SMART AGRICULTURE PLOUGHING TOOL USING EMBEDDED SYSTEM

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Abstract-- In India, most of the farmers are still following the traditional method and some heavy machineries for cultivation. This traditional method results in uneven spreading and undefined rate of crop cultivation. Mechanized application of farm yard manure is very important to boost the concept of organic and pollution free farming.This paper focuses on the use of different sensor technologies for agricultural applications.this paper proposes smart agricultural ploughing tool.

Index Terms—IR proximity sensors,DHT11,LCD,RF transmitter & receiver.

1.INTRODUCTION:

The increase in plant earnings (food or energy plants) with simultaneous consideration of the protection of the environment will be a global task in the future. The manual weed control, used in organic farming, without chem-ical or synthetic agricultural pesticide is one way to protect our environment. However, manual weed elimination is very expensive. Our cooperation partner *Westhof Bio* in Germany, for example, spends over 170 000 EUR per year for the manual weed elimination by human labor. Furthermore, it is more and more difficult to find human workers for this task. Hence, the need for research for automated nonchemical weed control systems is very large. However, up to now, no commercial system is available.

There are nonchemical physical weed control System that can successfully remove weed between plant rows, as shown in Fig. 1. However, they cannot remove the weed close to the plants (because the weed grows under the plant, as shown in Fig. 2 by the white circle), which is a very challenging task Some researchers are developing laser-based weed control systems for the close-to-plant weed control However, a commercial prototype is still not available. In the majority of cases, optical systems or multisensor system are used for the close-to-plant detection of weeds. These systems can measure the spectral reflection of plants and soil. As soil and plants have different reflections, it is now possible to distinguish both. Furthermore, a differentiation of plants is also possible.

Fig. 1. Typical carrot field of *Westhof Bio* in Germany

Fig. 2. Weed and carrot plants on a row dam of a field of *Westhof Bio* in Germany.

A further feature to distinguish weed from agricultural crop is the plant height. The plant height and the coordinates of the root exit point can be measured with 3-D sensing devices. In principle, there are three methods mainly used to acquire 3-D information: stereo vision (SV) systems, laser range scanners (LRSs), and time-of-flight (TOF) cameras.

SV systems usually rely on the principle of establishing correspondences. The major disadvantages of SV systems are the correspondence problem, the limited field of view, and the allocation problem. The LRSs deliver one scanning line of accurate distance measurements often used fo navigation tasks. The major disadvantage of LRS systems is the use of mechanical components and that they do not deliver 2-D intensity images and range data at the same time. TOF cameras, combine the advantage of active sensors and camera-based approaches as they provide a 2-D image of intensity and exact distance values in real time. Compared with SV systems, TOF cameras can deal with prominent parts of rooms like walls, floors, and ceilings even if they are not structured. SV systems have been already used for weed detection . However, the calculation of distance images takes a lot of time. On the other hand, the ToF system delivers distance images immediately with every measurement. In, the first system to find the root exit point was presented. This system consists of a low-cost ToF camera with a resolution of 62 × 51 pixel. The proposed systems works, but errors may occur. In this paper, we investigate four other sensors to find the root exit point. Beside a new ToF camera with a higher resolution, other optical sensors (Kinect I, Kinect II, and SV camera) were also investigated. To eliminate the weed, the Cartesian coordinates of the weed root exit point must be known and subsequently transmitted to a weed elimination unit. Hence, we extended the derived algorithm to be able to calculate the root exit point vector in Cartesian coordinates.

In, an algorithm to compute a match of two point clouds was presented. In this paper, we can now present how this algorithm calculates a range image for the used SV camera in real time. With this range image and the 2-D image, the root exit point vector can be derived.

This paper is structured as follows. In Section II, the optical systems and proposed algorithms are presented. Furthermore, the calculation of the root exit point vector is derived. Section III shows the laboratory setup and presents the experimental results of the systems and algorithms. It is closed with the discussion about the results. Finally, in Section IV, some conclusions are made.

II. Proposed Systems and Algorithm

A. Structure of the Proposed Algorithm

Each approach of the root search consists of a different composition of hardware systems and algorithms. Hence, the algorithms have been divided into four phases. These phases have been designed to provide the largest possible reusability. However, some phases have to be adjusted. In general, four phases of the following tasks can be assigned.

1) *Phase 1:* Extraction of plants from the background.
2) *Phase 2:* Finding root exit points in extracted plants.
3) *Phase 3:* Determination of the distance from the root exit point to the camera.
4) *Phase 4:* Calculation of the root exit point vector.

