithm to obtain the optimal segmentation threshold, binarized the color difference R-B component image, and used the least square method to fit the left and right boundary lines, extracted the center points of each line on the boundary line to generate the orchard navigation baseline *(Feng et al., 2012)*. Yang et al. used the least square method to obtain the navigation line between rows of corn on the chassis of high gap plant protection machine. Experiments showed that the algorithm had good anti-jamming performance and could adapt to the more complex field environment *(Yang et al., 2020)*. Zeng et al. used the least square method to fit the harvester operation navigation line to solve the problems of low contrast between the harvested area and the non-harvested area of mature wheat under strong light. The proposed method can accurately extract the wheat harvest sideline and get the harvester operation navigation line *(Zeng et al., 2020)*. *Peng et al.* proposed an image processing method based on "row threshold segmentation" to segment the tree trunk and background for the complex environment of dwarf and dense planting jujube garden. According to the vertical gray distribution of the trunk, the floating window gray vertical projection method combined with morphological open close operation was used to extract the trunk region, and the left and right edges were fitted according to the principle of least square method, and the geometric center points of each line on the edge line were extracted to generate the navigation baseline of jujube garden. Many experiments showed that this method was feasible in a variety of complex environments *(Peng et al., 2017)*.

The key to the accuracy of visual navigation is path recognition, which is always a difficult problem in unstructured environment. Therefore, according to the characteristics of inter row image of plum grove, an accurate path extraction algorithm is proposed to increase the safety of planting personnel and the production efficiency of plum plant, which lays a foundation for the realization of forestry equipment mechanization in plum grove.

MATERIALS AND METHODS

MATERIALS

Taking Bikeqi plum grove in Hohhot City as the research object, Canon EOS 6D digital camera was used to collect video image information. It mainly collected video information under different light conditions from April to May. The collected information was placed in the memory card to prevent the subsequent video image loss and facilitate the search for the required information.

Chose ASUS laptop with Intel Core i5 processor, 64 bit Win10 operating system, 2.50GHz main frequency and 4G memory. The software was mainly Matlab R2014a.

IMAGE PROCESSING

COLOR SPACE

RGB model is a color space often used in daily life, and there are many kinds of color description models in image processing. However, the three-dimensional coordinate form adopted by RGB color space model makes it very easy to understand, so it is widely used. R, G, B correspond to red, green, blue three color components, three different colors superimposed in RGB color space show different colors. RGB color space can be seen as a unit cube in a rectangular coordinate system. The color of any point is the accumulation of three color components.

The image collected in this study is RGB format, as shown in Fig.1.

Fig. 1 - Image collected in plum grove

HSV (Hue-Saturation-Value) color model is different from RGB color space model, which is generally represented by inverted cone. Although the visual effect of RGB color space model is better, it cannot reflect well the specific color information of the object, and HSV color space can very intuitively express the brightness, hue, and brightness of the color, which is convenient for color contrast and more conducive to image processing in later stage. Therefore, this paper chooses HSV color model for image processing based on the comparison of RGB and HSV color space models. The relation between them is shown in formulas (1) and (2).

$$\begin{cases} H = \begin{cases} \theta & B \le G \\ 2\pi - \theta & B > G \end{cases} \\ S = \dfrac{\max(R, G, B) - \min(R, G, B)}{\max(R + G + B)} \\ V = \dfrac{\max(R, G, B)}{255} \end{cases} \tag{1}$$

$$\theta = \arccos\left\{ \frac{(R-G)+(R-B)}{2[(R-G)^2 + (R-G)(G-B)]^{1/2}} \right. \tag{2}$$

HOMOMORPHIC FILTERING

In order to make the image clearly visible, highlight the key information, and make the image more conducive to observation and analysis, the image is enhanced. Image enhancement is generally divided into two parts according to its scope: spatial processing and frequency processing.

Homomorphic filtering combines gray-scale transformation with frequency filtering, takes the illuminance in the image as the basis of frequency-domain processing, and uses contrast enhancement and brightness range compression to improve image quality. In the homomorphic filtering, the gray value of the pixel is regarded as the result of the reflectivity and the illuminance. Therefore, if we deal with the relationship between the illuminance, the gray value of the pixel and the reflectivity well, the shadow area which is invisible to the naked eye can be shown.

Homomorphic filter makes the low frequency drop and the high frequency rise. It can reduce the illumination change and sharpen the edge details. At the same time, it is also a nonlinear filter. This technology is mainly based on the illumination reflection imaging in image formation, changing the gray range of the image to adapt to the new situation, so as to reduce or even disappear the uneven illumination in the image, eliminate the noise in the signal, protect the details in the image, and highlight the things in the beneficial area for the research.

In this paper, the dynamic Butterworth filter is selected, the expression is shown in formula (3).

$$H(u,v) = (\gamma_H - \gamma_L) / \left\{1 + c[D_0^n / D^m(u,v)]^2\right\} + \gamma_L \tag{3}$$

In this formula, γ_H and γ_L represent high and low frequency gain respectively, and their value ranges are, $\gamma_H > 1$, $0 < \gamma_L < 1$; m and n are dynamic operators; C and D_0 are constants, which are used to control the slope of transition section of filter function and represent cut-off frequency respectively.

