Automated Rose Cutting in Greenhouses with 3D Vision and Robotics: Analysis of 3D Vision Techniques for Stem Detection

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Abstract

The reduction of labour cost is the major motivation to develop a system for robot harvesting of roses in greenhouses that at least can compete with manual harvesting.

Due to overlapping leaves, one of the most complicated tasks in robotic rose cutting is to locate the stem and trace the stem down to locate the cutting position. Computer vision techniques like stereo imaging, laser triangulation, röntgen imaging and a new technique, called reverse volumetric intersection, are evaluated in this paper to determine which technique is most feasible for the task. Experiments with the techniques applied on different rose plant indicate that reverse volumetric intersection shows that this technique is most promising to locate the stem down to the cutting position in terms of robustness and costs.

INTRODUCTION

High labour costs and poor utilisation of product space are two of the areas where cost quickly add up for cut rose growers growing in traditional gutters. Also the poor availability of low cost untrained personnel for the task of rose cutting, the need of walking in and out long pathways and the tedious handwork is becoming a threat for future rose growing in the Netherlands. This has been recognised by several cut rose growers, system developers and research institutes several years ago and a task force was initialised to develop a mobile rose transportation system that bring the roses to the labourer instead of the other way around. At this time several mobile rose transportation systems are commercially available, varying from moving gutters with plants to individual plants in a single pot. Although a 30-40% reduction in labour cost is feasible with the mobilisation of the roses, reduction of manual labour will be a final factor of cost reduction (Wijchman, 2004). Also, with the mobilisation of the roses, the use of a robotic harvester instead of a human one is the next logical step in the automation process. Therefore, several research groups, institutes and commercial companies in the Netherlands have initiated the development of a robotic harvester for cut roses.

Unlike previous developed robotic harvesters (van Henten et al., 2002; van Henten et al., 2003), the robot harvester for cut roses will be located on a fixed position in the greenhouse and the rose plants are transported to the robot harvester by means of a mobile transportation system. The major parts of the robot harvester consists of robots for the cutting and handling of ripe roses and a comprehensive vision system for the visual guidance of the robots. The complicated task of rose cutting can be subdivided in a number of subsequent operations. The first step is pre-selection where a vision system detects the presence of potential ripe roses. When a potential ripe rose is detected, the next step is the determination of the ripeness stage of the rose candidate. If the rose is ready to harvest the vision system of the robot harvester must determine its corresponding stem, trace the stem to the connection with the rose plant, cut the stem at the correct cutting point and remove the rose from the cutting area. The detection and tracing of the corresponding stem between surrounding stems is the most challenging part of the research. The reason for this is that the use of robots for rose cutting requires 3D information about stem position and cutting location and thus the vision system must be able to determine this 3D location (XYZ). Furthermore, the entire stem is not visible from a single viewpoint due to occlusion from other stems and leaves. This requires the use of multiple views from the same stem at different angles and positions. The 3D information must be extracted from the multiple views and combined to locate the correct stem of the ripe rose in a combined 3D space. In this paper, imaging techniques like colour and röntgen stereo imaging, laser triangulation and a new concept called Reverse Volumetric Intersection (Kuzo et al., 2001; Niem et al., 1994) are evaluated for best performance for the application of 3D stem extraction. The evaluation is solely performed on the visual appearance of stem or parts of the stem in the resulting 3D images. The pros and cons of each individual technique for the purpose of automated rose harvesting in greenhouses is also discussed.

MATERIAL AND METHODS

Imaging and Lighting Setup

To obtain homogeneous lighting in the camera's field of view, a special lighting chamber with 14 high-frequency fluorescent tubes (6500K) is developed. A computer controlled rotation table is located in the middle of the lighting chamber to rotate the plant in front of the image acquisition equipment. The used camera’s are two 1ccd Dolphin AVT color camera’s with 8 mm Cosmicar lenses. The distance between camera and plant is 1.5m.

Stereo Imaging

For stereo imaging (Klette et al., 1998; Trucco et al., 1998) a stereo head is constructed with an inter spacing of 5 cm between the cameras. After each 15 degrees of rotation a new image set is recorded, resulting in 48 images of a single plant. The left camera of the stereo is aligned with the center of the turning table. For an initial evaluation of the feasibility of stereo imaging for stem detection commercially available stereo matching software (SRI International's Small Vision System: http://www.videredesign.com) is used. Although the matching software is based on correlation and thus not appropriate for stem matching, it will give an adequate indication of the stereo concept for stem matching.

