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Method and experiment for height measurement of scraper with water surface as benchmark in paddy field

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ABSTRACT

Leveling technology of paddy fields is an important part of the mechanization of rice production, which ensures the consistent depth of water layers to restrain the growth of weeds and improve the utilization of pesticides and fertilizers. However, when the working distance increases in paddy fields (due to laser energy attenuation and laser spot diffusion), the reliability and efficiency of existing laser-leveling technology decreases. To address those problems, a new leveling technology that uses water surface as a benchmark is introduced. The proposed method of water surface as a benchmark to measure the height of the scraper and a benchmark-Recognition algorithm embedded in the proposed method was developed. Experiments were conducted to validate the effectiveness and accuracy of the proposed method by comparing the results with those of existing methods (height measurement for scraper with laser plane as benchmark). The results obtained by the proposed method have similar trends in variation and higher resolution.

1. Introduction

The leveled paddy field (which ensures a consistent depth of water layers for paddy fields) saves agricultural water; increases crop yield; and improves the utilization of pesticides, fertilizers, and herbicides (Agarwal and Goel, 1981; Finney, 1996; Jat et al., 2009; Aryal et al., 2015). It also reduces production costs and environmental pollution and promotes sustainable agricultural development. Leveling is traditionally completed using a tractor that drags a stick or wood as an implement. The accuracy of leveling is mainly dependent on the weight of the implement and the softness and hardness of the mud. For example, profiling leveling is a traditional leveling technology that is used in paddy fields with low leveling accuracy, high labor intensity, and low efficiency, making it difficult for these fields to meet the requirements of precision leveling.

At present, only a few agricultural machines can automatically adjust the operation height according to the unevenness of the field. Precision-leveling technologies for paddy fields mainly include the laser-controlled (Jat et al., 2009) and global navigation satellite system (GNSS) controlled leveling technology. Laser-controlled leveling technology was applied to both dry and paddy fields, which greatly improved the accuracy of leveling, reduced cultivation costs, saved water, and increased yield (Jat et al., 2009). However, laser-leveling technology is easily influenced by external factors. For example, the accuracy of leveling is impacted when operating in strong light and wind (Xu et al., 2016). At the same time, an increase in working distance means the receiver is likely to miss the laser signal when tractors working in the field have rugged bottoms (Xu et al., 2016). GNSS technology receives the positioning information of the field surface without being affected by weather conditions and operates with high working efficiency. The dynamic positioning of RTK-GPS technology (with centimeter accuracy) also provides large-scale implementations of land leveling (Héroux and Kouba, 2001). Land-leveling systems based on GNSS were widely applied in the United States and other developed countries. At present, the area of paddy fields in China is increasing, which is resulting in large-scale farming with narrow ridges. Paddy fields have shelters (such as shelter forests) in both plain and hilly areas. In addition, most areas in China have not yet been established as a continuous operational reference system. To obtain high-precision GNSS positioning information, it is necessary to independently create differential reference stations. However, the signal is still affected by occlusion (Li et al., 2009). It is known that laser-controlled leveling technology is limited by distance restrictions. GNSS-controlled leveling technology also must address issues such as high cost and signal occlusion. A paddy field precision-leveling method consistent with the characteristics of a paddy field must meet the production requirements.

The relative height between the scraper and paddy field is an

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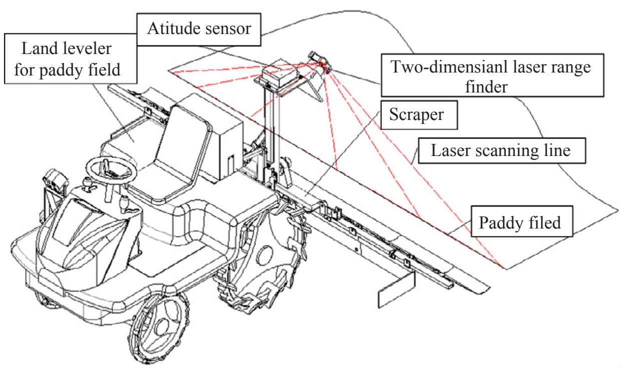


Fig. 1. Schematic of height measurement of scraper with water surface as benchmark in paddy field.

important controlling object of the scraper. Currently, Light Detection and Ranging is widely used in geography contour mapping and environmental reconfiguration (Hancock et al., 1998; Ehlert et al., 2010). This study proposes a height measurement method for a scraper that uses water surface as the benchmark in paddy fields. The paddy field is scanned by a two-dimensional laser range finder (2D LRF) to extract the water surface information. The relative height between the 2D LRF and water surface of the paddy field is used to provide a highly automated controlling reference for the scraper.

2. Eight measurement of scraper with water surface as benchmark in paddy field

The 2D LRF is mounted above the scraper of the 1PJ-3.0-type, laser-controlled leveling machine designed by South China Agricultural University. The laser scans the water surface of the paddy field behind the scraper in a direction that is parallel to the scraper, as shown in Fig. 1.

