Computers and Electronics in Agriculture 112 (2015) 128–138

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Development of agricultural implement system based on machine vision and fuzzy control

Qingkuan Meng [a], Ruicheng Qiu [a], Jie He [a], Man Zhang [a,*], Xiaodan Ma [a,b], Gang Liu [a]

[a] Key Lab of Modern Precision Agriculture System Integration Research, Ministry of Education, China Agricultural University, Beijing 100083, PR China
[b] College of Information Technology, Heilongjiang Bayi Agricultural University, DaQing 163319, PR China

ARTICLE INFO

Article history:
Received 1 April 2014
Received in revised form 11 September 2014
Accepted 3 November 2014
Available online 25 November 2014

Keywords:
Machine vision
Color space
Guidance line detection
Fuzzy control

ABSTRACT

To achieve accurate mechanical inter-rows weeding, an agricultural implement guidance system based on machine vision was designed. The guidance system consists of a color video camera, an industrial panel PC, a lateral displacement controller, a GPS receiver, a hydraulic system, and an agricultural implement. To improve the accuracy and reliability of the guidance system, the choice of color space, the method of guidance line detection, and the method of controlling the implement were investigated. First, considering the adverse effect of illumination variation on image processing, the HIS (hue, saturation, intensity) color model was used to process images, and a threshold algorithm based on the H component was used to produce grayscale images. Second, according to the characteristics of the crop rows in the image, a method of crop line identification based on linear scanning was proposed. To approximate the trend of a crop row in the image to a line, pixels at the bottom and top edges of the image were selected as two endpoints of the line. Candidate lines were created by moving the position of these endpoints. The line with the most target points was regarded as the crop line. Finally, fuzzy control was used to control the agricultural implement. This algorithm can effectively control the agricultural implement tracking the guidance line. Path tracing experiments were conducted at three different speeds of 0.6, 1.0 and 1.4 m/s in the corn field on a sunny day. The maximum lateral errors were 4.5 cm, 5.5 cm and 6.8 cm at the three speeds. The average lateral errors were less than 2.7 cm for all speeds. The experimental results demonstrated that the guidance system successfully adapted to changes in natural light and had good dynamic performance at all speeds.

1. Introduction

Using navigation technology in agriculture reduces the cost of crop production and improves the working accuracy of farmers. Agricultural robots are widely used in many agricultural fields, such as crop harvesting, crop row weeding, and automatic fertilizing. These robots have become an important part of modern precision agriculture (Benson et al., 2001; Slaughter et al., 2008). The main positioning sensors are GPS and machine vision (Tellaeche et al., 2008; Hague et al., 2000; Wilson, 2000). GPS provides high-precision, all-weather, and real-time 3D coordinates. However, GPS signals are easily blocked by buildings and trees, which reduce positioning accuracy. Compared with GPS, machine vision involves real-time processing, rich information, and a wide spectral range. Thus, guidance systems based on machine vision are widely used in agricultural production.

1.1. Literature review

Many scholars around the world have extensively examined machine vision guidance systems. These systems always use the RGB (red, green, blue) color space to process images. However, this color space is sensitive to changes in illumination. To reduce the adverse effects of changes in illumination on image processing, researchers have used the 2G–R–B factor to produce grayscale image (Søgaard and Olsen, 2003; Gee et al., 2008). Nevertheless, the three components (R, G and B) of RGB change with the light changes. The 2G–R–B factor could not completely eliminate the adverse effects of changes in illumination. By contrast, the YUV (luminance, chrominance, chroma) color space allows luminance and chrominance separation. This color space has been used to identify mature tomatoes (Lin and Hu, 2012). By analyzing the V component of mature tomatoes, leaves, and raw tomatoes, a threshold algorithm based on the V component has been used to recognize mature tomatoes. The YUV model is insensitive to variations in natural light, making it feasible for

* Corresponding author. Tel.: +86 10 627 379 14.
E-mail address: cauzm@cau.edu.cn (M. Zhang).

http://dx.doi.org/10.1016/j.compag.2014.11.006
0168-1699/

processing images, which are susceptible to changes in illumination. Yet the crop in farmland is green and YUV do not have the chrominance formed by subtracting luminance from green. Therefore it is not feasible to process crop images with YUV color space.