Laser Triangulation

In laser triangulation, a sheet of laser light is used to illuminate the sample, thus producing a line of light on the sample. When the sample or the camera is moved at constant velocity and perpendicular to the sheet, the produced light pattern can be used to retrieve shape information. Detailed information about later triangulation can be found in literature (Klette et al., 1998; Trucco et al., 1998). In our case, the camera is mounted on a vertical translation table and is moved at constant speed along the rose plant. For sufficient resolution, about 600 images per plant are required. From each individual image, depth is reconstructed from known positions and angles between camera, laser and plant.

Reverse Volumetric Intersection

Standard Volumetric Intersection (VI) uses the outer contour of the object from multiple angles to obtain a 3D volume (Kuzo et al., 2001; Niem et al., 1994). From each angle, voxels in 3D space which are located outside the object contour are removed from 3D space. This results in a 3D space where only object voxels remain after voxel removal from multiple views from different angles. A drawback of traditional VI is that small misalignments in imaging set-up result in falsely removed object parts which is dramatic for stem detection as stems are only a few voxels wide and thus easily removed. Although this is less important for fixed objects, small movements of the roses may effect the results severely. A new variant of the VI concept is the Reverse VI concept, in this case we start with an empty 3D voxel space and objects visible from different angles are projected as intersecting lines in the 3D space by accumulating the corresponding voxels at line crossings. For the example given in Figure 1, two views from two object from different angles results in two crossing planes of different widths in the 3D voxel space. Each intersection of an object from two or more different viewing angles accumulates the position of that object in the 3D space.

Röntgen Imaging

The disadvantage of the above concepts is the susceptibility for hanging leaves in front of the stem. If this is the case, more images from multiple angles are required to obtain sufficient dept information. In the worst case, the stem cannot be detected from any angle in the corresponding images and thus no 3D information for that particular position can be obtained. One technique known to be able to visualise the interior of objects is röntgen imaging. Although röntgen imaging itself gives no 3D information, stereo röntgen does. To examine the feasibility of stereo röntgen imaging for cut rose stem detection, röntgen images of a rose plant are acquired with a yxlon röntgen system (http://www.yxlon.com/index.htm).

RESULTS AND DISCUSSION

The algorithms for the above mentioned techniques of laser triangulation, stereo imaging and Revere Volumetric intersection have been implemented an tested on rose plants.

Results of Stereo Imaging

A representative result of stereo imaging is shown in Fig.2. The original left image of the stereo head is also shown for visual comparison. The software used to obtain the disparity image uses correlation to match objects in the scene. As a result the disparity map shows thickened objects with a width that depends on the selected correlation kernel width.

The gray value of a pixel in the disparity image represents the estimated (XYZ) position. Although the result show adequate depth estimation for clear parts of the stem or leaves, correspondence becomes a problem when leaves and stems are close together. Also, in case of partial overlap in just one image of the stereo pair, no match can be obtained and no depth information is available.

A second experiment has been carried out where prior to the matching a stem detection is performed. The results of the stem detection serves as input for the matching software. The results are also shown in Figure 2. This image shows the real problem with stereo matching; at the top of the rose plant the stem position can be detected, but at the lower part of the plant, almost no depth information could be obtained. It is obvious that this region is the most important region of the plant as the cut action takes place here. After an examination of all processed stereo plant images it shows that the lack of depth information in those regions is due a failure of the object matching, a stem is only visible in one of the images of the stereo pair and thus no depth information is available. Also, no object matching could be performed when a stem was in front of the leave. The green stem in front of the green leave background could not be detected by the matching software.

Results of Laser Triangulation

In situations as discussed above where a green stem is positioned in front of a green leave laser triangulation should be able to estimate the depth information in these situations. The laser triangulation results of the same rose plant as used in the stereo imaging experiment is shown in figure 3. The image shows more depth information of stem parts compared to the stereo imaging results. However, occlusion from either laser or camera results in missing depth information, as shown in the upper part of the plant. Also, depth information is missing in the lower part of the plant and thus laser triangulation form multiple angles is also required here.

