GPS-Based Intra-Row Weed Control System: Performance and Labor Savings

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Abstract

Researchers at UC Davis and elsewhere have demonstrated the technical feasibility of using RTK-GPS technology to automatically create crop plant maps at planting (Sun et al., 2010; Perez-Ruiz, 2011). This paper describes the development and field evaluation of a completely automatic system for intra-row weed control in tomato fields. This system uses an automatically generated GPS crop plant map to automatically control the path of a set of mechanical intra-row weed knives in order to kill weeds growing between tomato plants in the seedline. The manual labor savings were evaluated in controlled field trials and the labor savings benefits associated with the use of this system are reported.

Keywords: RTK GPS, Precision Agriculture, Weed Control

1. Introduction

Weed control is a very important issue for Californian vegetable farmers because even low numbers of weeds can reduce marketable yield (e.g., Lanini and LeStrange, 1991) and have a detrimental impact on produce quality and economic competitiveness. The number of herbicides currently available to vegetable crop farmers is limited and they are only partially effective. As a result, Californian farmers frequently rely on hand weeding and mechanical cultivation to control weeds. Labor shortages in the USA for agricultural tasks have been reported (Wood, 2005) as border security has increased. Thus the weed control task is a major issue particularly in the organic setting (Posner et al. 2008).

In geospatial relation to the crop plants, Blackmore et al. (2007) defined three weeding zones: inter-row, intra-row and a zone that is close to crop (called a safety zone in this research). Weeds present in the inter-row zone can be controlled effectively with conventional mechanical cultivation, but leaves weeds in the other two zones. Autoguidance systems based upon machine vision (Slaughter et al., 1995; Slaughter et al., 1999; Sogaard and Olsen, 2000; Fennimore et al. 2010) or GPS (Abidine et al., 2004) can be used to cultivate or spray very close to the crop plant row (~ 5 cm) at very high ground speed (up to 11 km/h), improving the effectiveness of inter-row cultivation. However, weed control in intra-row and close to crop zones is still conducted by hand in vegetable production in the USA.

Thus there is a need for new automation technologies that can provide both efficient and cost-effective weed control for intra-row and close-to-crop weed management zones in vegetable crops. The objective of this research is to show that a significant reduction in the current reliance on hand labor in organic and conventional production systems can be achieved by RTK-GPS geospatial location technology to both map the crop and planting and then utilize the as planted GPS crop plant map to automatically control a mechanical weed knife system that kills weeds in the intra-row zone.

2. Materials and methods

An automatic intra-row weeding machine was designed using a pair of intra-row mechanical weed knives setup for precision intra-row weed control using RTK-GPS based knife actuation. Knife actuation was achieved via pneumatic cylinders attached between a frame on the cultivation sled and the knife linkage arms, Fig. 1. The weed knives where positioned directly behind an inter-row close cultivation implement. With the precision intra-row knives in the operating position (called the closed position in this research), all weeds in the row center were killed, Fig 3a. Moving the knives to the standby position (called the open position in this research), created a knife-free uncultivated region about each crop plant, Fig 3b. The knife control system utilized a ruggedized, real-time, embedded controller (cRIO-9004, National Instruments, Austin, TX, USA) with a low-power CPU (195 MHz Pentium, Intel, Santa Clara, CA, USA) and 512 MB of nonvolatile flash memory storage. This system was designed to control the path of the weed knives based upon the real-time GPS location of the leading edge of the knives and their geospatial relationship to the crop plants. Crop plant location was determined from a GIS crop as planted map that was loaded into the memory of the embedded controller. When the knives were in the intra-row zone, shown as position 1 in Fig. 2, they were positioned in the "closed" position with interior knife tips touching and killing all weeds along the row centerline. As the knives reached the close-to-crop safety zone, they were automatically repositioned (or "opened") away from the row centerline and into the inter-row zone, safely bypassing the crop plant, shown as position 2 in Fig. 2. After passing the crop plant, the knives were automatically returned to the closed position at the end of the safety zone, resuming the task of intra-row weed control.

