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Research Paper

Navigation of autonomous tractor for orchards and plantations using a laser range finder: Automatic control of trailer position with tractor

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The autonomous control of a tractor-trailer system in orchards and plantations has frequently been observed for the transportation, loading and unloading of products between plants and trees. The objective of this research was to develop a control algorithm for a single-sensor tractor-trailer navigation system for navigating within a row plantation and travelling between plots. A control scheme for stopping the tractor-trailer for various in-field tasks, such as product loading/unloading using a laser range finder (LRF), is presented. The LRF was used to navigate a full-size autonomous agricultural tractor equipped with a two-wheeled trailer. For ease of operation in narrow rows, a sliding hitch bar (SHB) was developed to control the trailer by adjusting the position of the hitch-point between the tractor and trailer. Compared to the tractor-trailer system driven by human, the control system could navigate the tractor-trailer with the RMS differences of 0.275 m (SD: 0.009 m), 0.373 m (SD: 0.030 m) and 0.518 m (SD: 0.022 m) for *wide curve*, *tight curve* and *U-turn* experimental paths, respectively. The SHB unit also supported the navigation system with wider turn for the trailer than conventional single hitch point about 0.383 m (7.66% of the 5 m path width, SD: 0.028 m), 0.762 m (15.23% of 5 m path width, SD: 0.010 m) and 1.094 m (21.88% of 5 m path width, SD: 0.037 m) for *wide curve*, *tight curve* and *U-turn* experimental paths, respectively. The control system also stopped the tractor-trailer at the specified landmarks. The results show that the navigation of the tractor-trailer was demonstrated with satisfactory accuracy and that the trailer position was controlled by the SHB with a wider turn in the experimental paths. Therefore, this laser-based landmark navigation system, and the SHB unit, can be adopted for different applications of autonomous tractor-trailer systems with controlled trailer positioning.

1. Introduction

Normally, fieldwork in orchards and plantations such as palm or para-rubber trees requires a workforce. However, decreasing the size of the agricultural-related workforce is unavoidable. Presently, field tasks such as harvesting, trimming, fertilising, applying integrated pest management IPM, and transporting products use machinery. However, these

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Nomenclature

α	Steering angle, degree
θ	Angle between the tractor and trailer, degree
ICR	Point of instantaneous centre of rotation
ICR_T ($ICRx_T$,$ICRy_T$)	Position of ICR of the tractor, mm
ICR_t ($ICRx_t$,$ICRy_t$)	Position of ICR of the trailer, mm
k	Constant gain for P_{hx} calculation
lh_x	Distance from the centre of the SHB unit to hitch-point in lateral axis of SHB unit, mm
lh_y	Distance from the centre of the trailer to centre of SHB unit in longitudinal axis of the tractor, mm
l_T	Distance from the front wheel to rear wheel of the tractor, mm
P_h (x_h,y_h)	Position of hitch-point, mm
P_t (x_t,y_t)	Position of trailer, mm
P_{hx}	Shifted distance of the hitch-point, mm
R_t	Distance between ICR_t to P_t, m
GPS	Global positioning system
IMU	Inertial measurement unit
IPM	Integrated pest management
LRF	Laser range finder
PCI	Peripheral component interconnect
RTK-GPS	Real time kinematic–GPS
SHB	Sliding hitch bar

tasks still require skilled operator and younger workers may find these human-intensive tasks unattractive and seek employment elsewhere. Therefore, introducing simple, less expensive autonomous machinery could help to reduce menial human labour in these tasks.

Navigation systems that use multiple sensors, which increased both the expense of the autonomous system and the computation time, have been previously reported. In the last few decades, many techniques were developed based on multiple sensors, including machine vision, global positioning system (GPS), inertial measurement unit (IMU), and laser range finder (LRF). Therefore, the control systems have, in general, had high accuracy, high precision, and high performance. However, the use of multiple sensors has resulted in increased algorithm complexities. Dead-reckoning or path-following navigation methods have cumulative errors that could be improved by real-time calculations. Amount of available light is a major constraint in machine vision-based control methods, which have been adapted from indoor applications. GPS systems are popular for determining vehicle positions and have made a significant contribution to the automatic steering of agricultural vehicles. A number of studies have used GPS as a base sensor for navigating agricultural tractors (Bell, 2000; O'Conner, Bell, Elkaim, & Parkinson, 1996; O'Connor, Elkaim, & Parkinson, 1996; Stombaugh, Bensen, & Hummel, 1999; Van Zuydam, 1999). A GPS-based rice transplanter has also developed (Nagasaka, Umeda, Kanetai, Taniwaki, & Sasaki, 2004). However, GPS-based systems are limited by signal interruptions when operating under tree canopies or near high-rise buildings (Ahamed, Tian, Takigawa, & Zhang, 2009; Barawid, Mizushima, Ishii, & Noguchi, 2007).

However, navigation systems that use one sensor have not been as extensively reported. Laser sensors have been used on concrete ground for navigation (Ahamed et al., 2006a, 2006b). Outdoors, laser range finders can detect landmarks with high accuracy and navigate tractors to their target positions (Sutiarso et al., 2002; Takigawa, Sutiarso, Koike, Kurosaki, & Hasegawa, 2002). A laser-based guidance system was developed and capable of navigating an autonomous vehicle as it travelled between rows of trees in real time (Barawid et al., 2007). The study focused solely on recognising the straight lines of planted trees by using a laser scanner to navigate and Hough's transform to line up the tree rows and generate a straight path (Barawid et al., 2007; Hamner, Bergerman, & Singh, 2011; Zhang, Chambers, Maeta, Bergerman, & Singh, 2013). A control technique that finds the midpoint of a path with 900-mm hay bales on each side of the path has been reported (Subramanian, Burks, & Arroyo, 2006). The autonomous navigation of a combine harvester that detects crops height using LRF has also been studied (Choi, Yin, Yang, & Noguchi, 2014). A probabilistic model for navigation of the vehicle in maize field using LRF was also developed based on a particle filter. The LRF was implemented on a $0.8 \times 0.45 \times 0.3$ m prototype vehicle. The experiments were done in an early stage of plant development, 250–600 mm height. The research reported that the developed model can be applied in a field (Hiremath, Van der Heijden, Van Evert, Stein, & Ter Braak, 2014).

A map-based method has been published that navigates an unmanned ground vehicle using LRF and a map of the test field (Kurashiki et al., 2014). However, the map-based method requires maps that have been surveyed in advance of the navigation system. To reduce the cost in the autonomous system, an LRF-based system was investigated for the navigation of a full-size autonomous tractor through different paths (Thanpattranon, Ahamed, & Takigawa, 2015; Thanpattranon & Takigawa, 2010, 2011). However, field tasks often require the use of additional equipment besides a tractor. For example, harvesting requires the tractor to be equipped with a trailer. In the field, the tractor and its equipment might have to travel long distances along the plantation in order to load the products onto the trailer (Fig. 1a). Also, support vehicles might remain stationary to unload and transport the products from a loaded trailer (Fig. 1b). In some situations, tractor-trailers might also need to travel to another plot of land (Fig. 1c).

There are three conventional methods for attaching towed trailers to tractors: towed, semi-mounted and integral trailers. All of the methods used currently fix the hitch point of the tractor and the attached equipment. Semi-mounted or integral trailers must be lifted up while turning and towed trailers do not need to be lifted. The complexities of navigating and controlling a tractor with towed equipment are therefore considered.

The tractor-trailer control system with towed equipment and a hydraulically controlled swing drawbar were reported. The research utilised a control algorithm based on multiple sensors. However, a control algorithm used in the research