

Quality assessment of row crop plants by using a machine vision system

Michael Weyrich

Institute of Industrial Automation and Software Engineering
University of Stuttgart
Stuttgart, Germany
michael.weyrich@ias.uni-stuttgart.de

Yongheng Wang, Matthias Scharf

Chair of Automated Manufacturing and Assembly
University of Siegen
Siegen, Germany
yongheng.wang / matthias.scharf@uni-siegen.de

Abstract—This paper reports research results on developing a machine vision system to assess the quality of row crop plants. Comparing to the prevalent machine vision system employed in agricultural industry for weed-crops classification as well as plant density evaluation, the proposed machine vision system is able to detect the location of plants (weed / crops) and calculate the leaves' area for plant quality assessment, even if the leaves are overlapped with each other.

The developed machine vision system involves a camera system and an image processing system. The camera system uses a coaxial camera constructed by a RGB sensor and near infrared (NIR) sensor, which cooperate with a white front lighting and NIR front lighting respectively. Plants are firstly captured by the coaxial camera. The plants are segmented from background on RGB image; the overlapping edges of leaves are detected on NIR image. Afterwards the overlapping leaves are separated and assigned to the assessed stem position of plants. At last, based on the assigned leaves, the plants are separated, and the area of plant canopy is calculated. A set of experiments have been made to prove the feasibility of the proposed machine vision system.

Keywords—quality assessment; machine vision; crop plants; plant segmentation, plant localization, plant quality

I. INTRODUCTION AND STATE OF THE ART

Automatic detection of weed within agricultural fields has gained greater importance in the past years. The main purpose of farmers is to increase the turnout of their fields. Therefore it is very necessary to eliminate weed which could be done by either pulling out mechanically or usage of herbicide. In this paper a set up for a vision system will be proposed which is able to recognize weed from crop plants as well as to estimate the position of weed and crop plants with a high accuracy. The development was made for outdoor environment; therefore all the factors like wind, varying light condition, rain and so on were taken into account. In the last years several methods and systems based on machine vision have been developed. Most achievements have been made in the cultivation of cereal crops [1, 3 and 9], tomatoes [5], soybeans [10] and sugar beet crops [2]. The purpose is to develop an optimized automated process in which weed are detected among the rows of plants and automatically sprayed with herbicide in order to eliminate them. Comparing to the manual handling, it saves a lot of work, time and money. In addition, there are not only economical, but also ecological advantages due to a high

amount of chemicals that are saved and not wastefully sprayed on the fields [2].

The developed procedures are very similar to each other. In the first step images of the rows of plants are captured by a digital camera e.g. connected to the linkage of a tractor [2]. Alternatively in [4] the vision system is directly embedded in a small remotely piloted aircraft in order to conduct measurements in the fields. The camera type may vary in each system since it depends on the attribute of the plant which is used to distinguish between weed and crop. A color camera is used by comparing the leaf color (green) with the color of the soil cover [2]. Other attributes are e.g. leaf shape [11], the spectral signature or the texture [9] of the plant. Afterwards the images are analyzed by an appropriate algorithm which evaluates how much of the area is covered by leaves on soil respectively. The individual areas are expressed by percentage compared to the total area size in the image.

There are many possibilities to develop an appropriate algorithm. In the field of image processing there are several different tools which are able to recognize plants in an image. A common method is to use neural networks for the process of detecting weeds [2, 7, and 8]. Cooperating with a NIR-filter, the neural networks may segment plants with higher accuracy than the conventional threshold techniques [7, 8]. Other possibilities are Support Vector Machines [9] cooperating with the NDI-filters which are compared to the Bayesian classification in [12]. All these image processing algorithms are working in a similar way. During the binarization a black-and-white picture is created in which the crop is displayed white and the soil black. Therefore undesirable plants are detected more easily due to a higher contrast [3]. In general the accuracy is very high. At the automatic detection of volunteer potato plants within sugar beet fields based on neural networks it comes up to 97%. Using the Bayesian classification 85% of the volunteer potato plants is correctly classified.

