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# A VISION SYSTEM TO EFFICIENTLY HARVEST FRUITS WHICH GROW IN CLUSTERS

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***Abstract:*** Automatic fruit harvesting systems usually come up against some difficulties because of the environment in which they operate. In this paper, we will consider the problem of distinguishing individual fruits which grow in bunches or clusters. A cluster may contain fruits with similar color and texture, what makes them appear in the image as a unique uniform region. Therefore, it is not easy to distinguish the individual fruits using traditional detection methods. We propose a new vision system composed of two stereoscopic cameras and a matrix of laser diodes that is able to distinguish fruits that grow in bunches. A prototype of a harvesting robot based on it has been developed and tested with real strawberry crops in hydroponic greenhouses. Some examples of these experiments are included.

***Key words:*** *harvesting, fruit, robot, greenhouses.*

## INTRODUCTION

In the agricultural sector, there is a big interest in the substitution of the human handwork by automatic systems, due to production cost savings. Nowadays, many of the agricultural tasks are already automated, but there are still some activities that are carried out by human because they require certain skills. One of these activities is the harvesting of delicate fruits. In order to automate these tasks, it is necessary to develop robotic systems capable of harvesting each mature fruit individually, without causing damage to the fruits of the crop. Various systems have been studied and proposed for different types of crops such as apples, oranges, peaches, melons, watermelons, tomatoes, grapes, cucumbers, strawberries or mushrooms (see [6]).

Generally, these systems consist of an autonomous vehicle that travels across the harvesting zone provided with a vision system and a manipulation system. The vision system detects the fruits (distinguishing them from the rest of the crop), decides whether they are ready to be harvested or not and estimates their positions. The manipulation system is usually a robotic arm that moves an end-effector to the position previously determined by the vision system and performs the harvesting in an appropriate way.

Despite this simple principle of operation, automatic harvesting systems, and more specifically their vision systems, come up against some difficulties since the environment in which the system must operate is uncontrolled. Some well known limiting factors are occlusions of the mature fruits by leaves or by immature fruits, overlapping of several mature fruits, light reflections and shadows, strong illumination variations during the day, etc. These difficulties must be overcome in order to detect a high percentage of mature fruits, so that the system may be cost-effective. In this paper, we consider the problem of distinguishing individual fruits which grow in bunches or clusters.

In section 2, the main characteristics of vision systems reported for automatic harvesting are shortly reviewed. In section 3 the considered problem is stated and we propose and describe a new vision system to solve it. In section 4 we include some examples. Finally, section 5 concludes the paper.

## VISION SYSTEMS FOR FRUIT HARVESTING

A vision system for fruit harvesting must be able to perform the two main tasks: First, to detect the mature fruits in its field of vision and differentiate them from the other crop elements (leaves, stems, branches). And second, to locate the fruit in the 3-D space, calculating the coordinates to which the robotic manipulating system will be directed.

Several vision systems for harvesting applications have been reported (see [3] for a survey). Typically, the key element of these vision systems is a B/W or color camera which takes images from the harvesting scene. The detection of the fruit on those images is done by an image processing algorithm that normally includes a segmentation based on the intensity or color of each pixel or on the shapes that appear in the images. For the location of the detected fruits in the 3-D space different methods have been suggested.

One of the more typical methods is the use of a range measuring device, such as an ultrasound device or a laser range-finder [4], which complements the 2-D camera information with the third coordinate.

Another solution is the use of two cameras: one fixed on the vehicle, which globally analyses the scene, and the other one mounted on the manipulator hand, that guides the robotic arm as it approaches the fruit.

Another technique is stereoscopy, which consists on two cameras taking images from the scene from slightly different points of view. An object observed by both cameras will appear in both images at different positions. The 3-D position of the real object can be obtained from its 2-D positions in both images by means of triangulation. The main difficulty of this method is to obtain the points in both images that correspond to the same point in the real scene, which is known as the correspondence problem. This type of vision system has been proposed for several automatic harvesting systems, for example, for a cucumber picking robot ([8] and [9]) or for an orange picking robot [7].

## PROBLEM STATEMENT AND PROPOSED SOLUTION

All vision systems for fruit harvesting should overcome the difficulties produced by the uncontrolled environment in which they operate. In this paper, we consider the problem of distinguishing individual fruits which grow in clusters. A cluster may contain fruits with similar color and texture, what makes them appear in the image as a unique uniform region. Therefore, it is not easy to distinguish the individual fruits using traditional detection methods, based on color or shape. Some solutions that have been proposed are not totally satisfactory (see [2], [4], [5], etc.).

In order to solve the problem in a general case, it would be desirable to retrieve the range information that was lost in the imaging process, that is, the three-dimensional information of the surface of the bunch, in a fast, inexpensive and effective way.

