Rice Plant Height Estimation Using a Non-Survey Grade Laser Scanner: A Hokuyo UTM 30LX Case Study

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Abstract

This study evaluated the estimation of rice plant height without ground surface detection using a HOKUYO UTM 30LX laser scanner. The selected laser scanner is small and lightweight (approximate 0.37 kg) with a rectangular footprint. Field observations were conducted in 2016 with a line scanner installed above the rice canopy. Based on results of our investigation, the laser pulse of the HOKUYO UTM 30LX finds it more difficult to reach the ground surface because of the 4-cm long rectangular footprint. Although the laser scanner is small and lightweight, and the selected target areas in this study were larger than in the previous study, relatively accurate results were still obtained. More specifically, the top of the rice plant was found to correspond to $p^t = 1$*, and the bottom of the rice plant was chosen at four percentile ranks (* $p^b = 70$, $p^b = 80$, $p^b = 95$*, and* $p^b = 99$*). The relative vertical distance (*rD*) was identified as the distance between the bottom and top of the rice plant. According to the results,* rD *strongly correlated with H with* $r^2 \geq 0.86$ *in all cases, and the root mean squared error was 1.0 cm. The slope of the regression line was only close to 1.0 (*$r^2 \geq 0.96$*) for* $p^b = 99$*. The plant height exceeded the relative vertical distance by 22.0 cm. The accuracy of the results largely depends on the laser footprint size of the specific laser scanner used, and larger laser footprints correspond to larger bias between rD and H. Results of this study, which confirmed the viability and feasibility of our proposed method for estimating rice plant height using the HOKUYO UTM 30 LX, are presented and discussed.*

1. Introduction

For ensuring food security, which is a critical issue worldwide, the most important thing is to assure sufficient food for maintaining daily human life. Rice is the main food crop in Asian countries. Rice crop management is necessary for ensuring national food security and political stability because populations here consume rice in every daily meal for survival. Moreover, rice is the main source of income for farmers. Thus, rice production directly affects social security. Rice yields are being increased by applying new rice varieties and fertilizer technologies. Nowadays, consumers are aware of safe, affordable, and high-quality rice. Thus, to cultivate good quality rice and maintain its yield, it is necessary to monitor rice growth during the rice-growing season.

Plant height, plant stem number, and leaf color are three main physical parameters of rice plants. These parameters are measured to get information on rice crop growth (Yamamoto et al., 1994). In Japan, the rice growth parameters are collected periodically. Then, the farmers change the cultivated factors to maximize the growth. Over the past decades, these parameters were manually measured via fieldwork. For data collection, the field workers must access the target area to measure and record the necessary information. This process is repeated many times during the crop-growing season. In fact, the collected data may be affected by human errors such as misreporting or mislabeling. Moreover, accessing the target plants is difficult when rice plants are mature, especially in dense fields. In general, collecting information by fieldwork is a monotonous and labor-intensive process. Nowadays, remote sensing techniques are widely utilized in agricultural production to save time and labor (Atzberger, 2013). These techniques can be utilized to get information of a part of the field or the entire field, and they are believed to be a good solution for collecting and monitoring crop growth information (Willers et al., 2012).

Laser scanning is a useful method for collecting dense and accurate spatial data within short time duration (Lichti et al., 2002). Laser scanning allows recording data at spatial resolution smaller than the areal extent of the monitored element. Thus, problems related to the modifiable areal unit can be solved (Gotway and Young, 2002). In other words, the problem of creating different shapes from the same data set by grouping data points into increasingly larger areal units is solved. Laser scanners have proven to be effective tools in precision agriculture. Plant growth and changes in shape can be identified by precision laser scanning. Moreover, laser scanning has been applied for other purposes such as estimation of canopy height (Wang and Glenn, 2008, Huang et al., 2009, Zawawi et al., 2015 and Sibona et al., 2016), canopy structure (Rice et al., 2005), carbon stock (Maan et al., 2015 and Navarro-Cerrillo et al., 2018) and vertical plant density profile (Hosoi and Omasa, 2009 and 2012,).

With regard to the rice crop, precision laser scanner measurements have been widely performed using the terrestrial laser scanner (TLS) for monitoring crop height (Hoffmeister et al., 2010, Tilly et al., 2012, 2013 and 2014, Bareth et al., 2016 and Friedli et al., 2016). However, the ground surface or another reference surface close to the ground is required for computing the plant height. Unfortunately, their positions cannot always be determined, especially in wetland paddies or in dense fields. To solve this problem, we developed a method for estimating rice plant height without detecting the ground surface using laser scanner measurement in a previous study (Phan et al., 2016). Good results were obtained with the SICK LMS 200 line laser scanner that has a 2 cm footprint diameter. According to the previous results, the target areas were relatively small (90 x 60 cm) and located inside the test that had inclination angles less than ± 8 deg. The relative vertical distance (rD) computed by taking the difference between the bottom and top position of rice plant, correlated well with the measured rice plant height. The rice plant height was estimated to be 4 m according to the root mean square error (RMSE).

We expect that, rice plant height can be estimated for a large area using our proposed method. The relation between rDs and the measured plant heights may be affected by both laser footprint size and inclination angle. Fortunately, inclination angle effect could be ignored by limiting the target areas to those inclination angles less than ± 8 deg. However, if rice leaf widths or gap areas among leaves are smaller than laser footprint size, the laser pulses cannot reflect or reach the ground. As a result, the rDs may be inaccurately reported as smaller than it actually is. The regression slope between measured plant heights and rDs gets steeper, and the relation between the measured rice plant heights and rDs cannot be established.

