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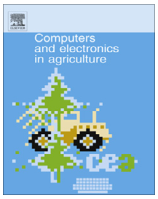

Original papers

Optimizing the path of seedling low-density transplanting by using greedy genetic algorithm

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ABSTRACT

Automated transplanters perform repetitive low-density transplanting and replugging of seedlings in greenhouses to resolve the labor shortage problem and consistently produce seedlings. The work efficiency of transplanters can be improved by optimizing the transplanting paths of end effectors. In this study, a greedy genetic algorithm (GGA) was developed for path optimization. GGA combines the characteristics of a greedy algorithm (GRA) and a genetic algorithm (GA). The performances of GGA, GRA, GA, and the common sequence method (CSM) in the path planning for seedling low-density transplanting were compared in terms of their optimization effects and computation time. Average transplanting paths were analyzed for sparse (32 and 50 holes) and dense (72 and 128 holes) seedling trays with 5%–20% randomly located vacant holes. Compared with the average optimization ratio of CSM, those of GA, GGA, and GRA were 10%, 8.7%, and 5.1%, respectively, for sparse trays, whereas 13.9%, 13.4%, and 11.8%, respectively, for dense trays. The standard deviations of GGA and GA overlapped in different vacant holes for the dense trays. The performance ranking of the suitable methods with short average paths was in the order of GA, GGA, and GRA. The superiority of GA over GGA gradually decreased with the increasing number of vacant and tray holes. The computation of path planning must satisfy the real-time operating requirement of transplanters. GA, GGA, and GRA consumed 9.61, 2.82, and 0.02 s, respectively, for the path planning for the dense trays. Compared with GA and GRA, GGA performed effectively in the path planning of seedling low-density transplanting due to its comprehensive performance derived from its path optimization ratio and low computation time cost. This combined optimization algorithm could have similar agricultural applications.

1. Introduction

Plug-tray seedlings need to be transplanted from high-density trays to low-density trays for further growth in greenhouses. Distinguishing healthy seedlings from unhealthy or missing ones and repetitively transplanting these healthy seedlings through the traditional manual mode require intensive labor. Researchers (Kutz et al., 1987; Yang et al., 1991; Simonton, 1991; Kim et al., 1995; Choi et al., 2002; Chien and Lin, 2005; Hu et al., 2014; Jiang et al., 2015) have developed a robotic transplanter by using opto-mechatronic technologies. Ting et al. (1990a,b) designed a sliding-needle end effector with a sensor installed on a selective compliance assembly robot arm robot, which is adaptable to a wide range of seedling sizes and shapes. The sensor-equipped gripper can fill growing flats with good seedlings. Meanwhile, Ryu et al. (2001) developed a robotic transplanter consisting of a vision system, an end effector, a manipulator, and tray conveyors. A vision system with a charge-coupled device can detect the empty cells in high-density trays by analyzing the seedling leaves. Tong et al. (2013) established an imaging system for automated transplanters; this system can measure the leaf area in plug trays for the evaluation of seedling quality. Image algorithms were also developed to segment the overlapped leaves and calculate the leaf area, including the intruding leaves, to improve the accuracy of determining the seedling quality. Several commercial robotic transplanters have been developed and used (e.g., Urbinati RW5 transplanter by the Transplant Systems Co., Ltd., Victoria, Canada, 2017; Pic-O-Mat Greenline Transplanter by Visser Co., Ltd., Gravendeel, Netherlands, 2017). The development of these robotic transplanters can reduce the labor load and lead to the consistent production of seedlings.

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To improve the transplanting quality and efficiency, researchers have introduced machine vision, mechanism creative design, and path planning methods to robotic transplanters. For example, the machine vision system can obtain the quality information of all the seedlings in a tray at one point (Ryu et al., 2001), whereas a proximity sensor can only examine pot seedlings individually (Ting et al., 1990a,b). Bouldin and Bouldin (1996) designed a transplanting apparatus with multiple end effectors and is suitable for seedling low-density transplanting using all the healthy seedlings in a high-density tray. This transplanting apparatus is more efficient than a similar machine with a single end effector. Hu et al. (2014) designed a high-speed robot that adopts a parallel translation mechanism with two degrees of freedom to improve the automation and efficiency of plug seedling transplanting. Dimensional synthesis and kinematic simulation were used to verify the rationality of the structure design and trajectory planning. Jiang et al. (2015) compared the performance of an ant colony algorithm (ACA) with that of a genetic algorithm (GA) in replugging unhealthy or missing cells. The two algorithms significantly improve the work efficiency by shortening the replugging process; however, their performances differ in terms of the run times and the number of empty cells and healthy seedlings. Nevertheless, the two algorithms satisfy the real-time operating requirements of replugging.