There are several techniques to obtain 3-D information from a scene, which can be classified into passive and active methods [1]. The most widely known passive method is stereo vision, whose main disadvantage is the correspondence problem, as previously said. This problem can be considerably alleviated by an active method, like structured lighting. The solution proposed in this paper (patent pending) is to use a stereoscopic vision system and a matrix of optical low-cost spot laser diodes to project their light whenever is necessary to distinguish individual fruit that grow in bunches.

The stereoscopic vision system is composed of two CCD color cameras, with parallel optical axis that point to the fruit harvesting region. The matrix of laser diodes is mounted on a pan-tilt platform, which is used to orientate the lasers towards the desired place. In each harvesting position, each camera takes an image of the scene, which is then processed in order to remove noise and distinguish those pixels whose color corresponds to the fruit characteristics from those that correspond to other elements (leaves, stems, background, etc). The resulting image contains groups of connected pixels or “blobs”, each one corresponding to a fruit or to a cluster of fruits.

Once the blobs in the images are found, the 3-D position and size of the correspondent fruit or cluster is calculated using the stereo information and it is decided whether the blob corresponds to a single fruit or to a cluster. If it corresponds to a single fruit, the positions of both the centroid and the upper point of the fruit are used to estimate the position of the peduncle to which the robotic arm will be steered. If the blob is a cluster of fruits, the algorithm to individualize each of the fruits of the cluster is initiated.

In order to discriminate the individual fruits in a detected bunch, the pan-tilt platform is oriented towards the cluster and the matrix of lasers is used to project a reticule of luminous spots during a short period of time. Simultaneously, the stereoscopic camera system takes a pair of images of this scene, which are then processed to detect those pixels inside the previous blob area whose intensity has notably increased and whose color correspond to the color of the laser light. After removing the noise, the images are composed of small blobs corresponding to the laser spots in the surface of the bunch. Next, the correspondence between the two images and the 3-D reconstruction of each spot is performed, obtaining, this way, a map of three-dimensional points over the surface of the bunch of fruits. With this information, the sets of spot-points belonging to each individual fruit are determined by calculating the 3-D distances among every pair of points in the reticule and clustering them with reference to the typical fruit size. Hence, the position of each fruit in the bunch is obtained with an accuracy of the order of the centimeter (depending on the gap between the light spots, that is, between the lasers of the matrix).

Finally, in our algorithm, the fruit which is closer to the cameras is selected to be harvested first. The positions of both the centroid and the upper point of this fruit are calculated and used in a mathematical algorithm to estimate the position of the peduncle in order to direct the robotic arm.

### An example

A prototype of a harvesting robot based on the above vision system has been developed and tested with real strawberry crops in hydroponic greenhouses. As an example, some experiments of a real harvesting moment are shown below. Fig.1a and 1b show a portion of the harvesting scene captured by both stereoscopic cameras, where a real bunch of strawberries can be seen from the two different perspectives. The bunch is composed of three strawberries. The two higher ones are mature (bright red) while the lower one is immature (pale red and green). The results of the color segmentation of these images are shown in Fig.1c and 1d. As expected, the immature strawberry does not appear in these images.

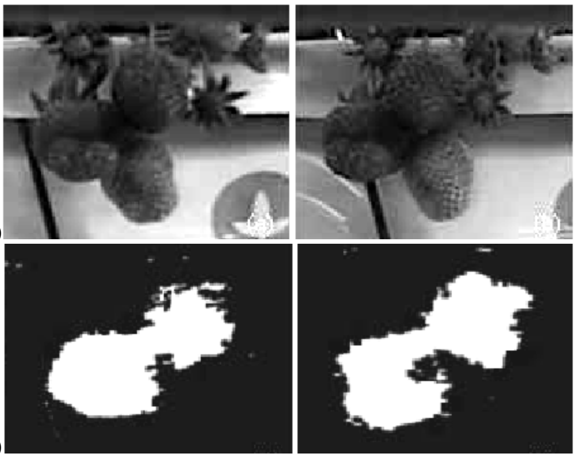


*Figure 1. Portion of left (a) and right (b) images of a harvesting scene taken with the stereoscopic cameras and color segmentation of these images (c and d)*

To discriminate the closest fruit to the cameras, the matrix of laser diodes illuminates the bunch and the cameras take a pair of images. These images are shown in Fig.2, where the light spots can be distinguished on the surface of the fruits.