All these image processing methods are preceded by a supervised learning process in which data is gathered in order to create a pattern that realizes a standardization of the image classification. Thereby the algorithm learns from the environmental conditions in the agricultural fields. It is able to adapt to most daytime conditions, such as light changes, source temperature and soil type [6]. After the classification and the detection of the weed the robotic spraying system, which is also embedded in the machine linked to the tractor, is able to

spray chemicals on the weeds. This procedure reduces the amount of used chemicals up to 95% and the crop is not affected. Moreover the ground is not burdened with much pesticide.

The paper is structured as followed. In Section II, the challenges faced in this work to detect the plants and assess the quality automatically under an out-door condition is discussed. In Section III, the machine vision system for assessment of plant quality is introduced, which involves the camera system and image processing algorithms. In Section IV, the experimental results are presents and a set of improvement are suggested in the future work. At last, it is summarized up in Section V.

II. REQUIRED WORKS AND CHALLENGES

To realize good results by using a vision system it is important to generate images with high repeatability (due to the constant imaging environment). Most vision systems are used indoor, so it is easy to establish stable conditions. This paper focuses to develop a vision system which can be used in agricultural industry. Due to this demand it is necessary to handle outdoor conditions. What are the main challenges one has to handle in such an environment? The first and most important one is light condition. The illumination situation of a plant changes continuously during a day because of the position of the sun, clouds, fog and so on. Furthermore, shade of other plants could change the illumination situation. The inspection of plants may take place in a limited time slot in each year due to the plant growth; therefore it may be necessary to apply the vision system on both day and night in order to complete a big amount of works during a limited time slot. The second challenge is wind. The wind causes plant movement which results in blurred images of plants. The third challenge is dirt on the plants which can change the appearance of leaves color and leads to difficulties to segment leaves from the background in images. The fourth challenge is the background itself. Affect of varying terra color and presence of foreign objects like straw, wood and etc. have to be eliminated by the image processing system. The last challenge is the plant itself. Due to its growth it can happen that leaves overlap each other which make it difficult to recognize a single leaf.

By taking all this challenges into account the required work is to build up a stable image processing system which can handle varying light conditions, problems caused by wind, changing plant background and dirt on leaves. The aim is to measure the plant position with high accuracy and to evaluate the plant quality depending of its growth.

III. MACHINE VISION SYSTEM FOR ASSESSMENT OF PLANT QUALITY

In this section, the machine vision system to realize the assessment of plant quality will be discussed.

A. Work Definition

Firstly, it is reasonable to clarify the main objectives of the vision system. The vision system should carry out the following two tasks:

- task 1 - measurement of plant position
- task 2 - assessment of plant quality

The plant position is usually understood as the stem position. However, in certain tolerance range, the center of plant canopy can be considered as the plant position. In contrast to plant position, plant quality is a fuzzy concept. With respect to variant purposes, the plant quality is expected to be defined by plant height, number of leaves, plant canopy (differ from leaf area index, which is related to unit ground surface area) or biological characteristics. In this paper, the plant quality is specified by the area of plant canopy.

Related to the previous clarification, the workflow of the proposed vision system can be represented in Fig. 1. By using a camera system, a target plant is captured; the obtained image is then pre-processed, e.g. histogram processing, noise reduction, in order to highlight the desired information and meanwhile suppress the non-relevant information. From the pre-processed image, the plant position is measured by three procedures: (1) the plant is firstly segmented from background; (2) the overlapped leaves are separated from each other; (3) based on the detected leaves, the stem position is assessed. After plant position (stem position) is measured, plant quality is then assessed by assigning leaves to their corresponding stems (in order to separate the individual plant), and calculating the area of plant canopy.

B. Preparation

To realize the proposed methods, a set of preliminary experiments has been made, which concerns camera perspective, illumination direction, camera types, and so on.

