A Leaf Detection Method Using Image Sequences and Leaf Movement

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Abstract

Besides harvesting the fruits, a very time demanding task is removing old leaves from cucumber and tomato plants grown in greenhouses. To be able to automate this process by a robot, a leaf detection method is required. One possibility for the detection is to exploit the different dynamic behaviour of leaves and stems in case they are excited by mechanical impulse such as an airstream. The objective of this paper is to investigate this technique using a camera and image analysis. For the experiments carried out, images of a tomato crop were used. Images were taken with a digital camera from different distances. To generate an air stream, different radial blowers were used. A sequence of 5 digital images was recorded with a sample rate of 1 second with different settings. To find the differences between the images, the intensity of the images were mathematically subtracted. The resulting binary images were further processed with the aim to extract the leaf positions. These steps included automatic thresh-holding, noise reduction and morphological image analysis operations. It was found that moving objects in the images could be detected using the method described above. Budging objects could only successfully be traced if colour, intensity or structure of the moving object differed with the colour, intensity or structure of the background. The blowing direction had a strong influence on the movements. It is concluded that with this technique not only leaves can be detected but also other parts as e.g. fruits, stems and branches can be discriminated.

INTRODUCTION

Already many years ago research was focused on robotics in horticultural crop production (e.g. Tillett, 1993; Edan, 1995). The reduction of labour costs, problems with the availability of skilled labour and the improvement of the production process both quantitatively as well as qualitatively were the main driving forces for research on the development of an autonomous harvesting robot for cucumber in greenhouses at Agrotechnology & Food Innovations, formerly known as IMAG B.V. (Van Henten et al., 2002, 2003).

Many of the robotic applications require locating the position of a special part of the plant, often vision systems are used for this purpose. McFarlane (1993) reported a system to detect segments of microplants, Yang (1993) and Wolfe and Sandler (1985) worked on a stem detection algorithm for different fruit. Meuleman et al. (2000) developed a cucumber fruit detection system. With vegetables, next to harvesting a very time demanding task is removing old leaves from the plants. This task has not only to be done for cucumbers but also for tomatoes, which are grown using a high wire cultivation system in Dutch greenhouses. To be able to automate this process by a robot, a leaf detection method is required. One possibility for the detection could be to exploit the different dynamic behaviour of leaves and stems when excited by a mechanical impulse, such as induced by an air stream. One may expect that leaves will show a stronger motion than stems and fruit. Analysing the differences in several images of the same scene should give the possibility of extracting the leaf positions. The objective of this paper is to investigate this technique. As far as the authors are aware, the use of motion analysis for plant detection has not been described in literature before.

MATERIALS AND METHODS

The experiments were carried out in February 2003 in an experimental greenhouse. In this greenhouse a normal tomato crop (*Lycopersicum lycopersicum*) was grown using the high-wire cultivation growing system. At a later stage some of the tomato plants were transferred to a laboratory where another set of images was acquired and analysed.

The camera used was a progressive scan 1 CCD chip colour camera (Sony DFW-X700), which allowed recording 15 fps (frames per second) at a resolution of 1024 x 768 pixels. The image analysis was carried out using the software LabView 6.1 and the IMAQ Vision builder (National Instruments) running on the Microsoft Windows 2000 operating system.

For the experiments in the greenhouse no artificial lighting was provided. For the recordings done in the lab the scene was illuminated using standard neon tubes.

In the greenhouse images of the crop were taken from 3 different camera distances: close (recording area of approx. 60 x 45 cm), normal (approx. 90 x 70 cm) and far (approx. 110 x 80 cm). For the first two settings a plate with light-brown background was set behind the crop row, for the "far"-setting no special background was provided, this resulted in a light background where the greenhouse-windows were visible. To generate an air stream, a radial blower mounted on a plant protection sprayer was used. The air stream was applied from an angle of approx. 45 deg. The distance between the blower and the crop row was 5 m. The machine allowed three different speed settings for the ventilator: slow (3.5 m/s), medium (5 m/s) and fast (6 m/s). For all camera distances and speed settings a sequence of 5 images was recorded with a sample rate of 1 second.

For the laboratory images a black background (black tissue) was mounted behind the plants. Three different camera positions were used: maximum detail (recording area of approx. 30 x 23 cm), very close (approx. 40 x 30 cm) and close (approx. 90 x 70 cm). A handheld blower (2500 rpm, wind speed approx. 5 m/s at a distance of 30 cm) was used to generate an air stream. The blower was hold at a short distance (20-50 cm) to the plants and moved back and forth a little bit during the image acquisition to cover the whole scene. Sequences of 5 images each were recorded for 4 different blowing directions: top-down, down-top, front and at an angle of 45 degree. Fig. 1 shows an example of such an image sequence.

All image-processing operations were carried out with greyscale images. A greyscale image is an 8-bit image whose palette contains 256 shades of grey. To find the differences between the 5 images, 2 images each were processed with two different basic arithmetic operations as described below. The pixel-by-pixel operations produced a resulting image in which the value of each pixel was based on the values of the pixels with the same co-ordinates in the two input images.

