Cauliflower Seedling Recognition Using Stereo Vision and K-Medoids Algorithm under Weedy Conditions

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Abstract. The natural field environment is unstructured where the illumination conditions are uneven, the soil background is complex and changeable. Also, the improper field management is likely to cause weeds whose colour and shape are similar to crops. Those factors make it hard to identify crops quickly and stably by traditional 2D image processing technologies. So the cauliflower seedling recognition method using binocular stereo vision and K-medoids was proposed in this paper. For the disparity map the Sum of Squared Differences (SSD) algorithm was used in the step of stereo matching. For the cauliflower seedling recognition the K-medoids algorithm was applied in the step of clustering. The experiment results showed that the average operation time of the SSD algorithm was 190ms. The real-time performance and matching effect of the SSD algorithm were superior to Belief Propagation algorithm (BP) and Dynamic Programming algorithm (DP). The average running time of the proposed method for processing the left image and its corresponding right images was 379ms, which meet the real-time requirements. The correct recognition rate of the method proposed was 98.75% of 240 pairs of cauliflower seedling images.

1. Introduction
Today, with the development of computer technologies, the computing capacity of computer has been greatly improved. And some experts have been studying on the application of stereo vision technologies in agricultural production for years.

Some Applications of stereo vision technologies for crops recognition in the natural field environment are shown as below. Li [1] applied a 3D time-of-flight camera to cauliflower seedlings and green bean plants recognition under weedy condition. However, manual thresholds were used which have poor adaptability. Smith [2] used a four-light photometric stereo apparatus to obtain high-resolution crop phenotypic texture, and applied it to weed detection, crop growth detection, potato size parameters acquisition and other fields. Panneton [3] et al. developed a binocular camera system to obtain 3D point clouds of crops and weeds in the field. Chen [4] et al. applied binocular stereo vision to early weed recognition, in this paper height information and row spacing information were used to identify weeds and crops in 3D point clouds space.

In this paper, cauliflower seedling recognition method using stereo vision and K-Medoids under weedy conditions in natural environment was proposed. This proposed method is to solve the problems of cauliflower seedling recognition rapidly, accurately and stably, under weedy conditions in nature environment, where the illumination conditions are changeable, the background of field is complex, and the colour and shape of the weeds are close to crops.
2. Materials and Methods

2.1. Image Acquisition Device and Image Processing Platform
The image acquisition device includes a laptop of Lenovo G480 20149, 8GB RAM, Inter Core i5-3210M @ 2.5GHz, powered by Windows 7 flagship 64-bit system SP1 (DirectX 11), and a binocular camera VR Camera (The resolution of the camera is 1280*480. The frame frequency of the camera is 30fps. The field of view is 120°. The baseline length of the camera is 60mm. The working distance the camera is 500mm to 2000mm. USB2.0). The image processing platform is OMEN by HP Desktop PC 880-p1xx, 8GB RAM, Inter Core i7-8700@3.20GHz 6 core, powered by Windows 10, 64 bit (DirectX 12). The image processing software is MATLAB R2016b (Math Works Corporation at Nedik, MA, USA). The camera calibration board is 30mm*30mm checkerboard calibration board. The cauliflower seedling images are shown in figure 1.

2.2. Binocular Camera Calibration and Stereo Rectification
Zhang Zhengyou binocular camera calibration method was use in the step of binocular camera calibration. The binocular camera’s intrinsic matrix, rotation matrix and translation matrix were obtained, and then these matrixes were used for binocular cauliflower seedling images rectification and original cauliflower seedling point cloud reconstruction. 24 pairs of calibration board images were used for binocular camera calibration.

In order to eliminate the radial and tangential distortion of the binocular cauliflower seedling images and make the left and right cauliflower seedling images satisfy the epipolar constraint. The Bouguet’s method was used in the step of stereo rectification. So that the binocular disparity searching method could be changed from 2D plane searching method to 1D linear searching method.