1) Camera perspectives: Firstly it is important to determine what kind of perspectives benefits the purposes of (1) plant position measurement and (2) plant quality assessment. Fig. 2 shows the three different perspectives: top-down, forward and lateral perspectives. The challenges on the top-down perspective are, the stems are obscured by leaves, which leads to the difficulties in measurement of plant position; the plant leaves are overlapped by each other, which leads to the difficulties in area assessment of plant canopy, the number of leaves. The forward perspective exacerbates these

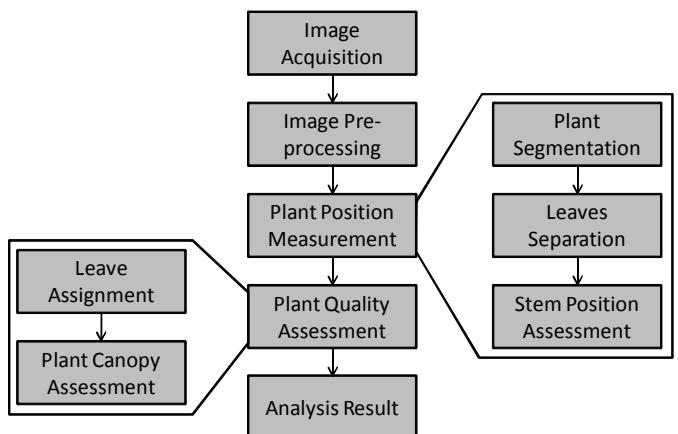


Fig. 1. Representation of workflow.

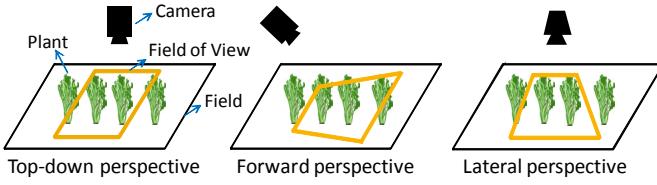


Fig. 2. Variant camera perspectives.

two challenges. Using the lateral perspective, camera can although detect the stem postions, however with the distorted perspective it is difficult to assess the plant canopy area.

2) *Illumination direction*: The front lighting can highlight the leaves and the overlapped edges with respect to another illumination collocation. Therefore, a camera with top-down perspective and front lighting source is chosen for image acquisition.

3) *Grayscale or colorscale camera*: The contrast of leaves to soil, wood, defoliation, stones, straw on grayscale images in different illumination spectrum are calculated respectively. It is concluded that, it is impossible to segment plants by using the monochrom information on the grayscale images. Therefore, a color camera is recommended for segmenting plants from background. In addition, the grayscale camera highlight the overlapping edge much more than colorscale camera. Therefore, a grayscale image is recommended for detecting overlapping edges.

4) *Spectrum of illumination*: Due to the application of a color camera, the visable spectrum is naturally expected. Therefore the white LED, or halogen light can be utilized as illumination. A near infrared (NIR) lighting coperated with the grayscale camera is also ulitized to detect overlapping edges.

5) *Potential Application of 3D Camera*: 3D technique is prevalent nowaday. A set of experiments of stereo, kinect, light structured cameras has been made. However, due to groove structure, unevenness of field, low depth resolution of 3D camera, 3D cameras will not be considered in this work. Fig. 2 shows the 3D images by BumbleBee XB3.

Based on the preliminary work, a camera system with the camera-illumination collocation shown in Fig. 4 is proposed to be used for the assessment of plant quality. The camera system consists of a coaxial camera, and two front lighting - white lighting and infrared lighting. The coaxial camera includes a RGB CCD sensor, a NIR CCD sensor and a coaxial objective. The coaxial objective will transmit the reflected light to both two sensors. However, to RGB sensor, the infrared spectrum is filtered out; while to NIR sensor, the visible spectrum is filtered out.