Method 1: Absolute Difference

One image gets subtracted from another image and the absolute value of the difference is returned. If images I_1 to I_5 are the input images, each pixel of the resulting image D is assigned the value

$$p_d = \sum_{i=2}^{5} |p_1 - p_i|$$

where p_i is the value of pixel P in image I_i and p_d is the value of pixel P in the resulting image D. If the resulting pixel value is greater than 255, it is set to 255.

Method 2: Subtraction

One image gets subtracted from another image. If images I_1 to I_5 are the input images, each pixel of the resulting image S is assigned the value

$$p_s = \sum_{i=2}^{5} \max(p_1 - p_i, 0)$$

where p_i is the value of pixel P in image I_i and p_s is the value of pixel P in the resulting image S. If the resulting pixel value is greater than 255, it is set to 255.

Fig. 2 to Fig. 4 show the results of the application of these methods. The resulting images were further processed with the aim to extract the position of the tomato leaves. After segmenting the objects of interest with an automatic threshold, objects in the image smaller than 5 pixels were removed as part of a noise reduction operation. Furthermore, the morphopogical image processing operations erosion and dilation were used to remove long and small structures. The intersection of this image with the segmented image gave a good representation of the leaf-area present in the scene. Fig. 5 illustrates this procedure.

RESULTS AND DISCUSSION

In Fig. 6 some results of the image processing are presented. The regions coloured grey and white in the resulting images represent areas detected in the summed up difference images. The white coloured area is the remaining area after the advanced image processing procedure (noise reduction, removing of small structures and objects).

Summarizing it can be concluded, that moving objects in general, but leaves in particular, can be detected using both methods described above. The effect of different calculating methods can be seen in the images in Fig. 3 and Fig. 4. Using the absolute differences, highlights in the resulting image all regions were the leaves moved over. In case of leaves shifting heavily this results in an outstretched region so that it is difficult to determine the accurate position and form of a leave any more.

Analysis of images acquired with a large object distance did not result in detailed information of the leaf position. Only the images taken (very) close to the plants/leaves made it possible to extract the leaf area.

A slow air stream speed did not cause enough movement to be able to extract leaves from the images. Medium and full speed settings worked better although using the high speed setting the risk of moving the whole plant (incl. stem) increased.

The air stream direction had a strong influence on the movement of the plant parts. Blowing from the front, down-top and 45 degree direction caused the leaves to move much more than blowing from the top-down direction. Choosing a proper direction of the air stream will improve the information about the leaf position.

Moving objects can only successfully be traced with this method, if the colour, intensity or structure of the moving object differs from the colour, intensity or structure of the background. This means that detecting a moving green leaf in front of a green background will be less successful than detecting the same leave in front of a i.e. white or black background. For the experiment carried out, a high contrast background was always provided. However, if a leaf or group of leaves was moving in front of other leaves or a green stem it was difficult to find it back in the difference images. The white wire where the plant is attached to could be detected easily in the images with a dark background; having a bright background this was not possible any more.

The edges of the plant stem and also of the fruits become also visible in the difference images. The described technique can therefore be used to determine the position of the branches and the points of attachment of the leaf stalks. Having a dark background (or creating a dark background using intense flashlight in combination with a short exposure time) the method illustrated can be used to detect the position of the white coloured plant wire. If this information is unwanted, it is in most of the cases possible to remove it by the advanced image processing techniques described.

Detecting the part of the leaf that is shifting in the wind does not automatically give information about where the leaf exactly is attached to the plant stem or where the leaf is located without blowing – its rest position. From a 2-dimensional image the leaf position in space cannot be determined; additional range-imaging techniques such as *e.g.* stereovision or laser triangulation must be applied to solve this task.

CONCLUSION

It can be concluded, that using sequences of images and movements induced by a mechanical impulse such as an air stream caused by blowing is a method, which gives not only the possibility to detect leaves but also to discriminate other parts as e.g. stems and branches or the wire the plant is attached to.

ACKNOWLEDGEMENTS

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Figures

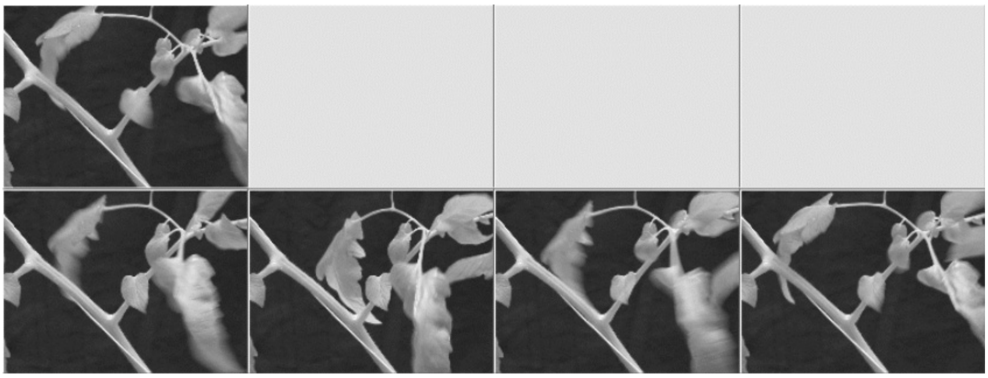

Fig. 1. Sample sequence of 5 images. Top row: I_1., bottom row left to right: I_2, I_3, I_4 and I_5.

