Computers and Electronics in Agriculture 122 (2016) 133–138

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Developing a selective thinning algorithm in sugar beet fields using machine vision system

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ARTICLE INFO

Article history:
Received 9 June 2015
Received in revised form 14 January 2016
Accepted 24 January 2016
Available online 9 February 2016

Keywords:
Machine vision
Thinning
Overlapping
Sugar beet
Image processing
T-test

ABSTRACT

Row crops thinning is an effective operation in the production of most agricultural crops. However, it is costly, exhausting and harmful for the health of workers. The main purpose of this research is developing a high accuracy algorithm to recognize sugar beet plants and eliminate excessive plants. Images were captured with a CCD digital camera when all plants had 4–6 leaves. In this study, two methods were used to recognize sugar beet plants, the mass center algorithm (MC) and the average width algorithm (AW). Images revealed that overlapping between plants is the main problem in plants recognition. The average width method is appeared to be more accurate than the other method, especially in high overlapping conditions. Moreover, the mean of accuracies in removal of plants, which should be removed, are significantly different ($\alpha = 0.05$) by *T*-test. Device testing in vitro conditions indicated that accuracy of average width algorithm in detection of excessive plants is reached to 88%. The results showed that three sequential images should be checked simultaneously in order to reduce errors in recognition of excessive plants.

1. Introduction

Population explosion and some phenomena such as drought and environmental pollution were affected the soil and agricultural products, so it is critical to do extensive changes in agricultural methods. One of the most important, costly, and exhausting operations of production is Practices which are done during the growth steps of products. Optimum performances of these operations have a great role in raising products yields in the field (Van Der Weide et al., 2008). Removing of excessive plants from the surface of field, due to reach the standard density and optimum distance between plants, is called "thinning". In the most of agricultural products, number of cultivated plants per unit of area should be considered more than the amount required, to reach the optimum yield. Because there are unexpected reasons such as seed viability, improper planting depth, the attacks of birds and pests, vibrations of planters, and also not adjusted planting machines. This problem leads to increase the number of plants per hectare and also create disordered distances between them, so thinning is necessary. It has an effective role in raising products yields per unit of area and also easing the mechanized harvesting operations (Åstrand and Baerveldt, 2002). Thinning is often done by workers using hands, which is basically an exhausting, time consuming, and costly operation. Moreover, if the time management about thinning was been ignored, it can cause inverse effects on products yields in the field (Slaughter et al., 2008).

Sugar beet (*Beta vulgaris*) is one of the most important sucrose resources. Its products such as bagasse, molasses, and lime were been used as food for livestocks and soil fertilizer. One of the most important matters, cause not to be planted sugar beet by farmers, is high costs related to thinning and weeds controlling operations which are time consuming (Bakker et al., 2008). So using planters can overcome this problem.

The air flow between plants with appropriate distances modifies the environmental factors that influence floor evaporation (Sun et al., 2016) and decreases the probability of diseases, so thinning is necessary to reach the standard density of plants in the field. It decreases competition among plants and maintains more nutrients, sun light, and water for remaining plants. Thinning and creating desirable distances between plants will result more uniform sizes tubers, ease mechanized harvesting operations, and raise performance of the harvesting machine (Van Der Weide et al., 2008).

In the recent years, the collective application of new technological advancements and improved management practices in farming has been raised in the field of precision agriculture, of which a major aspect is site-specific crop management for optimized

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http://dx.doi.org/10.1016/j.compag.2016.01.025
0168-1699/

and efficient field-crop production (Symonds et al., 2015). In mechanized thinning, removing of plants was randomly at first, and it is done using the distance which already has been determined by the farmer. However, modern thinners perform selectively and precisely according to the technology development. Hence, selective thinners are preferred among them, because they select excessive and weak plants correctly (Tillett et al., 2008).

Tian (1995) checked out possibility of using machine vision system for determining the main plants in the field. He faced with some problems due to the non-uniform light of the environment. Four features were studied in the captured images; length, compaction, the logarithmic ratio of height to width, and the ratio of length to perimeter. The results showed that about 61–82% of the main plants in taken images had been recognized correctly. Siemens et al. (2012) offered an automatic multi-purpose system using machine vision for doing practices during the growth stages of plants. This machine has been made for doing operations such as thinning, weeding, and variable fertilizing of lettuce. The performance of the device was assessed by measuring the distances between plants before and after thinning and comparing thinning times in manual and mechanized methods in 6 randomized blocks without considering the overlapping of plants. Consequences revealed that there was a significant difference between the manual and mechanized thinning.