Results of Reverse Volumetric Intersection

The rose plant was placed on a rotation table in front of a color camera. An image of the plant was captured every 15 degrees of rotation resulting in 24 images of a single plant. A dedicated stem detection procedure was developed to remove all objects but stems. Only stem positions were placed into the 3D accumulator space. A stem visible in two or more images already results in a crossing of two intersecting lines in the 3D space. Each extra line through that crossing increases the accumulator at that position. The value of the accumulator is represented with a colour in the images. Figure 4 shows the results of a plant with three stems which has been processed. In the first column, the original image of the plant is shown for visual comparison. The images in the second column show two planes from the top view (Z-axis) of the 3D space, the images in the third column show two planes from the side view (x-plane). The first slider in the images represents the relative position in the 3D space, the second slider represents the thickness of the extracted slices which are summed and shown in the figure. In the first image of the second column 2 crossings are visible, these crossings represent the two top roses. In the second image of the second column, the three crossings represent the three stems. Note that the 3D cube is rotated 90 degrees clockwise. In the third column, two planes from the x-axis are shown. In the first row, the two stems are clearly visible while the third one is vaguely visible. In the following intersection, the top of the third stem is visible more clearly. The cluttered values at the lower part of the 3D space (as shown in the x-axis planes) are due to the false stems detected at the bottom of the rose plant, these stems are below the actual cutting point. The next step with the RVI concept would be the detection of the stems in the 3D accumulator space. Hough based techniques can be used to obtain the stems at the crossings (Gerig, 1987).

Röntgen Imaging

The image of the plant and the corresponding röntgen images are shown in figure 5. The rectangle drawn in the original colour image indicates the measurement area of the röntgen device. In the original image only parts of two stems are visible. This is in contrast with the röntgen images where 5 stems are visible. The thin leaves are completely transparent for the röntgen rays, they are no longer completely visible in the images. However, the small stems and vains of the leaves are still visible, which makes recognition of true stems more difficult.

Prior to image processing, image correction is required to compensate for the radial intensity decrease starting from the centre of the image to the edge of the image.

Although the stems are visible, recognition of the correct stems is still a challenging task for stems which are partly covered by other stems (2 stems in the left part of the röntgen images).

However, the biggest concern of using röntgen imaging might not be the image processing but the fact that röntgen rays are used for detection. Röntgen imaging demands severe safety regulations like trained personal and an isolated röntgen imaging room. Besides this, the effect of radiation on the growing of cut roses is also not known and requires further research.

CONCLUSIONS

For a successful 3D co-ordinate estimation with stereo vision, objects or features need to be present in both images of the scene and easy detectable for a proper matching. The amount of leaves and number of stem present in certain type of cut rose cultivars prevent good stem good detection with stereo matching. This limits the use of stereo matching algorithms for the true (XYZ) estimation of the stem.

Laser triangulation is technique which is able to estimate depth information from a scene even when the scene is complex in the sense of occluding objects. Although the laser triangulation is capable in detection a stem in front of a leave, overhanging leaves result in occlusion of either the laser or the camera and thus no depth information can be estimated from that particular part of the scene. As the majority of occlusion and overhanging leaves occur at the cutting position of the plant and thus no good estimation of the depth is possible, laser triangulation is not the preferred method for automated harvesting of cut roses.

Full range depth information of an entire plant from multiple angles (either with stereo imaging or laser triangulation) requires good calibration and heavy image processing as the result from different 3D views must be combined to a single 3D space.

Röntgen imaging is a technique which is less sensitive for overhanging leaves, the stems are visible in the images. Although detection of stem from two röntgen images and using this as input for stereo imaging is still a difficult task, the equipment and the required safety regulations makes this imaging technique a costly one.

The advantage of the Reverse Volumetric Intersection method is that multiple cameras acquire all a single image of the same scene and from these multiple images a single 3 dimensional view is reproduced. In straightforward scenes, a few angles are sufficient for the true XYZ estimation of the stem, for a more complex scene the addition of multiple camera's might give sufficient information about stem position. The attractive part of the RVI concept is that adding more camera's from different angles result in more information and to a lesser extent in more processing. However, even the RVI concept will fail if no stems are visible in any of the images taken from all angles. Therefore, best results can be obtained with cultivars which have a more open structure with small leaves.