Fig. 2 shows the processing rendering and histogram after using Butterworth filter.

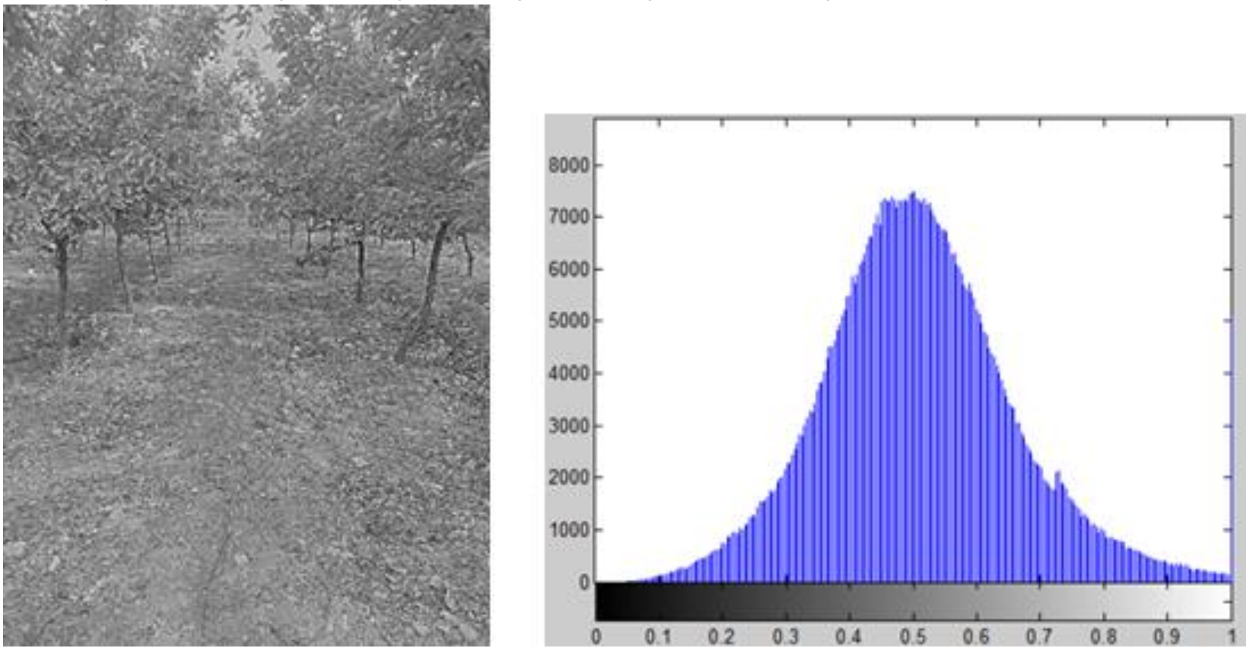

Fig. 2 - Processing rendering and histogram

Image segmentation

Image segmentation means that according to the characteristics of image gray, color, spatial texture and geometric shape, the image is divided into multiple regions by using appropriate image segmentation algorithm. The same region has the same property, and different regions are differentiated. In short, image segmentation is to separate the object from the background in a given image. As for the gray image, the pixels in the region generally have the property of gray similarity, and the pixels in the region edge or the outside show more gray discontinuity.

Image segmentation requires high level of technology and occupies a very large part in image processing, so many researchers have been studying and developing it since 1960s and 1970s.

But up to now, although there is not a perfect method for the problem of image segmentation, there are many methods and results that can be directly used, and these knowledge and rules about image segmentation have reached a consensus.

Threshold segmentation is an easy and efficient method in image segmentation. If the information needed in the image is obviously different from other information, threshold segmentation is often used. The guiding idea of Otsu is clustering idea, which divides the image into two parts: target and background according to the gray level. The variance of the same region is the smallest, and that of different regions is the largest. At present, the simplest algorithm in threshold segmentation is Otsu algorithm, which is easy to calculate and understand, and image contrast and illumination have little effect on it.

The image of threshold segmentation obtained by Otsu is as follows, which can be seen in Fig.3.

Fig. 3 - Otsu segmentation rendering

FEATURE POINT EXTRACTION

In the acquired image, the plum trunk was separated as the target, and then the feature points were extracted according to the segmented image, and the navigation path algorithm was designed according to the feature points.

Feature refers to the fact that a specific object in the part is different from other parts or is a collection of multiple features, which can be obtained by measurement and observation. For different images, each image has its own unique characteristics, which can be distinguished from other images. In an image, the brightness, color, spatial relationship, and edge and so on, which can be directly seen here, are called natural features, while the moment, histogram and other feature information of the image need further processing.

Generally speaking, the gray level on the edge of the image changes slowly, but the change on both sides is obvious, and the edge is the basic feature of the image. It mainly exists in the target, background and region. Therefore, it is the most important basis of image segmentation. The basic idea of edge detection is to first detect the edge points in the image, and then connect the edge points into a contour according to a certain strategy to form a segmentation region.