With this structure, the optical sensors of the 3-D ToF camera, the Kinect I, the Kinect II, and the high-resolution red–green–blue (RGB) camera (single SV system) are investigated. The differences between the sensors are visible in the captured images (RGB, grayscale, and range image). The ToF camera provides grayscale and range images, whereas the high-resolution RGB camera provides only RGB images.

Fig. 3. Original image of the ToF camera with a resolution of 204×204 pixel.

The Kinects I and II deliver RGB and distance images. Because of these differences, Phases 1 and 3 have to be accommodated to these systems separately. There must be one phase for RGB images and one for grayscale images to extract the plants from the image. Equally, Phase 3 is different for all used sensors. However, Phases 2 and 4 stay unchanged. In the following, the four phases will be discussed in detail by the example of the high-resolution ToF approach.

B. Phase 1 of High-Resolution ToF Approach

In Phase 1, the plant should be extracted from the background in the grayscale image taken by the ToF camera. (The ToF camera provides a grayscale image and also a distance image.) A photonic mixer device (PMD) pixel is an active TOF vision system with inherent suppression of uncorrelated light signals such as sunlight or other modulated light disturbances. More advantages of a PMD TOF vision system are the acquisition of the intensity and range data in each pixel without high computational cost and any moving components as well as the monocular setup. Its working principle is explained in detail in.

The modified Laplacian edge detector uses the follow-ing matrix:

$$\mathrm{LP}_{\mathrm{mod}} = S \cdot \begin{bmatrix} -1 & 0 & -1 \\ -1 & 6 & -1 \\ -1 & 0 & -1 \end{bmatrix}. \tag{1}$$

With the shown matrix, the filter operates mainly on vertical edges. The plants represent most of the vertical lines in the image. Hence, the modified Laplacian edge detector detects those vertical lines. The scale factor S is used to transform the image into an 8-b scale space. The resulting image will be examined based on its histogram. In the bimodal histogram, the intensity value at the minimum between the two maxima (one maximum represents the background and the other one the plants) is chosen for the global threshold. Fig. 3 shows the original image of the ToF camera PMD Camcube 3 with a resolution of 204 × 204 pixel. Subsequently generate a binary image like Fig. 4 with the threshold.

C. Phase 2 of ToF

In Phase 2, the root exit points on the 2-D binary images from Phase 1 are being found. An iterative algorithm will

Fig. 4. Resultant image of Phase 1 by the ToF algorithm.

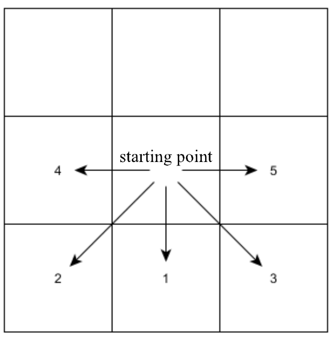

Fig. 5. Search directions of the proposed plant root exit point search algorithm.

be used for this search. It starts at the top-left corner of the image and then processes the image line by line. It searches for a white pixel that represents a plant in the picture. If the algorithm has found a white pixel, this pixel is used as a starting point for finding the plant root exit point. The successive search direction used by the iterative algorithm is shown in Fig. 5.

An Iteration step starts with the starting point. If the corresponding pixel is a white pixel (plant pixel), this pixel will be the new starting point for the iterative algorithm. In the case of a black pixel (no plant is present), the algorithm tries searching directions 2 and 3, respectively. The algorithm assumes that both destination pixels are equivalent. Hence, if both pixels are white, both will be taken as new starting points leading to two search branches. In the absence of plants on the destination pixel of search directions 2 and 3, search directions 4 and 5 are chosen and the same procedure is applied. If the algorithm finds a white pixel, it will begin with the next iteration step. In addition, the algorithm counts its iterations. The plant root exit point is the minimum of the plant's structure, which is determined if a number of iteration steps are executed and no other new starting point can be found. The number of the steps is a condition for terminating the iteration in case the iteration does not find an end. The number depends on the resolution of the image. The fragments, the tiny white points, just have a little number of iteration steps. They can be filtered out by the quantity of iteration steps. They are not plants as seen in Fig. 4.

Fig. 6. All root exit points are marked with a white circle.

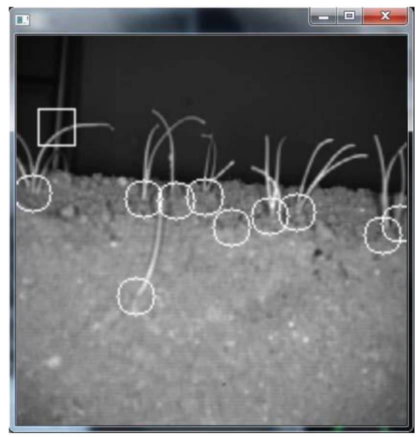

Fig. 7. Same result after the plausibly check. However, here all real root exit points are marked with circles and not real points are marked with rectangles.