The water surface of the paddy field is used as a static benchmark to obtain the relative height between the scraper and reference surface. The 2D LRF fixed on the scraper with a certain inclination angle β scans the paddy field and obtains data of the scanning point. Only the points fit to the water level are extracted to calculate the height of the scraper. The vertical height from the 2D LRF to the water surface $H_x$is shown in Fig. 2.

An attitude sensor is fixed on the 2D LRF to measure and compensate the tilt angle of the 2D LRF. β and α are the pitch angle and roll angle of the 2D LRF, respectively, as shown in Fig. 2b. H_x is computed by a benchmark-recognition algorithm to achieve automatic attitude control of the scraper.

3. Benchmark-recognition algorithm

3.1. Effective scanning width of the 2D LRF

To avoid interference data caused by field ridge and fluctuation of the water surface, the effective scanning width of the 2D LRF is set to no longer than the width of scraper L, and the effective angle of the 2D LRF is set to ± γ. The effective scanning width of the paddy field is calculated as

$$L_{laser} = 2\cdot L_{high}\cdot \tan\left(\gamma\cdot\frac{\pi}{180}\right) \tag{1}$$

where L_{laser} represents the effective scanning width of the 2D LRF, in meters. L_{high} is the installation height of the 2D LRF, in meters. γ is the scanning angle of the 2D LRF, in degrees.

3.2. Attitude correction of the 2D LRF

The height between the water surface of the paddy field and the sensor (with consideration of the attitude correction) is

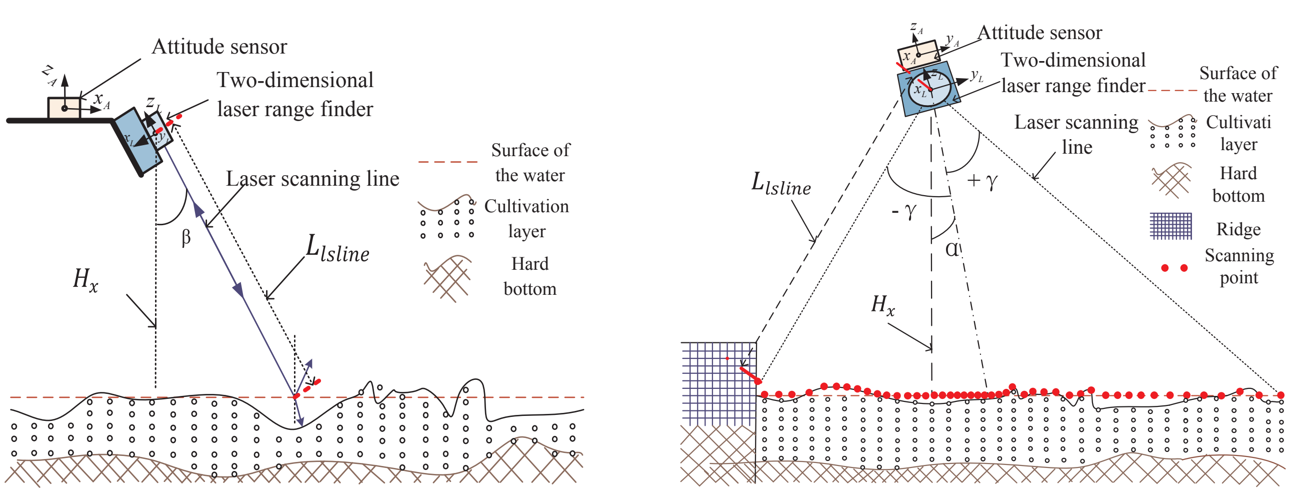
$$H_{laser} = L_{lsline}\cdot\cos(\alpha+\gamma)\cdot\cos\beta \tag{2}$$

where L_{lsline} is the linear height between the 2D LRF and scanning point on the water surface of the paddy field, in meters. α and β are the roll angle and pitch angle of the 2D LRF, respectively, which are measured by the attitude sensor in degrees. H_{laser} is the corrected relative height.

3.3. Height clustering

The height H_{laser} obtained in real-time scanning by the 2D LRF includes unfavorable noise, thus, a weighted average method is employed to acquire the noise-free data H_{laser}, in centimeters.

As shown in Eq. (3), H_{laser} is clustered according to the mode principle (Peterson and Miller, 1964; Groth and Bergner 2006; Manikandan, 2011; Pouliot et al., 2012), and the single-digit position of H_{laser} is rounded as an indicator. For example, if the value of H_{laser} is 12 cm or 17 cm, the result of this equation is 10 cm or 20 cm, respectively. Meanwhile, the number of occurrences of the same height values are recorded and saved in the corresponding clustering set, as shown in Eq. (4).



a. Sketch of field height measurement. b. Sketch of field inclination angle correction.

Fig. 2. Principle diagram of the height measurement of scraper with water surface as benchmark in paddy fields.