FIGURE 1: Photograph of the RTK-GPS automated transplant mapping system being used to plant tomato transplants on the UC Davis campus farm.

A field test was conducted during the spring of 2011 using processing tomato transplants as the target crop. The field site was located at the Western Center for Agriculture Equipment (WCAE), on the University of California, Davis campus (Latitude: 38.53894946 N, Longitude: 121.7751468 W). In this test, sixteen rows were planted (single crop row/bed, 1.5 m bed spacing) with an improved version of the GPS mapping transplanter described by Sun et al. (2010). The transplanter was operated at a ground speed of 1.6 km/h using rows that were laid out in a predominantly East-West direction. The transplanter sled was pulled behind a tractor steered by an RTK GPS autoguidance system (model EZ-Guide 500, Trimble Navigation Ltd., Sunnyvale, CA, USA). All seedbed preparation operations were also conducted with a tractor steered by GPS autoguidance using a common set of GPS AB line coordinates for all tillage, planting operations and weed control tasks. No herbicides were used in the trial, in order to simulate weed populations common to organic production systems. The GPS crop plant map was created using the optimization method of Ehsani et al. (2004), but modified for real-time odometry sensing.

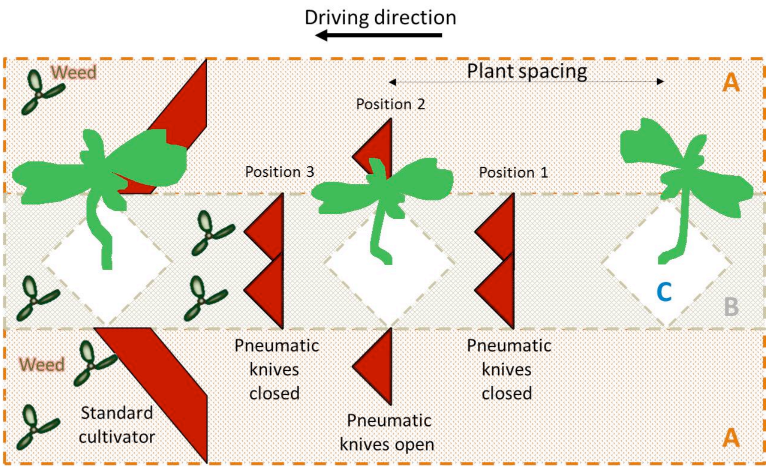

FIGURE 2: Diagram showing the three weeding zones: A=inter-row (orange dashes with < symbols), B=intra-row (gray dashes with small square inside), and C=safety zones and the ideal path of the weed knives

Approximately three weeks after transplanting, the automatic intra-row weed control system was evaluated. Weed densities were measured prior to precision cultivation. The automatic weed knife system was operated at a travel speed of 1 km/h. Half of the test plot (8 rows) was randomly assigned to the automatic intra-row weed control and the other half used as a control treatment for weed control using traditional manual control of intra-row weeds. Labor savings in follow-up hand weeding was documented by measuring the time required for experienced laborers to hoe remaining weeds after the automatic system had been operated and compared to the amount of time required to hand hoe the control rows using a randomized complete block design in assigning farm laborers to weeding treatments. All results were analyzed by ANOVA using the SAS PROC GLM statistical software.

3. Results and discussion

In total, 2278 tomato transplants were automatically mapped using RTK-GPS during planting in the sixteen rows of the test plot for this study. The mean weed density in the test plot was 23.9 weeds/m^2 and no significant difference in weed load between treatments was observed (p-value=0.44). RTK-GPS Fixed quality was obtained for all GPS antenna positions recorded during transplanting and mapping performance was comparable to that observed by Sun et al., (2010).