The edge of an image can be said to be the most basic feature. The main purpose of edge detection is to identify which brightness change is most easily seen in an image. At present, Sobel operator and Prewitt operator are widely used in edge detection. It can not only locate the boundary accurately, but also suppress the noise.

Sobel operator has better edge effect on the image with gradual change of gray level and noisier, simple calculation and fast operation speed. Therefore, this paper selects Sobel operator to detect the edge of plum grove image, as shown in Fig. 4.

Fig. 4 – Otsu feature point extraction

NAVIGATION PATH ALGORITHM GENERATION

After the image is processed by the above operations, the linear equation is obtained by path fitting. At present, the commonly used line fitting methods include least square method, Hough transform and its improved algorithm or vertical projection method *(Guan et al., 2020)*. Because Hough transform is more robust, it is widely used. But the path algorithm fitted by the least square method is more accurate and faster. Therefore, in this paper, the least square method is used to fit the path information after obtaining the feature points.

In fact, the least square method fitting is that there is a corresponding Y under a given m sequences X. These corresponding sequences can be regarded as m points, and the coordinates of each point are (X, Y). The least square method is to find a straight line with y =kx+b, so that the sum of squares of the distance between the m points and the straight line y = kx+b (residual error is ∑| yi-f (xi) | ^ 2) is the minimum. The solution of each coefficient is obtained by its derivation. The above m (X, Y) point sets are brought into the overdetermined equations, and the values of each coefficient are solved. The final equation expression is determined by the obtained coefficient values. The navigation baseline generation effect can be seen in Fig. 5 below.

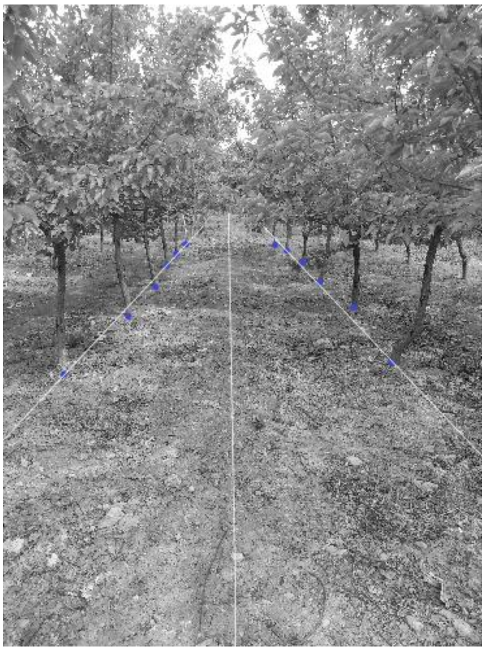

Fig. 5 - Navigation baseline generation effect

EXPERIMENTAL RESULTS AND ANALYSIS

The resolution of the selected image was 3648 × 2432. The image was collected at different times of one day, and a total of 120 images were obtained. In these images, the plum trunk was used as the recognition target to process the images, and the results were sorted out as shown in the table below.

Table 1

Plum trunk recognition results

Test conditions	Images number [sheet]	Accurate detection [sheet]	Accuracy [%]
Strong light	30	19	63.3
Weak light	30	22	73.3
Front light	30	21	70
Back light	30	17	56.7

From the analysis of the results in the above table, it can be seen that the detection rate of the algorithm is low under strong light and back light, while the detection rate can reach 70% or more under both front light and weak light. Under the strong light, the intensity of light in the plum grove is high and the light distribution is uneven, so the shadow of the image is large, and the difficulty of using the algorithm increases. In the case of back light, the image is not clear due to the influence of light, and the characteristic of plum trunk cannot protrude well. In conclusion, the algorithm performs better in weak light and front light environment, but the detection accuracy needs to be improved in strong light and back light environment, so the algorithm needs to be further optimized on the basis of the original research.

CONCLUSIONS

This paper took Bikeqi plum grove in Hohhot City as the research object to study the algorithm of visual path navigation in plum grove. After image acquisition in plum grove by camera, Matlab R2014a was used to process the image. The intersection of plum trunk and the ground was taken as the feature point, and the extracted feature points were fitted to obtain the main information about the navigation path. This paper mainly studies the following parts:

(1) The HSV color model was used to separate the plant from the background in the three HSV channels. The V channel was selected, and then homomorphic filtering was used to enhance the image.

(2) Otsu was selected to segment the image, and the intersection of plum trunk and ground was determined as the feature point of the image. So the feature information of intersection point can be extracted.

(3) According to the information of the feature points, the least square method was selected to fit the data to get the navigation algorithm, and the navigation algorithm was tested. The results show that the proposed algorithm can generate the navigation baseline more accurately. The detection rate of the algorithm is low under strong light and back light, and the detection rate can reach 70% or more under front light and weak light, which can provide a certain foundation for realization of mechanical vision navigation of plum field management.

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