Tillett et al. (2008) invented a device for weeding and thinning of transplanting cabbage plants. They used machine vision system in order to determine the main plants. Locating the main plants was through calculating the ratio of red, green, and blue components of images. Hence, the effect of shades in the field reduced. Garford Farm Machinery Ltd. presented this machine with more developments and modifications, commercially. Results indicated that algorithms of row and main plant detection had proper performances.

The important point in all researches is performing the designed algorithm based on the variable distance between plants. So the algorithm can choose the weakest plant among the other plants. The most important problem in designing the thinning algorithm is determining the overlapping of plants. Whereas numerous studies have focused on recognizing and also distinguishing weeds from main plants, such as texture analysis, but there is not any research considering the overlapping. The main purpose of this study is manufacturing and evaluating a thinning machine which is able to recognize excessive sugar beet plants that have overlapping on each other.

2. Materials and methods

2.1. Designing and manufacturing process

Selective thinning machine was designed and manufactured for evaluation of algorithms in a laboratory scale in Department of Biosystems Engineering, Urmia University, Urmia, Iran (Fig. 1). This device consists of a CCD digital camera (Sony Cyber-Shot, W200, Japan), control circuit of thinning operator, driving DC motor (Bühler Motor, 350 W power, Germany) for activating operator, and rotary hoe as thinning operator.

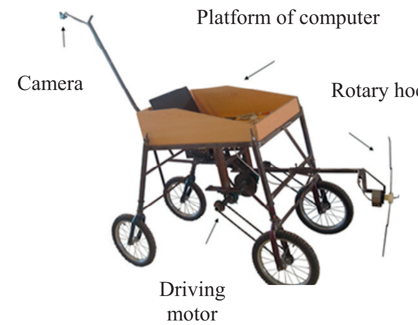

Fig. 1. Selective thinning device made in Urmia University, Urmia, Iran.

2.2. Image acquisition

Images have been captured from four sugar beet fields located in north-west of Iran at 36°E latitude and 45°N longitude, which planted by a pneumatic planter. Density of planting was 100–200 thousands per hectare. Image acquisition was done from early May to late June in 2013–2014. Images were acquired by a CCD digital camera with $1538 * 2048$ pixels resolution in JPEG compression format. They were taken in completely uncontrolled conditions of light, in different hours of a day with various weather conditions. Planted rows divided into equal distances with markers due to calibration of images (Fig. 2b). A frame was used for installing camera at a specified height. Images were captured in areas with 1 m distance on the rows. The vertical height of captured images from the surface of field was 1 m, with 0° (Fig. 2b) and 40° (Fig. 2a) angles from vertical line. Images, which have been taken at an angle of 40°, are perspectives. They will use for routing the machine. However, vertical images use to develop the algorithms of excessive plants detection.

2.3. Image processing and feature detection

Image processing and analysis were performed using MATLAB R2011b (The Mathworks Inc., USA). The main role of image processing is making variations in pictorial data and creating a new image. It means that some parts of original images improved in terms of quality and noises were diminished or omitted generally. Variations of light intensity in various weather conditions (cloudy, sunny, etc.) impacted on light intensity of images and even all parts of them. This could significantly change the main color components of images. So some equations should be used to separate plant from the soil background. Since the color of plants is green, the green component in plants is higher than the average of two other components (red and blue) which is (Eq. (1)):

$$2G - R - B > 0 \quad (1)$$

where R, G, and B are red, green, and blue components of images, respectively. By using this equation and choosing zero for threshold, plant can be separated from the soil background (Liu and Paulsen, 2000).

2.4. Designing the algorithms

The number of plants in images should be determined for designing thinning algorithms. To achieve this goal, two algorithms, the mass center (MC) and the average width (AW) of plants, were designed.

2.4.1. The mass center of plants algorithm (MC)

In this method, the number of plants in images and their mass centers are recognized after removing background. Then, the distance between mass centers of near plants are measured. In Fig. 3a, number of sugar beet plants is 12, whereas it was counted 7 in binary image (Fig. 3b). Because some plants (plants #3 and 4, #7, 8, 9, and 10, and #11 and 12) have overlapped on each other. Finally, algorithm compares distance between two adjacent plants with predetermined distance (depending on plant density per hectare). If distance between two adjacent plants is less than