Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-16 (2016) 299–304

Design and Evaluation of a Levelling System for a Weeding Robot

Lin Chen*. Supod Kaewkorn. Long He*****
Qin Zhang**. Manoj Karkee*******

** Department of Biological Systems Engineering, Washington State University, WA 99350 USA (Tel: 509-781-2513; e-mail: lin.chen2@wsu.edu).*
*** School of Engineering and Technology Mechatronics, Asian Institute of Technology, Thailand (e-mail: kmin_5@hotmail.com)*
****Center for Precision and Automated Agricultural Systems, Washington State University, WA 99350, USA, (e-mail: long.he@wsu.edu)*
*****Center for Precision and Automated Agricultural Systems, Washington State University, WA 99350, USA, (e-mail: qinzhang@wsu.edu)*
****** Biological Systems Engineering, Center for Precision and Automated Agricultural Systems, Washington State University, WA 99350, USA, (e-mail: manoj.karkee@wsu.edu)*

Abstract: Weed control is a critically important task in organic crop farming. Even though there are machines available for inter-row weeding, manual weeding is still the only choice for weed control in organic farms, especially in the narrow spaces between crop plants (intra-row weeds). Such an operation is highly labor intensive and costly in organic vegetable production. Automatic or robotic weeding could provide a potential solution for addressing labor related issues. In intra-row weed control, weeding end-effectors need to be positioned accurately to remove weeds growing very close to the plant while the robotic vehicle is continuously moving on a generally uneven and uncertain field surface. This study was aimed at assessing the performance of an end-effector auto-levelling system designed to accurately control the position of the end-effector during weeding operations in vegetable crops. The performance assessment was conducted via a set of laboratory experiments using a specifically designed and fabricated proof-of-concept prototype. To achieve the desired level of performance in actual field conditions, the prototype system required maintaining the end-effector base at horizontal position within a ± 0.25º angular error when the testbed (laboratory prototype) roll and pitch angles were varied from -8º to 8º. The test results verified that the developed end-effector base levelling system could maintain the drift of the end-effector tip position within 18 mm when input roll or pitch angle reached 8º. Meanwhile, the corresponding position error caused by angular error of the levelling plate was limited in 0.2 mm when the levelling plate at a height of 10 cm, which means the levelling system can efficiently reduce the effect of the rough field. The regularity of the end-effector tip position drift can also help us with end-effector control.

Keywords: Weeding robot, Levelling system, Angle error, Position error, System performance.

1. INTRODUCTION

Weed control has always been a critical challenge in vegetable crop production (Kaierle and Marx 2013). Nowadays, common practices for weed control include chemical weeding, mechanical weeding, and manual weeding (Olson and Eidman, 1992). Chemical weeding has the lowest cost, but it can lead to pollution and herbicide residue (Colbach et al., 2010). Mechanical weeding can hardly achieve a high level of efficiency and complete weed removal, and it can cause some crop injury (Fogelberg and Gustavsson, 2002). Manual weeding is always associated with low productivity and high labor cost (Schuster et al., 2007). Moreover, in organic vegetable fields, only mechanical or manual weeding could be used (Bakker et al., 2006). In order to reduce the cost and dependency on human labor in organic vegetable production, the development of robotic weeding becomes a viable choice (Young and Pierce, 2014). Recently, two major types of robotic weeding devices have been developed: namely tractor drag devices and self-powered machines. For the first type, the weeding device is dragged with a tractor which requires a driver for the tractor. For the second type, the machine is often automatically guided and performing weeding tasks also automatically supported by a combined application of sensor systems, communication technologies, positioning systems (GPS) and geographical information systems (GIS) (Pedersen, et al., 2008). This reported study is focused on the second type of weeding robot.

Generally, a weeding process includes two parts, weed detecting and weed removal. Reported previous studies indicated that the weeding detecting rate could reach a level of 88.3% to 91.2% by using a 3D camera technology (Ji, 2014). However the weed removing rate is still much lower