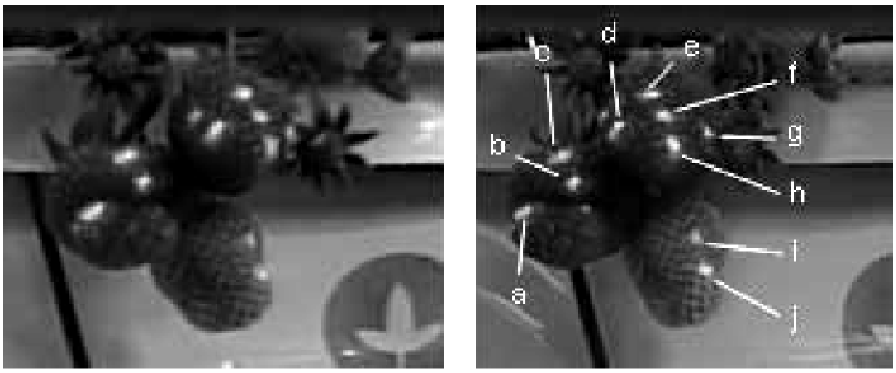


*Figure 2. Portion of left and right images taken with the stereoscopic cameras at the moment of the laser illumination*

In this case, the processing system reconstructs the 3-D position of the spots (see Fig. 3) and determines that 5 spots (d, e, f, g and h) belong to the closest fruit (the highest in Fig. 2). One spot on the surface of this fruit (the one on the left) could not be reconstructed because in the right image the correspondent blob was so small that it was considered as noise. With the 3-D positions of the 5 remaining spots, the coordinates of the point to which the robotic arm will be then directed were determined. It was checked that the peduncle of that fruit was in that position, with an error of less than 0.5 cm.

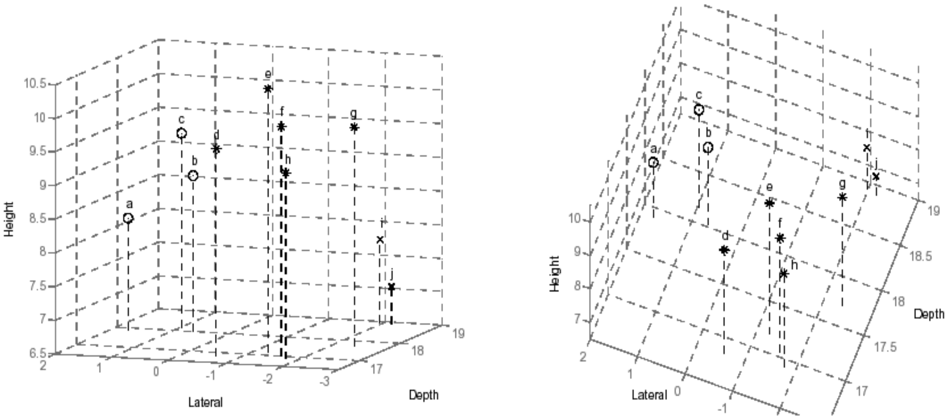


*Figure 3. 3-D reconstruction of the laser spots: two perspective views*

## CONCLUSION

In this paper we propose and evaluate a new vision system composed of two stereoscopic cameras and a matrix of laser diodes, that, unlike most traditional vision methods, is able to distinguish fruits that grow in bunches. This is of utmost importance in some types of crops. As opposed to scanned range finder based method, this method is much faster, what makes it perfectly suitable to the real-time requirements of an automatic harvesting system.

Furthermore, it can be used regardless of the bunch size and the layout of its fruits. A robot based on it can be the basis of a truly operational multifunction harvesting system with industrial application in real crops. A prototype of a harvesting robot based on the above vision system has been developed and tested with real strawberry crops in hydroponic greenhouses. The tests have shown that the system can accurately detect the position of each mature fruit of a bunch. Further research should include an exhaustive analysis of the robot performance in the greenhouse, in terms of percentage of harvested mature fruit and percentage of harvested immature fruit for both single and clustered fruit. Considering this analysis, some improvements could be done.

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## VIZUELNI SISTEM ZA UBIRANJE PLODOVA KOJI RASTU U GROZDOVIMA

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***Sadržaj:*** Primena automatskih sistema za ubiranje voća obično nailazi na teškoće obziorm na okolinu u kojoj rade. U ovom radu razmatran je problem identifikacije pojedinačnih plodova koji se razvijaju u grupi plodova. Skupovi plodova mogu da sadrže u sebi plodove slične boje i teksture što dovodi do toga da se na slici pojave kao uniformna jedinstvena oblast. Iz toga razloga nije jednostovano identifikovati pojedinačne plodove upotrebom uobičajenih metodama. U radu je dat predlog novog vizuelnog sistema koga čini dve steroskopske kamere i matrične laserske diode koje mogu da razdvoje plodove koji rastu u skupu. Na osnovu ovog sistema napravljen je prototip robota za ubiranje koji je ispitan u ubiranju jagode gajene u zaštićenom prostoru, u hidroponskom sistemu. Prikazani su neki primeri iz ovog eksperimenta.

***Ključne reči:*** *ubiranje, voće, vizuelni sistem, robot.*