The automatic intra-row weeding machine successfully killed intra-row weeds between tomato plants without a significant (p-value=0.57) reduction in crop plants. Video analysis of knife operation showed satisfactory dynamic performance in following the desired cutting path. A significant (α=0.01) reduction in the amount of man-hours required for follow-up hand weeding was observed in rows automatically weeded by the machine. Figure 4 shows boxplots for the distributions of the man-hours required for hand weeding in the test. In the control treatment a mean of 206.7 h ha^{-1} was required to hand weed the intra-row and close-to-crop zones. Although the boxplot for the control treatment appears asymmetric, the Shapiro-Wilks test failed to reject the assumption of a Normal distribution for either treatment (p-values > 0.1). The additional hand weeding required in region B in Fig 2. For the RTK GPS automatic weeding treatment following the automatic intra-row weed knife operation was 99.7 h ha^{-1}. This data shows that the automatic system developed can replace a significant amount of hand hoeing labor currently required to perform weed control in areas between crop plants in the row centerline.

(a) (b)

FIGURE 3: Photographs showing the operation of the automatic, mechanical, intra-row weed knife system. Fig 3a shows the knives in the operating or "closed" position, where weeds growing along the row centerline between crop plants are killed. Fig 3b shows the knives in the standby or "open" position, where the knives are temporarily placed in the inter-row zone to bypass the tomato plant. Note in actual operation the cutting edge of the knives are located ~2cm below the soil surface. They were positioned at the soil surface for visualization purposes in this figure.

Overall, a 52% reduction in the man-hours per hectare was obtained by using the automatic GPS-based intra-row weeding machine. Assuming hand weeding labor costs of US$10 per hour, this level of labor reduction potentially represents a significant savings in the cost of manual labor for hand hoeing. The cost savings in hand labor will need to offset the equipment cost, making the system more economically advantageous in organic production systems where weed loads tend to be highest. Utilization of RTK GPS equipment for other tasks in the crop production system can help disperse the equipment cost across many cultural practices, reducing the equipment cost penalty in the weed control operation and may make it economically viable in conventional production systems.

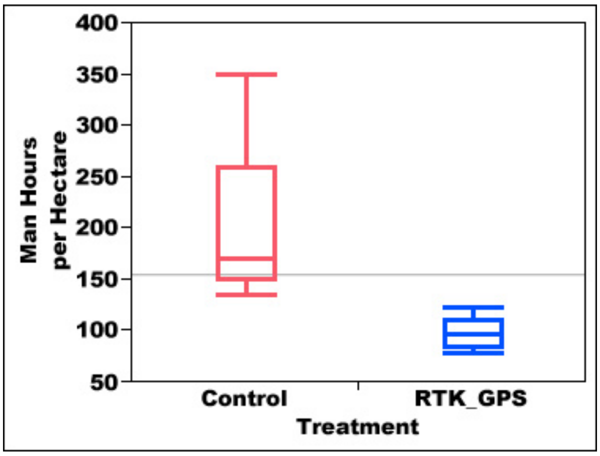

FIGURE 4: Comparison of intra-row hand weeding labor required for RTK GPS automated weed control vs. conventional hand hoeing.

4. Conclusions

An automatic intra-row weeding machine was successfully designed and tested, using real-time automatic RTK GPS mapping of crop plants during transplanting and automatic RTK GPS based weed knife path control for mechanical removal of weeds growing between crop plants along the row centerline. The system was tested in a processing tomato field where a common set of GPS AB line coordinates was used for all operations from initial tillage and seedbed preparation until automatic intra-row weed control was conducted about one month after planting.

A pair of intra-row mechanical weed knives was successfully used for precision intra-row weed control, significantly reducing the amount of follow-up hand labor required to remove all weeds in the close-to-crop zone. Overall, a 52% reduction in the man-hours per hectare was obtained by using the automatic GPS-based plant mapping and intra-row weeding machine.

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