In the next section, the detailed works will be introduced. The step image pre-processing mentioned in Fig. 1 aims at reduction of noise reduction, and highlighting of desired information is in this paper not to be discussed.

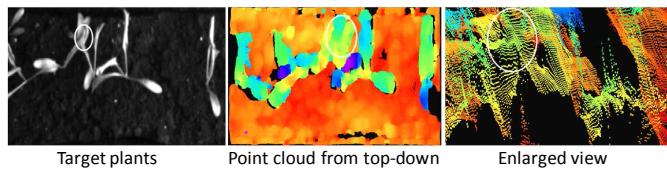


Fig. 3. Images captured by BumbleBee XB3.

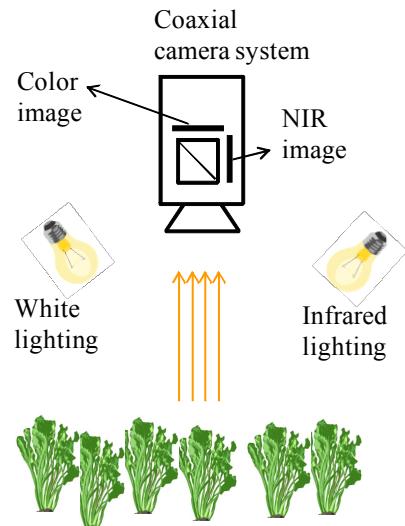


Fig. 4. Camera-illumination collocation.

C. Plant Position Measurement

1) Plant segmentation

The plant segmentation is an importance process to locate the plant and its boundary in images in order to enable the further analysis e.g. assessment of stem position, leaves area, etc. Due to the complex background (presence of foreign objects, e.g. wood, withered leaves, straw, stones, even plastic), variant techniques have been applied. By directly using thresholding in the RGB / HSL color space, the plants can be segmented, since they appear green with respect to the foreign objects. However this is not reliable in case over- and underexposures. In [1, 7, 13, and 16], the methods concerning ExG, ExG-ExR, $I_1I_2I_3$, and IV_1V_2 , which are derived from the basic color space, are applied. As result, by thresholding V_1 channel in the color space of IV_1V_2 is a stable method to segmented plants in outdoor condition. Fig. 5 shows the segmentation results of three plant images captured by different degrees of exposures. One can observe that, by using IV_1V_2 the plants are stably segmented from background.

Some green weeds have the same color channel like crop plants, therefore through the segmentation of plant, the weeds is not eliminated. For distinguishing the weeds and plants from segmented images, the pre-knowledge is needed to distinguish the weeds based on the shape of leaves, the location of weeds (crop plants are only planted in regulated lines).

2) Leaves segmentation

The most challenges of leaves segmentation is that, the leaves overlap with each other. Therefore, the critical issue of leaves segmentation is to detect the overlapping edges. For this purpose, two principles for choosing a proper camera system must be grasped:

- Suppress the texture information of leaves

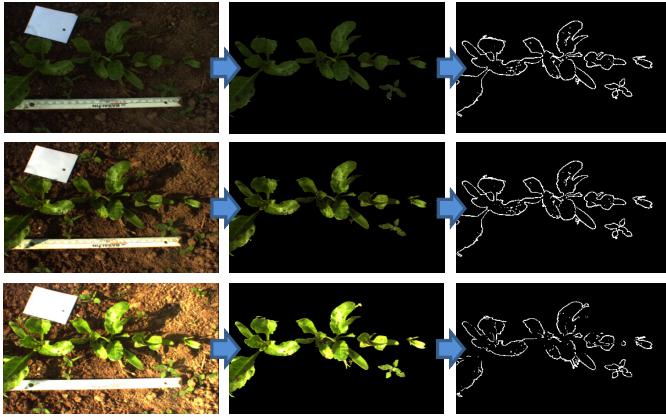


Fig. 5. Segmentation results by using IV1V2 color space. The first column shows three original images in different degree of exposure; the second column presents the corresponding segmented images; the third column presents the outer contour of plants.