2.3. Binocular Stereo Matching
The Sum of Squared Differences (SSD) algorithm was applied to obtain disparity map of binocular images after stereo rectification. SSD algorithm is a local window stereo matching algorithm. The calculation formula of the disparity \( d_L(u, v) \) at the pixel point \((u, v)\) of left image \( I_L(u, v) \) is as shown in the formula (1):

\[
d_L(u, v) = \arg \min_{d \in \{0, 1, \ldots, d_{\text{max}}\}} \sum_{i=-m}^{m} \sum_{j=-n}^{n} [I_L(u+i, v+j) - I_R(u+i-d, v+j)]^2
\]

where \( d_{\text{max}} \) is the maximum disparity value and \((2n+1) \times (2m+1)\) is the matching window size. The disparity map \( D_L(u, v) \) is constructed from the disparity value of each pixel point \((u, v)\).

2.4. Original Point Cloud Reconstruction Invalid Point Removal and Point Cloud Down-Sampling
The 3D point cloud of the cauliflower seedling can be obtained by using the internal parameters of the left camera and disparity map \( D_L(u, v) \) through the triangle similarity principle. Invalid point removal refers to removing the Inf and NaN points from the cauliflower seedling point cloud and providing the effective point index. And then the cauliflower seedling point cloud was transformed from ordered point
cloud into disordered one. In order to reduce the running time of the clustering algorithm, the disordered point cloud needs to be down-sampled. The non-uniform box grid filter [5] was applied to the disordered point cloud for obtaining the sparse point cloud.

2.5. K-Medoids Clustering
Because K-medoids algorithm [6] is insensitive to the outliers and has good robustness, a partitioning Around Medoids (PAM) [7] algorithm of K-medoids algorithm is used to process the 3D point clouds after down-sampling for recognizing the cauliflower seedling points.

2.6. Outlier Filtering of Cauliflower Seedling Points
Due to the mismatched points in the binocular stereo matching step, a small number of outliers will present in the cauliflower seedling point cloud, after 3D point cloud reconstruction and point cloud down-sampling. And some of outliers would be classified into cauliflower seedling points in clustering step. So before cauliflower seedling clustering the K Nearest Neighbors (KNN) algorithm [8] was applied for outlier filtering, and the pure cauliflower seedling points will be obtained finally.

3. Results and Discussions

3.1. Stereo Rectification Analysis
The rectified images are shown as figure 2. The radial and tangential distortion of binocular cauliflower seedling images were eliminated after stereo rectification. And at the same time the left image and its corresponding right image satisfy the epipolar constraint. That is to say, the tow points in the left image and its corresponding right image of the same real place were located on one horizontal line. Because of interpolation and cropping in the binocular stereo rectification step, the rectified image’s resolution was changed from 320 * 240 to 357 * 257.

![Figure 2. Rectified images.](image)

3.2. Analysis of Stereo Matching Results
Figure 3 represents a line graph corresponding to the SSD values at pixel point (150, 150) of the left images, at this very moment the size of matching window was selected as 55*55 pixel, and the maximum disparity value was selected as 55 pixel. According to the nature of the SSD algorithm, when the SSD reach the minimum value, the corresponding disparity is the best matching disparity at the point (150, 150). The best matching disparity values for the three pairs of images are 39, 39, and 35 pixel, respectively. The results show that when the maximum disparity value is 55 pixel, it can meet the requirements of binocular stereo matching in different situations.

![Figure 3. SSD of pixel point (150, 150).](image)
Table 1. Running time of SSD, BP, DP.

| Image | Running time of SSD (ms) | Running time of BP (ms) | Running time of DP (ms) |
|-------|--------------------------|-------------------------|------------------------|
| a     | 192                      | 21585                   | 20074                  |
| b     | 190                      | 21644                   | 19861                  |
| c     | 189                      | 21310                   | 19945                  |

Table 1 shows the operation time of SSD algorithm, Belief Propagation (BP) algorithm [9] and Dynamic Programming (DP) algorithm [10]. The average running time of the SSD algorithm is 190ms, which is only 0.88% of BP algorithm of 21513ms and 0.95% of DP algorithm of 19960ms. So the real-time performance of SSD algorithm is much better than BP algorithm and DP algorithm.