The iterative algorithm counts the steps and all ways with not enough steps are ignored. Therefore, the algorithm calculates the root exit points and provides the 2-D pixel coordinates from the image.

D. Phase 3 of ToF

Phase 3 determines the distance from the root exit point to the camera. The ToF camera provides a grayscale image and also a distance image. This distance image is superimposable onto the grayscale image. For finding the distance from the root exit point to the camera, the proposed algorithm reads the distance of the distance image. Moreover, the distances can be used to find errors from the second phase. All root exit points found by the iteration algorithm are marked with circles in Fig. 6. The real root exit points are marked with circles in Fig. 7. These errors can be filtered out with a simple plausibility check. As mentioned before, the TOF camera provides a distance image. For the plausibility check, the distance of the found root exit point is compared with some distance values of the surrounding pixels. If the distance values are in the same range of 1 cm, the root exit point has been successfully determined by the algorithm. This value was determined by a series of images and contains the accuracy of 5 mm of the camera system on dark areas.

Fig. 8. Calculation basis for the root exit points.

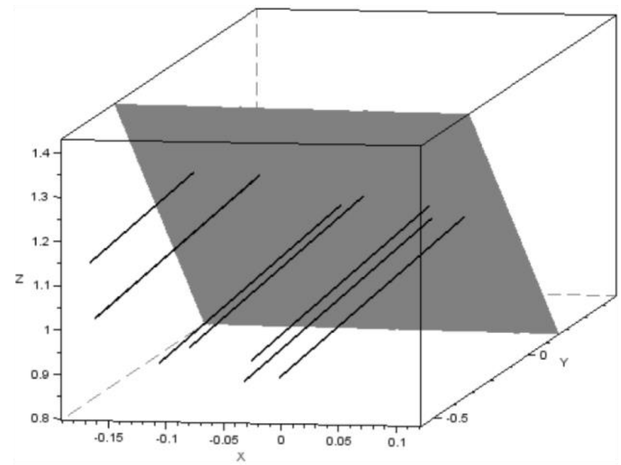

Fig. 9. Calculated root exit point vectors and the regression plane.

E. Phase 4 of ToF

In Phase 4, the root exit vector will be determined. The root exit point vector is a vertical vector standing where the plant meets the soil. For this vector, the level of the earth has to be defined. The algorithm uses the root exit points to find this level. All root exit points are on the same level of the soil, so the algorithm can calculate a regression plane from the points. This plane has the same level as the soil and can be used to calculate the vertical vector. A root exit point with the index i can be described with the vector P_i as

$$P_i := \begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix}. \qquad (2)$$

Here, x_i, y_i, and z_i are the space coordinates that can be calculated from the pixel coordinates of the image and the distance. With these coordinates, a system of equations can be described like

$$\begin{pmatrix} N & x_i & y_i \\ x_i & x_i^2 & x_i y_i \\ y_i & x_i y_i & y_i^2 \end{pmatrix} \cdot \begin{pmatrix} a \\ n_x \\ n_y \end{pmatrix} = \begin{pmatrix} z_i \\ z_i x_i \\ z_i y_i \end{pmatrix} \qquad (3)$$

With a, n_x and n_y being the parameters of the regression plane and N being the number of root exit points. Therefore, the root exit point vector can be described with two vectors: one vector for the starting point and the second vector for the end point. Both vectors can be described as

$$V_{\text{start},i} = \begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix} \qquad (4)$$

$$V_{\text{end},i} = \begin{pmatrix} x_i \\ y_i \\ z_i \end{pmatrix} + \eta \begin{pmatrix} n_x \\ n_y \\ n_z \end{pmatrix} = \begin{pmatrix} x_i + \eta \cdot n_x \\ y_i + \eta \cdot n_y \\ z_i + \eta \cdot n_z \end{pmatrix} \qquad (5)$$

with x_i, y_i, and z_i being the space coordinates from the i_{th} root exit point and n_x, n_y, and n_z being the calculate parameter of the regression plane. The η factor describes the length of the root exit point vector. Fig. 8 shows the basis for calculation for the root exit point vectors, and Fig. 9 shows the regression plane in gray and the vertical root exit point vectors by the black lines.