Summarising, the RVI concept is the most promising 3D concept for 3D estimation of stems for an automatic cut roses harvester and this concept will be developed and implemented in future research.

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Figures

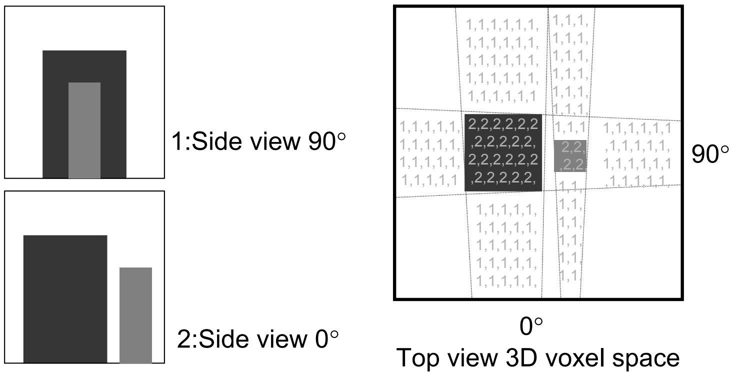

Fig. 1. The principle for Reverse Volumetric Intersection for two views (0 degrees and 90 degrees) and two synthetic objects. At crossings in 3D space pixels are accumulated.

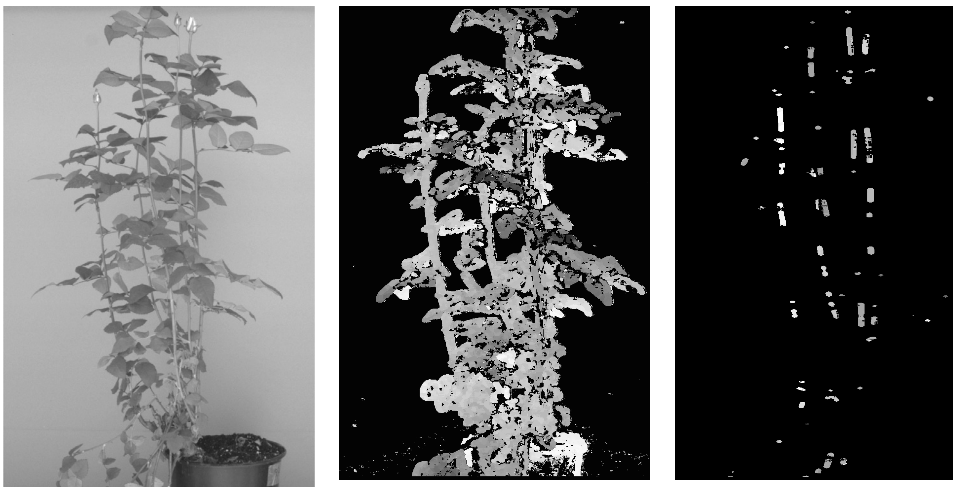

Fig. 2. The original rose image (left) and the resulting depth map after correlation based matching (middle) and the resulting depth map after stem filtering the original images.