Disparity maps of SSD algorithm, BP algorithm and DP algorithm are shown in figure 4. As can be seen in figures 4a-4c, the boundaries between the cauliflower seedling regions and background regions are obvious, and the broccoli regions and background regions are relatively smooth. As is shown in figures 4d-4f, the boundaries between cauliflower seedling regions and the background regions are blurred, and there are a large number of mismatched regions in the disparity maps obtained through the BP algorithm. So the disparity maps obtained by the BP algorithm have the worst matching effect. As is shown in figures 4g-4i, the details of cauliflower seedling regions and background regions can be well preserved in the disparity maps obtained through the DP algorithm, such as the cauliflower seedling edge contour information, the vein information and the weed details in the background regions. However, there is a clear horizontal streak phenomenon in figures 4g-4i. In summary, the matching effect of SSD algorithm is much better than that of BP algorithm and DP algorithm.

![Figure 4. Disparity maps of SSD, BP and DP.](image-url)
3.3. Analysis of 3D Reconstruction, Invalid Point Removal and Down-Sampling Results

It can be seen that there is no difference in the appearance between figures 5a-5c and figures 5d-5f, because the NaN or Inf points could not be displayed in all of the original point clouds. The point number of the point clouds were changed from 91749 to 85749, 86619, 86193, respectively, after the invalid points were removed. And the cauliflower seedling point clouds were changed from ordered point clouds into disordered ones. For further reduce the point number of cauliflower seedling point cloud and the operation time of the clustering, the non-uniform box grid filter was applied to the disordered point cloud to acquire the sparse point cloud. After that, although there only sparse point cloud left, all the features of the dense point cloud were preserved completely. The results are shown as figures 5g-5i. The number of points in the sparse point cloud becomes the system’s default minimum number of 4096.

![Figure 5. Original point cloud, Point clout after invalid points removal, Point cloud after down-sampling.](image)

3.4. Analysis of Cauliflower Seedling Points Clustering Results

Shown as figures 6a-6c, the cauliflower seedling points can be identified completely and stably by the K-medoids algorithm. The real-time performance of the recognition step will affect the real-time performance of the whole proposed method in this paper. The average operation time of the K-medoids algorithm for the cauliflower seedling recognition is 86ms. In summary, the K-medoids algorithm had a good recognition effect of cauliflower seedling and real-time performance.

Although the cauliflower seedling points can be identified entirely and stably by the K-medoids algorithm, some outliers would still present in classified cauliflower seedling points. So the K Nearest Neighbor (KNN) algorithm was applied for outlier filtering, and the ideal cauliflower seedling points were obtained finally as shown in figures 6d-6f.
4. Conclusions

In this paper, cauliflower seedling recognition method using binocular stereo vision and K-medoids is proposed. This method could overcome the inherent defects of traditional 2D machine vision in the recognition of cauliflower seedling under weedy conditions in natural field, especially, when the colour and shape of crops and weeds are close, the background of the field is complex and varied, the natural light illumination is uncontrollable. To process the left image and its corresponding right image with the resolution of both 320*240, the total average running time of the method is 379ms. The correct recognition rate of the method is 98.75% for 240 pairs of binocular cauliflower seedling images.

The SSD algorithm is proposed in the step of stereo matching. The experimental results prove that the SSD algorithm could satisfy the stereo matching requirements under different situations, while the size of matching window is selected as 55*55 pixel and the maximum disparity value is selected as 55 pixel. The real-time performance and the matching quality of the SSD algorithm are better than BP algorithm and DP algorithm. To process the rectified left image and its corresponding right image with the resolution of both 357*257, the running time of SSD algorithm is 190ms.

Acknowledgments

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