- Suppress the fake edges caused by e.g. shadowing, wrinkle

A set of experiments have been made with multispectral camera - Nuance EX, color camera Marlin F-080C, and 3D camera - BumbleBee XB3. Due to the low depth resolution and high noise, the most of 3D camera will not be considered. Color camera facilitates the segmentation of plants from background; however it doesn't suppress the leaves' texture and fake edges. From the experiments with multispectral camera, it is found that the edges emerge with high contrast in near infrared spectrum. Therefore, a grayscale camera with NIR front lighting is recommended to detect overlapping edges.

Fig. 6 shows process of separating leaves by detecting overlapping edges. With help of mask image (it is a binary image indicating the segmented plants) obtained in the previous step plant segmentation, plants can also be segmented in NIR images. Outer contour of plants can be easily extracted by applying morphological close- and open-operators on the mask images. In contrast, the extraction of the inner edges (the overlapping edges is a kind of inner edges) is tedious. In [17], variant edges extraction techniques are present, e.g. laplacian detector, Marr-Hildreth edge detector, canny edge detector, and so on. Besides in [18], the phase congruency is discussed. In this paper, it is recommended to apply canny filter or phase congruency to detect the inner edges in case of homogeneous or inhomogeneous illumination respectively. Furthermore, the inner edges include not only the overlapping edges, but also fake edges and edges caused by texture changing. However, the overlapping edges have the following specific characteristics: (1) the overlapping edges are connecting with outer contour; (2) the overlapping edges connect with outer contour with sharp angles. Cooperated with this information, the edge tracking technique can be applied to filter out the non-relevant edges. At last the separated leaves are obtained by applying watershed to the filtered images with outer contour and inner edges.

3) Stem position assessment

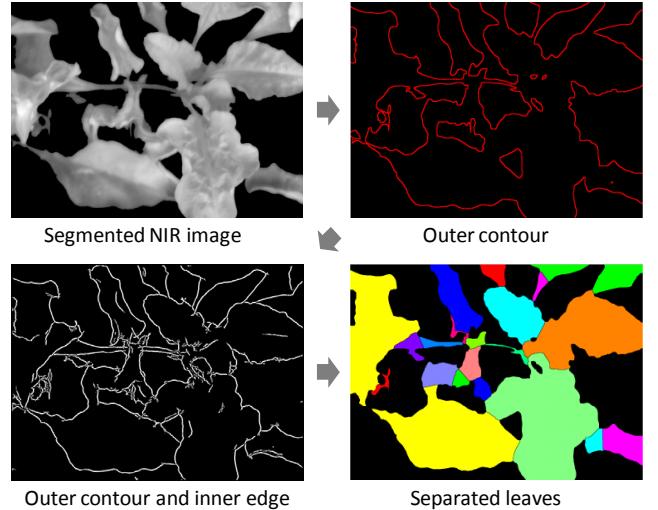


Fig. 6. Separating leaves by detecting the overlapping edges.

Due to the top-down perspective, the stems are often obscured by leaves, or appear perpendicularly to camera. For these reasons, stem positions are difficult to be detected directly from images. In this paper, the stem position assessment is realized by the following procedures:

- Extracting the symmetrical axis of leaves. If a leaf doesn't appear symmetrically, the bisecting line in the direction of maximum feret diameter is extracted instead.
- Generating the intersection of each symmetrical axis / bisecting line. Fig. 7 shows the intersections of symmetrical axis of leaves.
- Filtering out the non-relevant intersection by the constraints: (1) intersections should locate in the range of image; (2) intersections should near the alignment of row crops; (3) intersections should locate at one end (with a certain distance) of a leaf.
- Determination of remain intersection as the real stem position.

These processes are also illustrated in Fig. 8. In the last images, three stems are determined.

D. Plant Quality Analysis

Based on the obtained stems position, the leaves should be assigned to their relevant stems in order to separate the plants. Then the quality assessment of individual plants is possible.