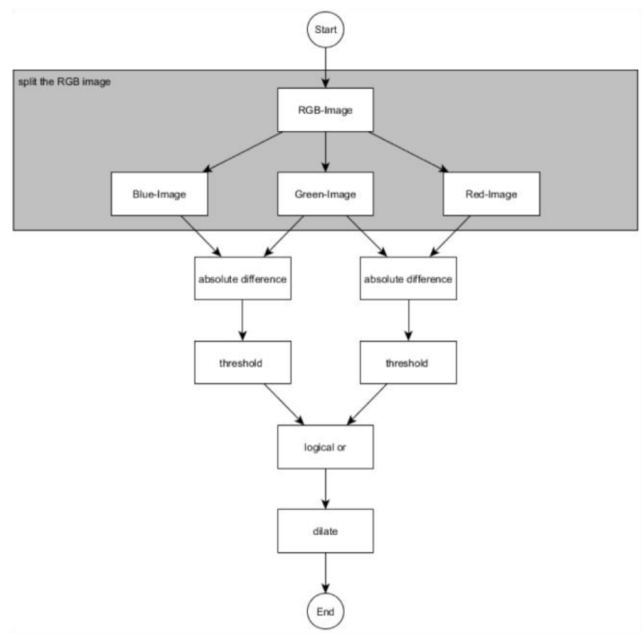

Fig. 10. Steps for the extraction of plants in an RGB image.

F. Four Phases for an RGB Camera

If an RGB camera is used, Phase 1 is different. The RGB image has more information than the grayscale image. Fig. 10 shows the steps for the extraction of plants. The first step is to split the RGB image into an image where only the red color information, only the green color information, and only the blue color information can be seen. Then calculate the absolute difference of the blue and green images and calculate the absolute difference of the green and red images. By means of a histogram, both calculated images are converted into binary images. Now the binary images are combined by a logical OR. The last step is a dilatation function to strengthen the result. Fig. 11 shows an RGB image where the root exit points are searched and Fig. 12 shows the resultant image from the first phase. It is very important that the result of Phase 1 is a binary image. Only a binary image can work with Phase 2. Phase 2 of the ToF camera can be used for an RGB camera as well (reusability). Unlike the ToF and

Fig. 11. RGB image with plants.

Fig. 12. Result where the plants are extracted from the background.

the Kinects I and II, the high-resolution RGB camera cannot get a distance image. Hence, Phase 3 is different for the RGB camera. However, the distance can be calculated by an SV algorithm. The SV calculates the distance out of two images from two different perspectives. The calculation needs a lot of time. In our approach, the distance of every pixel is not needed, and therefore, the calculation of the range image is achieved in real time.

It is better to calculate only the necessary points (the root exit points). This will save calculation time. The two images with the root exit points generate two point clouds. In , it is described how two point clouds can be merged with a real-time algorithm. The result of the merging can be seen in Fig. 13.

The white dots of Fig. 13 are the root exit points from the image. The black dots are the root exit points of the other image from the other perspective. The gray line is the displacement vector, which is necessary to calculate the distance by SV. Afterward, the root exit point vectors are calculated in Phase 4.

III. Experiments

A. Experimental Setup

In Fig. 14, the laboratory setup in our dark room is shown. A physical model of the carrot dam was built consisting of an approximately 1.20-m long soil hill with artificial plants

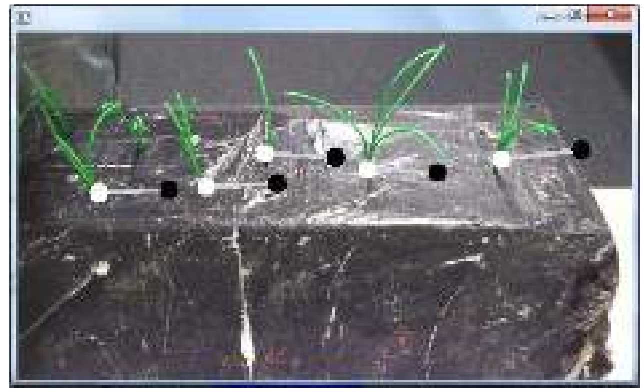

Fig. 13. Result of the merging.