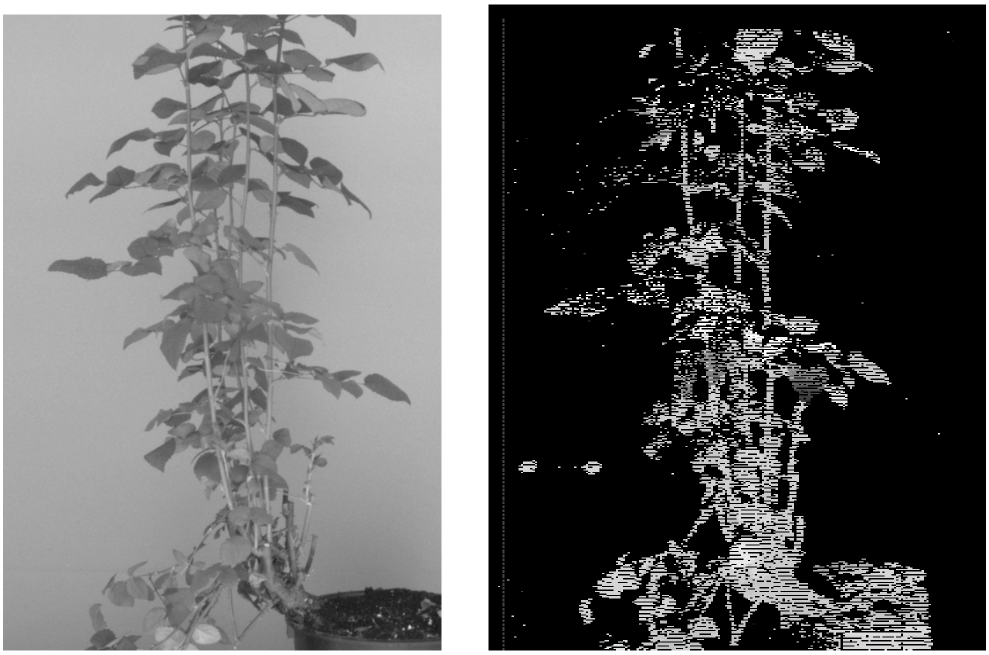

Fig. 3. Original image (left) and the corresponding 2.5D depth image of the laser triangulation.

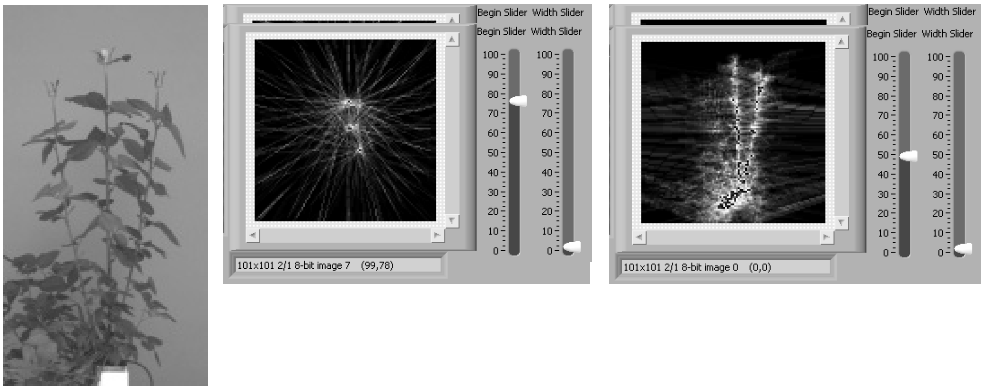

Fig. 4. RVI results. Original rose plant with 3 stems (left); 2 planes from the z-axis (middle column) and 2 planes from the x-axis.

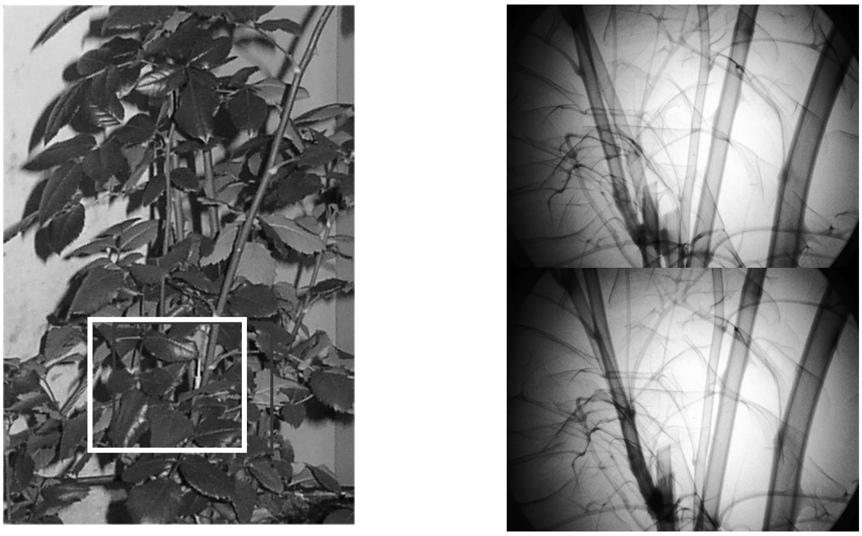

Fig. 5. The original rose plant with the square indicating the measurement area(left), the corresponding röntgen image (upper right) and the röntgen image after a small rotation of the plant (lower right).