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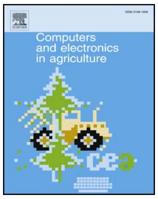

Original papers

Development of a prototype robot and fast path-planning algorithm for static laser weeding

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A B S T R A C T

To demonstrate the feasibility and improve the implementation of laser weeding, a prototype robot was built and equipped with machine vision and gimbal mounted laser pointers. The robot consisted of a mobile platform modified from a small commercial quad bike, a camera to detect the crop and weeds and two steerable gimbals controlling the laser pointers. Visible-one laser pointers were used to simulate the powerful laser trajectories. A colour segmentation algorithm was utilised to extract plants from the soil background; size estimation was used to differentiate crop from weeds; and an erosion and dilation algorithm was developed to separate objects that were touching. Conversely, another algorithm, which utilised shape descriptors, was able to distinguish plant species in non-touching status regardless of area difference. Next, in order to reduce route length and run time, a new path-planning algorithm for static weeding was proposed and tested. It was demonstrated to be more efficient especially when addressing a higher density of weeds. A model was then established to determine the optimal segmentation size, based on the route length for treatment. It was found that the segmentation algorithm has the potential to be widely used in fast path-planning for the travelling-salesman problem. Finally, performance tests in the indoor environments showed that the weeding mean positional error was 1.97 mm, with a 0.88 mm standard deviation. Another test indicated that with a laser traversal speed of 30 mm/s and a dwell time of 0.64 s per weed, it had a hit rate of 97%.

1. Introduction

Weeds negatively affect crop yields by competing with the crops to acquire nutrients and other resources (Slaughter et al., 2008). Currently, chemical weeding (herbicide) is widely used as a traditional solution (Bakker et al., 2010). However, herbicides are viewed critically because of their negative environmental impacts (Marx et al., 2012). Moreover, consumers increasingly prefer the choice of natural, organic foods, which has not been exposed to toxic chemicals (Blasco et al., 2002). There are also an increasing number of herbicide-resistant weed species being recognised (251 species by the International Survey of Herbicide Resistant Weeds, 2017). In response to these challenges, many non-chemical weeding methods have been developed ranging from electrocuting (Diprose and Benson, 1984) through to using mechanical or physical methods (Pannacci et al., 2017). Nørremark et al. (2008) developed a cycloid weeding hoe for both inter- and intra-row weeds, based on GPS position of the crop. Tillett et al. (2008) developed a vision based inter- and intra-row mechanical weeding robot using rotating discs for transplanted crops, which can remove 80% of weeds. Similarly, Ahmad (2012) presented a weeding mechanism with rotating tine for intra-row weeding robot. Besides, O'Dogherty et al. (2007) proposed a mathematical model for inter- and intra-row hoeing. Moreover, another kind of mechanical weeding robot equipped with a real-time kinematics GPS to detect crop planting geopositions has been developed by Pérez-Ruiz et al. (2012). This system was reported to have a mean error of 0.8 cm and a 1.75 cm standard deviation when travelling at a speed of 0.8 km/h.

However, the common challenge with all of the above inter- and intra-row mechanical weeding robots is that they require the crops to be well distributed. Selective weeding could provide solutions for crops regardless of distribution, which is more closely aligned with the way that humans kill weeds. In addition, as has been reported by Griepentrog et al. (2006), a selective weeding strategy could decrease the energy input even more by 10–90%. Midtiby et al. (2011) developed a real-time machine vision based, micro-spraying weed control system, but only 37% of the smaller scentless mayweed were effectively controlled. After that, Underwood et al. (2015) presented a micro-dot targeted and steerable spraying robot for weed control. However, such methods of selective spraying still rely on herbicide application, which is not permitted in organic farming. Due to the unsatisfactory aspects,

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other weeding techniques such as laser weeding seems to offer a potential alternative (Marx et al., 2012). Some researchers, such as Heisel et al. (2001), used a laser beam to cut the stems of weeds as a method of weed control, while Marx et al. (2012) proposed a weed damage model that utilized laser irradiation-based weed control method. Mathiassen et al. (2006) also investigated the effects of laser treatment towards weeding, purporting that the laser exposure time and laser spot size could be optimised to kill the weeds. Nadimi et al. (2009) designed a laser weeding test setup to simulate dynamic targeting weeding. Also, some concepts of robotic arms for laser weeding have been presented (Ge et al., 2013; Xuelei et al., 2016). To demonstrate the feasibility of laser weeding, it is meaningful to develop an autonomous mobile robot for this purpose.

Therefore, the aim of this study was to design and test, in the laboratory, a novel prototype laser weeding robot, and to explore its feasibility for successful application in the agriculture industry.