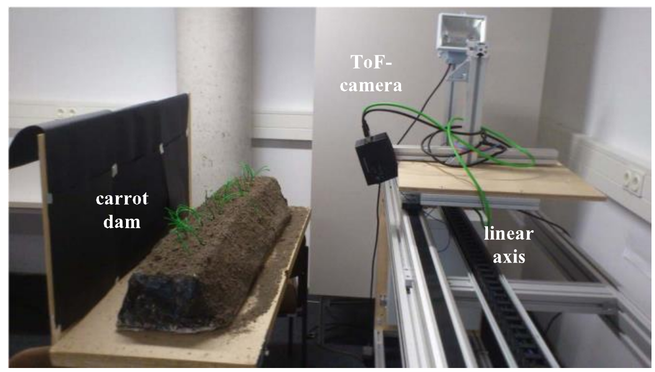

Fig. 14. Model of the carrot dam in the laboratory.

with a length between 5 and 15 cm on its top. For the experiments, commercial cameras are used. An RGB camera (Canon EOS d550 with a resolution of 5184×3456 pixel), a ToF camera (PMD Camcube 3 with a resolution of 204×204 pixel), the Kinect I (a color resolution of 640×480 pixel and a distance resolution of 320×240 pixel) and the Kinect II (a color resolution of 1920×1080 and a distance image with 412×524 pixel).

The camera systems are mounted on a linear axis at a distance of the model from circa 80 cm. The cameras are moved in steps of 5 cm along the linear axis until the physical model of the carrot dam has passed. A magnetic length measurement system is mounted on the linear axis to capture the movement of the TOF camera system with a high precision of ± 50 μm. The intensity and distance image of the camera are captured and processed with the software OpenCV. Depending on the camera resolutions, 15 to 20 images are needed to capture the 120-cm long dam. Thus, the dam is scanned completely and the results can be compared reproducibly with each other.

B. Experimental Results

The different cameras have different results. The results are shown in Table I. The differences are caused by different resolutions, objectives, and algorithms. The high-resolution camera and the ToF camera system do not have a wide angle lens as the Kinects do. Therefore, there is a different point of view.

TABLE I

RESULTS OF THE DIFFERENT OPTICAL SENSOR TECHNOLOGIES

System	Number of real root exit points	Automatic root exit detected points		
		Number	Positive	False positive
Kinect I	190 (100%)	237 (125%)	140 (74%)	97 (51%)
Kinect II	193 (100%)	261 (135%)	192 (99%)	69 (36%)
Stereo Vision	164 (100%)	234 (143%)	164 (100%)	70 (43%)
Cam-Cube	93 (100%)	132 (142%)	91 (98%)	41 (44%)

C. Discussion

The numbers in automatic root exit detected points in Table I show that all systems detect more root exit points that really exist. This is no problem for the proposed application. Then all route exit points (agricultural crops, weeds, and soil) are classified by the classifier, which has to be developed in the next step and will be presented in the future. Its task is the differentiation between agricultural crops and weeds. However, this algorithm should have no problem to differentiate between a real root exit point that really exists and a nonexistentant root exit point (corresponds to soil only). The results of the classifier are only the weeds that need to be destroyed.

At the moment, the implemented plausibility check for the ToF approach reduces the number of false positive rates. If finer parameters would be used for the plausibility check, the robustness and speed of the system would suffer. It is more important to detect all real root exit points at least once. Not every image shows all root exit points, but the overlapping of the images causes the excessive number of detected root exit points. It is true that the Kinect II has a very big hit probability, but the permanently installed aperture angle proves as obstructive. The SV that was implemented by the high-resolution camera brought the best results after scaling the resolution down to 800×400 pixel. Although it is a waste of the camera's resources, the flood of information would otherwise be too high for this application. Although the system works fine with a higher resolution, the results of the smaller resolution are equally as good and calculated faster. The Camcube 3 is a very robust, quick, and simple system with a high hit probability. In addition, the 3-D information is automatically given in the image and has an accuracy of circa 2 mm. The Kinect I also has a wide aperture angle and is linked with its small resolution, and therefore, the area of interest has fewer details. In addition, its type of distance measurement for this construction is not ideal, so that the area of interest has gaps.

IV. CONCLUSION

In this paper, different plant root exit point algorithms and different systems for weed control applications in organic farming have been presented. The different algorithms are robust and deliver reproducible results. It was paid attention in the design of the various algorithms. A four-phase structure was identified to be the best option for reusability.

The studied camera systems all come from the low-cost sector, which is important for the final price of the application. Furthermore, it has to be taken into account that the sensors have to work in a harsh environment. Due to the low cost of the sensors, they can be easily replaced with no high maintenance cost.

For the experimental setup, a physical model of the carrot dam has been created and the proposed algorithms have been investigated with different camera systems. The experimental results have shown that the used systems are applicable for the plane weed control application in organic farming. Now the algorithms and the accuracy can be tested on the organic field. With these results, we are able to calculate an extensive error. The next important step is to examine the precision of the positioning to eliminate the weed by the estimated error. We hope to present the results soon.