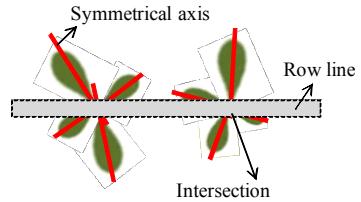


Fig. 7. Intersection of symmetrical axis of leaves.

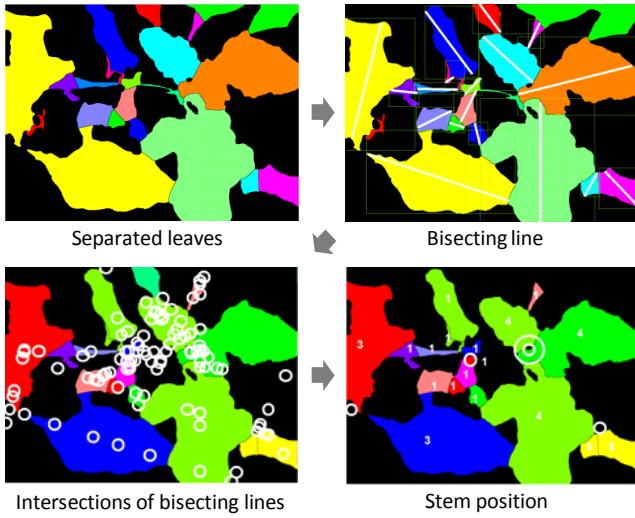


Fig. 8. Stem position assessment by using the intersection of symmetrical axis / bisecting line of leaves.

Leaves should be near their stems as well as the direction of their symmetrical axis / bisecting lines. After leaves assignment, the area of leaves (plant canopy) can be easily calculated. Fig. 9 illustrates the plant quality analysis. The accuracy of leaves assignment is very dependent on the accuracy of stems position. If the stem position has been wrong determined, the leaves may not correctly be assigned

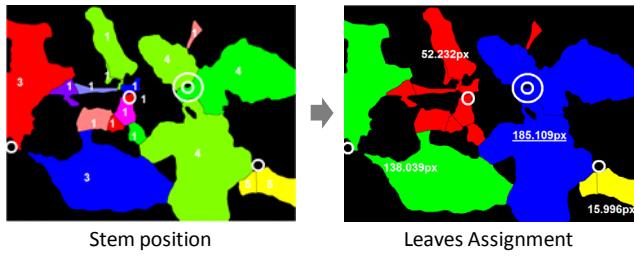


Fig. 9. Plant quality analysis based on the found stems position.

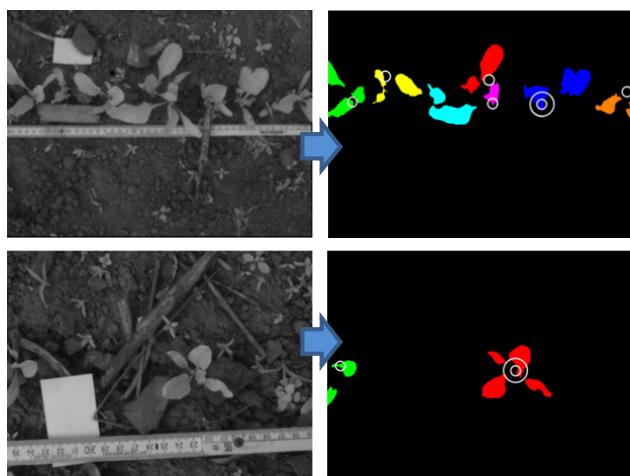


Fig. 10. Two examples of plant quality assessment.

IV. EXPERIMENTAL RESULTS AND FUTURE WORK

Due to the lack of a coaxial camera system, a grayscale camera of Marlin F-145B2 and a colorscale camera Marlin F-080C are used instead in this work. The proposed method was programmed in LabVIEW 2009 and C++. The program runs in a computer with the CPU of 3GHz, the RAM of 4GB RAM. The time of total image processing takes about 1 second per image.