Many methods for crop row identification have been developed. Marchant and Brivot (1995) proposed an algorithm for crop row identification that took advantage of the relationship between crop rows coordinates and camera calibration coordinates and combined with the Hough algorithm to detect crop rows. Yang et al. (2004) used Hough transform and a dynamic window to extract navigation features from the natural environment. This image processing method was tested using an experiment platform built on a wheeled tractor. Experimental results demonstrated that the algorithm was valid and feasible. The disadvantages of Hough transform are complex in calculation and time-consuming, which cannot meet the real-time performance of guidance system. Burgos-Artizzu et al. (2011) presented a computer vision system for crop row identification. This system consisted of two independent subsystems: a fast image processing subsystem that delivered results in real-time (fast image processing), and a slow and accurate processing subsystem (robust crop row detection). This system successfully detected an average of 80% of crops under different conditions. Si et al. (2010) used the least squares method to detect early-stage crop rows. The center points of crop rows were extracted as feature points and were classified into different clusters. The least squares method was used to fit the feature points to determine the crop line. The drawback of least squares method is sensitive to weed noise, which reduces the accuracy of crop line detection. Jiang et al. (2009) presented an algorithm based on a randomized method for crop row recognition. During image preprocessing, a vertical projection method was used to estimate the position of crop rows. A candidate line was determined by two different localization points, which were randomly selected from a feature point space. A threshold rule was used to determine whether the candidate line was the desired one. In this algorithm, the selections of random points and threshold rule are crucial, and then the stability of crop lines is difficult to be guaranteed.

In agricultural robot control, Li et al. (2008) designed a proportional–integral–derivative (PID) controller for an automatic guidance vehicle (AGV) based on machine vision. According to navigation parameters, the PID controller controlled the motor of the AGV to track lines. Simulation and experiment results showed that the designed control method can track paths precisely and reliably. However, the control parameters of PID controller are difficult to be set in the complex environment of farmland. The inappropriate parameters would cause the poor adaptability of path tracking. Zhou et al. (2009) proposed a linear tracking method based on fuzzy control. Simulation and experiment results showed that the VGA could track the road accurately and reliably. Cho and Ki (1999) used a fuzzy logic controller to control an autonomous sprayer vehicle through orchards. The input information for the fuzzy logic controller was supplied by both machine vision and ultrasonic sensors.

The RGB color space is always used to process images. However, this color space is sensitive to changes in illumination and causes image segmentation information to become unclear. Therefore, selecting an appropriate color space for image processing is important. The least squares method and Hough transform are the primary algorithms used to detect crop rows and guidance lines. However, the speed and accuracy of these algorithms need to be improved further. Fuzzy control and PID control are widely used in agricultural robot navigation. Fuzzy control does not rely on complex mathematical models, making it suitable for navigation robot control.

1.2. Objectives of the study

As can be seen from above researches, there are two problems need to be further studied. One is the adaptability of guidance system under varying illumination condition. The other is the time consuming and robustness of guidance line detection algorithms. The overall objective of this study is to develop a real time precision agricultural implement system based on machine vision dedicated to inter-rows weeding in maize crop field. The main differences between our research and previous studies are the choice of color space and a new method oriented to guidance line detection. The following specific objectives are selected for this research:

1. In order to solve the problem of illumination interference for image segmentation, HIS color space is selected for image processing.
2. Develop a new method to detect guidance line. Unlike traditional guidance line detection approaches, the advantages of the new method are real-time and robustness in guidance line recognition.
3. Develop a fuzzy controller for the lateral control of agricultural implement.
4. Test the agricultural implement system based on machine vision at three different speeds in the corn field under varying illumination condition.

2. Materials and method

2.1. Design of agricultural implement guidance system

The structure of the agricultural implement guidance system is shown in Fig. 1. The hardware used in the guidance system mainly consisted of a color video camera, an industrial panel PC (PPC), a lateral displacement controller (LDC), a GPS receiver, a hydraulic system, and an agricultural implement. The camera was focused on the field surface from an inclined angle to obtain images that cover up to about four rows simultaneously. New images were continuously transferred to the computer, which processed them and calculated the necessary lateral movements of the agricultural implement. A GPS receiver embedded in the industrial PPC was used to obtain dynamic data under open field conditions. RS 232 serial communication at 115,200 baud was adopted to communicate with the GPS receiver. The communication protocol between

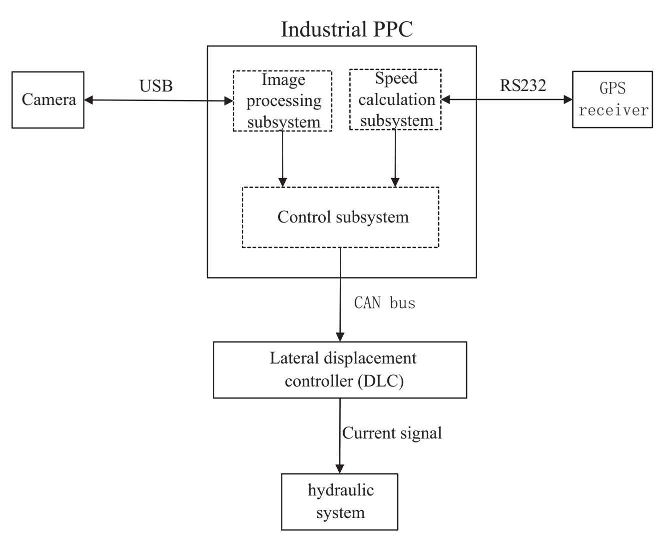

Fig. 1. Structure of agricultural implement guidance system.