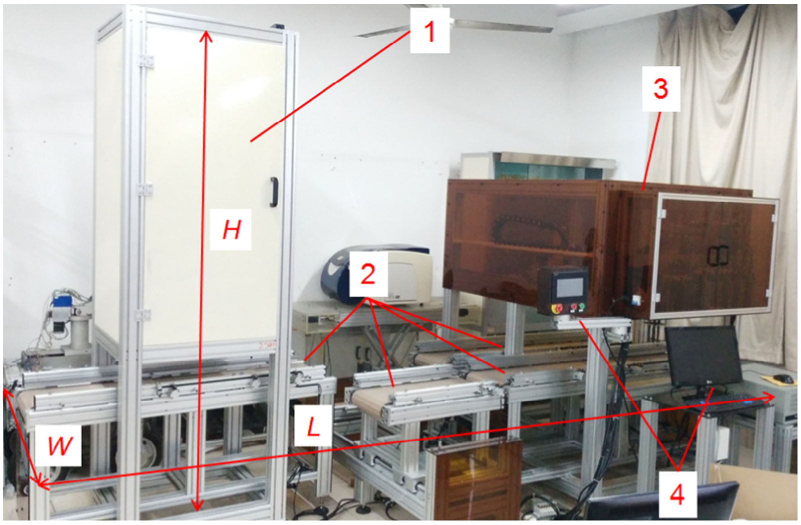
The problem in the current research is described as follows. Transplanting healthy seedlings from high-density trays to low-density trays for maximal growth is an important task for automated transplanters in greenhouses. The end effector performs a reciprocating movement for seedling clamping and planting between high and low-density trays. Optimizing the transplanting path can improve work efficiency. Path planning of the seedling low-density transplanting is a combinatorial optimization problem similar to the knapsack or traveling salesman problem (TSP). TSP is a typical non-deterministic polynomial problem, and its solution time increases significantly with the expansion of the problem scale. Many studies have obtained optimization results for the classical TSP by adopting artificial intelligence algorithms, such as a greedy algorithm (GRA) (Haim and Nira, 2005), ACA (Garcia-Martinez et al., 2007), GA (Tang and Liu, 2000), dynamic programming (Khalil and Mahdi, 2015), backtracking (Yannis et al., 2009), and branch-and-bound method (Christian and Dominique, 2008). Jiang et al. (2015) and Tong et al. (2013) verified that path planning effectively improves there plugging efficiency by optimizing GA. The total numbers of healthy seedlings in a high-density tray and the empty holes in a low-density tray are relatively larger for the low-density transplanting task than for the replugging task. The computation time of GA increases with the increasing number of holes. Satisfying the real-time operating requirements of seedling low-density transplanting is a challenge for path planning algorithms, especially when using dense seedling trays (more than 72 holes). Many studies have resolved the computational efficiency problem by improving basic GA methods, such as developing heuristic GA (Keshanchi et al., 2017), hybrid GA with decomposition phases (Paes et al., 2017), and non-dominated sorting GA (Yang et al., 2017).

This study aims to improve GA and consequently satisfy the path planning requirements of automated transplanters for low-density transplanting of seedlings in greenhouses. The specific objectives are as follows: (1) develop GRA for path optimization with a short computation time in seedling low-density transplanting; (2) develop a greedy genetic algorithm (GGA), which is a combination of GA and GRA, for path planning in seedling low-density transplanting to obtain superior optimization effect and computation time; and (3) compare the performances of these algorithms for path planning.

2. Materials and methods

2.1. Automated transplanter for seedling low-density transplanting

Fig. 1 shows an automated transplanter that consists of machine vision, tray transfer, control, and transplanting units. The dimensions of the machine are 3800 mm × 1100 mm × 2300 mm ($L \times W \times H$). Low-density transplanting and replugging of seedlings can be implemented using this transplanter system. The middle conveyor in the tray transfer unit delivers the seedling trays, which are detected by the machine vision unit, to double the terminal conveyors in the transplanting unit for the replugging task. The low-density vacant tray (referred to as LD tray hereafter) occupies one terminal conveyor in the transplanting unit, whereas the high-density tray with healthy seedlings (referred to as HD tray hereafter) occupies another terminal conveyor delivered from the



1. Machine vision unit, 2.Tray transfer unit, 3. Transplanting unit, 4. Control unit
Length L=3800 mm, Width W=1100 mm, Height H=2300 mm

Fig. 1. Automated transplanter in a greenhouse.