The propose method performs with perfect result if the plants are planted with an enough distance. However if the plants are planted in a small and irregular distance, the method may misassign the stem position. The images shown in Fig. 10 improve this argument.

There are lots of ways to improve the results:

- The plants can be planted in a certain distance, such that, the intersections within this distance can be considered as fake stem position.
- The plants can be planted in an enough distance, such that, the plant will not grow to each other, which may alleviate the overlapping' problem.
- To apply an additional camera, that performs the lateral perspective. Although the lateral perspective may miss the stems, if the stem is not high enough and obscured by leaves. Fig. 11 shows the plants images from lateral perspective, from which the stem position is in a sense detectable.

In real agricultural industry, the proposed method should work in out-door condition. In order to ensure the stable working of the propose method, some improvements should be made to the camera system. Under the out-door condition, the lighting condition is affected by movement of sun and cloud, which may lead to under- and overexposure. To prevent, an auto-iris objective is recommended, which is able to adjust the iris size to adapt the changing condition of lighting. Wind is another problem under out-door condition. The slight wind may wobble the leaves, which leads to the blurred images of plants. Besides, the weather, e.g. raining, is also a critical impact to the proposed method. To prevent these problems, a shield is recommended to be imposed on the camera system. Based on these improvements, the recommended components of camera system in the future are summarized in Table I.

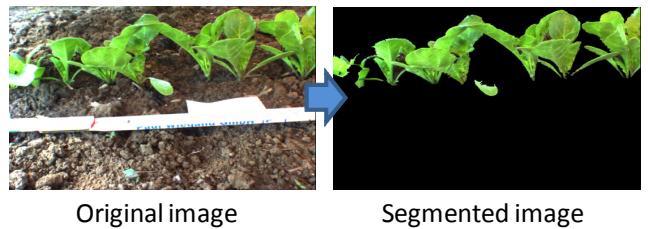


Fig. 11. Plants in lateral perspective.

TABLE I. RECOMMENDED COMPONENTS

Components	Remarks
Coaxial camera	A coaxial camera constructed by a RGB sensor and NIR sensor; top-down perspective
Illumination	White LED front lighting and NIR LED front lighting
Auxiliary camera	Two colorscale cameras for detecting the stem position; lateral perspective
Objective	Auto-iris objective; preventing over- / underexposure
shield	Preventing from wind / raining / varying lighting condition

V. CONCLUSION

In this paper, a machine vision system is proposed to assess the plant quality of growth. Differ from the traditional vision system used in agricultural industry, that concerns the weed-crops classification or plants density assessment, the proposed machine vision system aims at detecting the plant location, and assess its quality. The main work for developing the machine vision system, and corresponding experimental results are present in this paper. It improves that, the proposed machine vision system is feasible and can be considered to the application in agricultural industry.

The proposed machine vision system involves a camera system and an image processing system. The camera system consists of a coaxial camera constructed by a RGB and near infrared (NIR) sensor, which cooperate with a white front lighting and NIR front lighting respectively. Combining the information of RGB and NIR images, plants (even overlapped plants) can be segmented with each other and then the sizes of plants are assessed. The machine vision system can be utilized in the variant applications. For instance, in order to protect crop plants (e.g. vegetable) from weeds, the field should be examined regularly. The weeds should be detected and eliminated by spraying herbicide on it at an early growing stage. The propose method in this paper can carry out this task. It can detect the position of weeds, and spray the herbicide directly on the stem positions rather than on the entire leaves. This method prevents the extensive usage of herbicide, it on the one hand reduces the investment, on the other hand reduces the pollution of environment. In agricultural industry, sometimes, the plants which grow slowly should be detected and uprooted earlier in order to ensure and enhance the growing of remain plants. The propose method in this paper is also much recommended to this task.

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