（要約）

Image Processing of a Binocular Stereovision System for Strawberry Harvesting Robot

（イチゴ収穫ロボットのためのステレオビジョンシステムの画像処理）

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博士論文の要約

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Strawberries are one of the most popular fruits in Japan, and are profitable for farmers because of their high price. Japanese strawberries are mainly grown in greenhouses and have a long, labor-intensive harvest season, which has hindered the expansion of production scale, so the processes need to be automated.

In previous studies, the strawberry harvesting robot's machine vision was mainly based on several plane pictures without stereoscopic vision, which used color information, morphology, edge extraction or neural network to detect the strawberry region and then give enough stem position information. The detecting accuracy for single strawberry was high. However, when the strawberries are overlapped each other, the stems are dense, or fruits (including unripe fruit) and leaves are crowded together, the detecting accuracy was extreme low. Moreover, considering the actual cultivation conditions and the problems indicated in previous studies, there is a low rate of accuracy for detecting the strawberry peduncle using images on multiple planes without stereovision even for a particular variety of strawberry. For successful strawberry picking, the robot end-effector must be provided with sufficient information on the peduncle position. Meanwhile, for strawberries that are sorted according to shape and size, the shape information will be useful for the automatic sorting and packing processes.

Inspired by the earlier studies, with the goal of obtaining the 3D shape (surface information) and peduncle position of the strawberries(even for the overlapped strawberries), a new system was proposed: a binocular stereovision system capable of reconstructing the 3D shape of a strawberry and calculating the 3D coordinate position of the peduncle.

The system worked as follows: in the strawberry detection operation, the binocular cameras simultaneously acquired left and right images of the plant. Then, the strawberries and segment of the peduncle region were detected. For the peduncles, the picking point was determined from the lines

in the left image and the corresponding lines in the right image, using the Hough method. Having established the 2D coordinates of the picking point in both images, the stereovision algorithm was applied to calculate the corresponding 3D world coordinates. Then, the 3D coordinate data was supplied to draw the position of each strawberry in a new picture to determine the picking order. Finally, a template matching algorithm was used to reconstruct the strawberry surface.

For recognizing/detecting of the strawberries, two methods were developed. The first one based on Histogram of Oriented Gradient (HOG) descriptor associated with a Support Vector Machine (SVM) classifier. The detection includes two stages: first get the HSV color information to detect the strawberry-like region, use the 5 Region of Interest (ROI) regions to calculate the HOG descriptor, and then feed it to the HOG/SVM classifier to detect the strawberries. The dimensions of the vector were reduced effectively and can achieve higher detection speed and accuracy. The final results show that this classifier achieves good detection accuracy (86.53%) performance at reasonable run time, and can deal well with the slightly overlapped strawberries. The second one used the 3D points cloud. After obtained the 3D points cloud (shape information) of the strawberries, used the clustering method to detect the overlapped strawberries. For the seriously overlapped strawberries, the accuracy was about 52%. Combined these two methods together, the final accuracy can be calculated as 71% in the whole study, it was considered to be better than the previous studies.

For the setup and the peduncle position accuracy, in order to find the optimal spacing of the setup, after detected the strawberries, several different sized spaces between the binocular cameras were tested. The binocular cameras with a spacing of 55mm performed best, and when the distance between strawberries and the cameras was about 500 mm with the highest accuracy (the RMSE of the calculated Z coordinate (distance) was 1.958 mm). Finally, according to the strawberries distance and size, the algorithms for calculating the picking order were proposed.

For the 3D shape of the strawberry, it was reconstructed using the binocular stereovision system based on pattern matching algorithm. The positional RMSE in the reconstructed contours were less than ±1 mm for most of the tested samples. The results also showed that this system can reconstruct the strawberry's 3D shape as effectively as a laser scanner.

Keywords: Strawberry, Binocular, HOG/SVM, Peduncle location, 3D points could