Fig. 2. Subtract images from sequence shown in fig. 1. From left to right: I_1-I_2, I_1-I_3, I_1-I_4, I_1-I_5.

Fig. 3. Result image *D,* absolute difference method.

Fig. 4. Result image *S*, subtraction method.

	Original image (Result image *S*, subtraction method).
	Automatic threshold: Segment objects of interest. Noise reduction: Remove objects smaller 5 pixels.
	Morphology: erode and dilate to remove small objects and long and small structures.
	Calculate the intersection of dilated image with threshold image. Show result as overlay of original colour image.

Fig. 5. Step by step procedure of segmenting leaves.

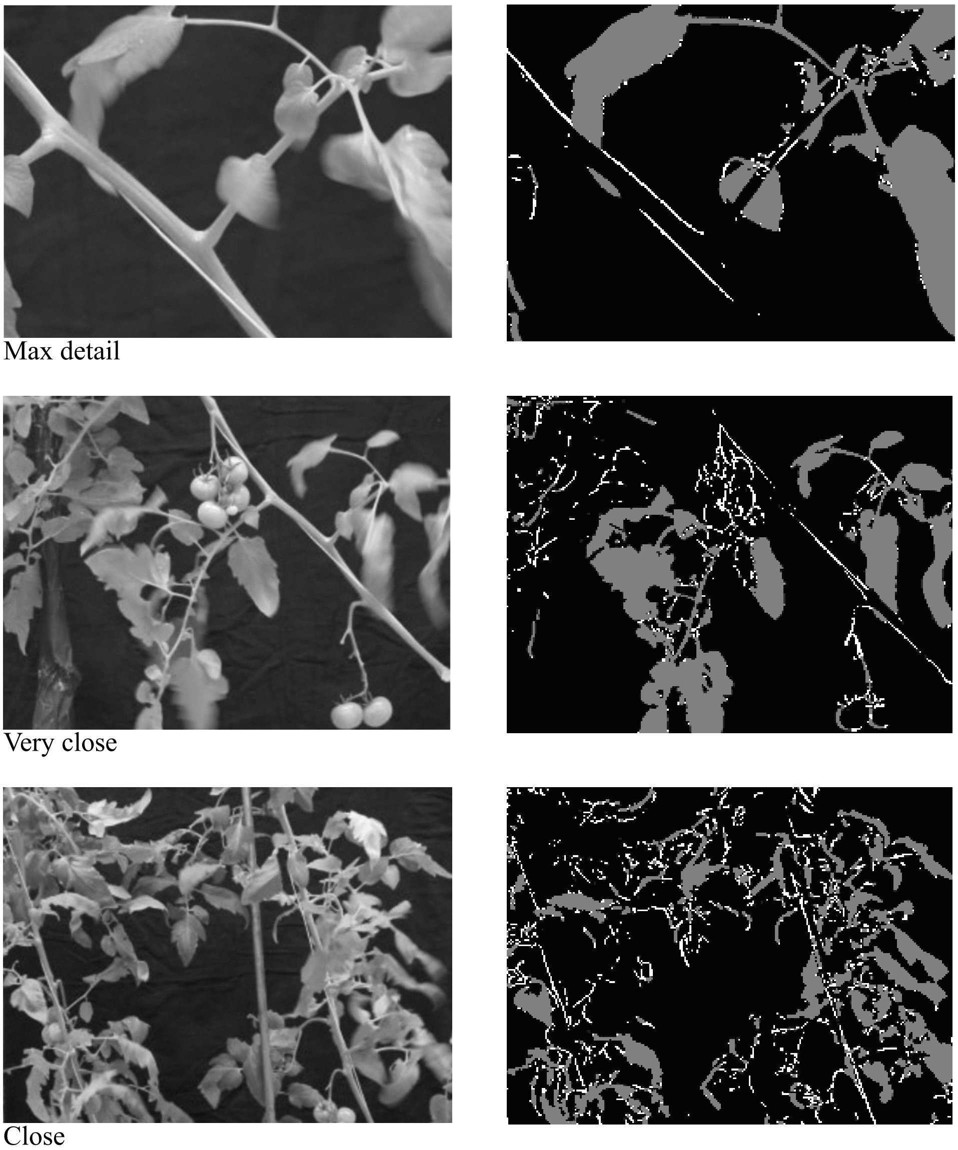

Fig. 6. Sample images taken in the laboratory, different distances, wind direction “down-top”, method: “subtract”. Left column: original images. Right column: processed images. Grey and white regions: result after applying automatic threshold on the resulting image. Grey only: segmented leaves after advanced image processing (see text).