2. Materials and methods

2.1. System overview

The prototype laser weeding robot comprised of three subsystems: a robotic platform, machine vision and a laser pointing system. Fig. 1 shows the whole hardware assembly of the laser weeding robot. A centrally mounted, downward facing camera gave the field of view, as well as two gimbals, each holding a laser pointer were mounted on top of the frame, which, in turn, was fixed on the front of the robotic platform. The frame was 49.5 × 39.5 × 39.5 cm (length × breadth × height) and the overall size of the robot was 150 × 65 × 65 cm.

The system architecture is illustrated in Fig. 2. The three subsystems were coordinated by a central program written in MATLAB (2015a). The architecture used a distributed control strategy in such a way that each subsystem has an independent controller, thus ensuring that the system can be easily integrated. The image acquisition grabbed the image and passed it to the weed recognition program. The path planning system then used the weed centroids to control the gimbals. Feedback loops were built into all levels of the platform and gimbal controllers.

2.2. Robotic platform

2.2.1. Robot hardware

As shown in Fig. 1, the robotic platform had been modified from a small all-terrain vehicle (ATV) which was robotised to provide automated steering and speed control.

In terms of speed control, the ATV was equipped with a motor driver that used a three-wire hall-effect speed control throttle to change the motor speed. The throttle was removed and replaced with a 1–4 V analogue version to control vehicle's speed via the pulse-width modulation (PWM) output of a microcontroller. An Arduino Mega 2560 was then selected as the platform controller.

To achieve accurate and automatic steering control, as shown in Fig. 3, a Linak LA12.1P-100-12-01 linear actuator was installed to rotate the steering mechanism. As the linear motor either extended or retracted, the vehicle turned right or left accordingly, and provided positional feedback to the controller. Both the maximum thrust and holding force of this actuator were 500 N, thereby maintaining the stability of the steering angle regardless of normal moving resistance.

2.2.2. Circuit design and control

Two relays were established for control of the linear actuator, thus providing the options of three different states: extend, retract or hold. The relays were controlled by the same Arduino as the speed control. The linear motor itself had a slide potentiometer provided feedback on the stroke length.

The objective of the speed control mechanism was to enable automatic adjustments with which to establish and, maintain a desirable speed. An optical encoder was mounted on the rear wheel to sense platform displacement and speed. Subsequent tests on the platform revealed that the average time for moving the length of one tray (214 mm) was 1.56 s giving a maximum speed of 0.14 m/s.

The vehicle controller interface was divided into three modules: power management, steering, and speed, as shown in Fig. 4.

2.3. Machine vision

2.3.1. Image acquisition and coordinate transformation

Burgos-Artizzu et al. (2011) proposed a one camera system for weed detection, with a pre-set height and camera angle. Similarly, this study used a single camera with one precondition: keeping the pose of the camera to the ground to be the same as the calibrated pose, so that the

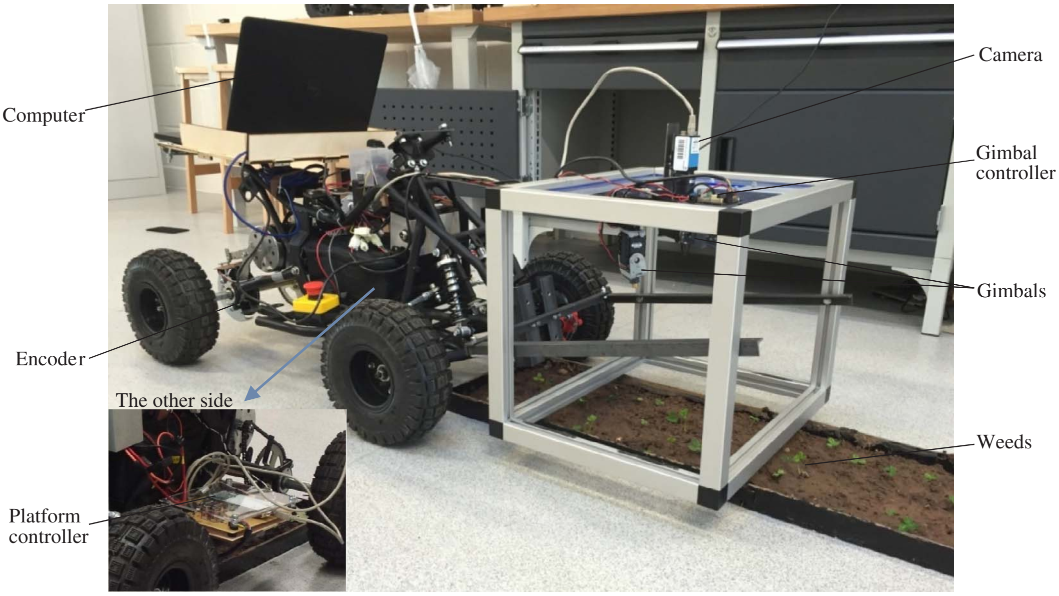

Fig. 1. The laser weeding robot.