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.055

than what can be detected (Lati et al., 2016). If we could identify and locate all weeds in a field, those weeds should technically be removable. However, as a robotic weeding platform is running on uneven field surface which will result in a hard-to-predict roll and pitch motions of the platform. Such motions make it very difficult to control end-effector positions which cause the end-effector to miss the target resulting in decreased efficiency, and even worse may remove plants. In this case, a major challenge for successful robotic weeding is how to control the unpredictable variations in platform attitude when weeding robots are traveling in rough crop fields to achieve acceptable end-effector positioning control to effectively removing the targeting weeds. As many weeds grow very close to crop plants, a capable robotic weeding system requires having a high positioning accuracy, which requires a stable and precisely levelled base where a weeding end-effector can be mounted. Two possible methods could be used for achieving the goal of automatically levelling an end-effecter base on a mobile platform. One is the use of two rotation motors to adjust the roll and pitch angles of the end-effector base in response to the platform with roll and pitch changes to achieve the base levelling requirement. Another one is using a multi-bar (made by cylinders) structure to level the end-effector base. Both based on the same principle, but different mechanical designs. The first design uses fewer actuating elements which need to be controlled but carries less load, and the second design could carry heavier load but often requires using more actuating elements which makes the system more complicated. In this proof-of-concept study, we are focusing on assessing the principle and the potential of using an auto-levelling mechanism to improve end-effecter position control accuracy. Therefore, the mechanism with simpler structure was selected to design the laboratory-scale end-effector base levelling system research prototype, and then fabricated and evaluated in the laboratory environment.

2. CROP FIELD CONDITION

2.1 Cropping Systems Modelling

To evaluate the performance of the proposed end-effector base levelling system in laboratory environment, it is essential to model and represent field conditions as close as possible. Organic onion and carrot fields in WA with typical cropping practices were used as example cases for this study (Figure 1). Geometric dimensions of cropping systems including bed width and inter-bed spacing were measured in commercial fields at Mercer Canyon Inc. (Prosser, WA) to simulate field conditions.

As illustrated in Figure 1(a), a ditch width (also the pathway for robot wheels) of the cropping system is 25 cm. The figure also shows that the distance between the centers of the wheel base (between left and right side wheels) of a field robot platform should be 100 cm. Figure 1(b) illustrates the side view of a typical ditch surface condition on which robot wheels will travel, and such a rough surface will induce noticeable variation in roll and pitch angles of the robot platform while moving. Field inspection indicated that the uneven driving surface will have a maximum level difference of 20 cm with a minimum distance of 38 cm between the peaks.

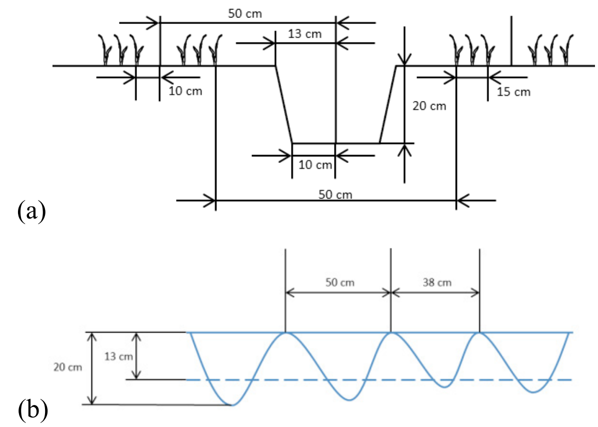

Fig. 1. Geometric dimensions of typical onion and carrot cropping systems in Mercer Canyon Inc. (Prosser, WA): (a) front view of the crop beds; and (b) A typical condition of the ditch surface.

2.2 Test-bed Design Specifications

To make the testbed capable of representing the real field condition as closely as possible, it is critical to define a set of system design specifications based on the field measurements. Assume the wheel base (center-to-center distance between left and right wheels) of the robotic platform is 100 cm. So the maximum amplitude of the uneven ditch surface (20 cm) was used to calculate the maximum value of the rotation angle of the platform during field operation (Equation 1).

$$\psi = \arctan\left(\frac{20\text{ cm}}{100\text{ cm}}\right) \approx 11° \quad (1)$$

The axial-base length (center-to-center distance between front and rear axials) of a robotic platform is normally greater than that of the wheel base; therefore the uneven surface induced pitch angle should always smaller than the roll angle. It allows us to use the angle for both roll and pitch to prove the concept in this study. Furthermore, in real field condition, the soil on top of the mound is often compressed more by the weight of a mobile machine than the soil on bottom, which means the maximum height difference on robot pathway is less than 20 cm. Therefore it will be reasonably accurate if we define a controllable angle range of attitude angles from -10° to 10° for the testbed.

3. LABORATORY SCALE TESTBED DEVELOPMENT

3.1 Experimental Testbed Design

Based on preliminary field measurements and afore defined platform specifications, a laboratory-scale auto-levelling mechanism proof-of-concept testbed (Figure 2) was designed and fabricated for evaluating the capability and performance of proposed auto-levelling mechanism.

The concept-approval testbed included two parts: a base frame and a levelling frame as shown in Figure 2. On this testbed, the base frame represents the robot platform and different patterns of rolling and pitching motions can be