To observe rice plant in larger areas, an UAV-based line laser scanner is expected to be used in near future. In such a situation, a small and lightweight laser scanner is necessary to develop an effective and accurate measurement system. Therefore, estimating rice plant height without ground surface detection using a small and lightweight line laser scanner must first be tested. There are many small and lightweight laser scanners. Unfortunately, the size and shape of their footprint are not always similar to the SICK LMS200 (2 cm diameter at a 3 m distance from the sensor to the circular shape). In this study, the application of our method for data recorded by a laser scanner that has a slightly larger footprint size and non-circular shape is evaluated. The HOKUYO UTM30LX which has a rectangular footprint is chosen for observing rice plants. To obtain valid data, field observations were conducted in 2016 with a line scanner installed above the rice canopy. The scanner could move a long distance of 8 m along a rail under motorized power. According to results of our field observation, our proposed method was found to be feasible for the purposes of measuring rice plant height in wide areas using a small UAV in the near future.

2. Experimental Site

The test field was in a paddy field of the Niigata Agricultural Research Institute in Niigata Prefecture, Japan. According to the local practice of rice cultivation, paddy fields are plowed and filled with water. The basal application of fertilizer is performed before the rice plant seedlings are transplanted into the field in mid-May. The normal rice-growing season starts in May and ends in late September. The field observation data were collected during the vegetative phase of the rice-growing seasons in 2016 (about two months after transplantation). Each rice plant hill containing four initial seedlings was transplanted by a planting machine into the test plot with a row spacing of 30 cm at a moderate level of planting density (15.1 plant hills/m^2). The rice cultivated was Koshihikari, the rice variety which is studied in our previous research. In addition to laser data, we also collected the growth parameters of the rice plants via field investigations.

3. Data Acquisition

Two test plots located inside the test field were studied. Rice plant height (H) and rice plant stem number (S) were manually measured at irregular intervals during the study period to obtain data for validation. The results showed that H increases linearly over time. S also increases rapidly and reaches its maximum value at approximately 50 days after transplanting (DAT) in both plots (Figure 1). We used the laser scanner HOKUYO UTM 30LX (Table 1). This is small, accurate, high-speed device and can obtain measurement data in a wider field of view up to a distance of 30 meters with millimeter resolution in a 270° arc. In this study, the scanner was hung at a height of about 3 m from the ground surface as previous study (Phan et al., 2016). It could move a distance of 8 m along a rail under motorized power (Figure 2). The scanning plane was set vertically downward with 60° of field of view. The laser beam wavelength was 905 nm. The angular resolution was set at 0.25° to ensure that the scanning point density was similar to that in our previous study (Phan et al., 2016). At an observed distance of 3 m, the dimensions of the HOKUYO UTM 30LX's rectangular footprint is 0.8 × 4 cm, which represents a larger area than the 2-cm-diameter circular footprint of SICK LMS 200 used in our previous study (HOKUYO, 2018 and SICK AG, 2016). However, the footprint coverage areas of the two laser scanner at an observed distance of 3 m of are similar. Moreover, it is believed that using high-density laser pulses, the scanners could obtain and record information for an entire rice canopy.

Laser scanner measurements were made during the vegetative phase of the rice-growing season, during which plant height increases rapidly. Seven observations were carried out in total between June and July 2016. In addition, an extra laser observation was performed after harvesting the crop in September to obtain information of the bare soil.

4. Results

4.1 Data Extraction

Two test plots are identified in the test field. Each test plot is 1 m long and narrows at inclination angles of ± 8°. The test plots in this study are larger than those in our previous study. In the previous study, the laser range data were converted to vertical distances (D), which represent the distances between the scanning points and the installation height of the laser scanner (Equation 1). Here, D_i, θ_i and r_i are the vertical distance, the inclination angle, and range value of the i^{th} scanning point in the scanning line, respectively (Figure 3).

$$D_i = r_i cos\theta_i$$

Equation 1

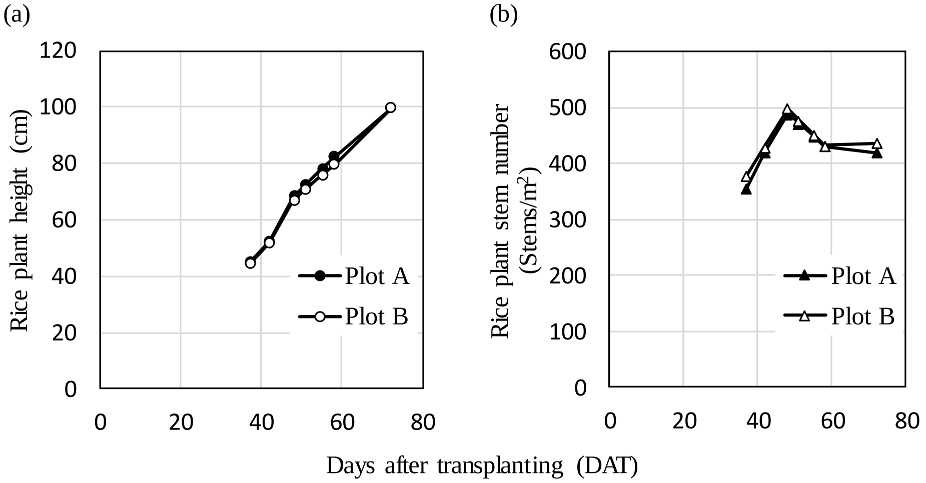

Figure 1: Measured physical parameters, namely, (a) rice plant height (H) and (b) rice plant stem number (S) in the growing season in 2016

Table 1: The specifications of Hokuyo UTM 30LX

Power source	12VDC±10%
Light source	Semiconductor laser diode(λ=905nm)
Detection Range	0.1 to 30m
Field of view	270°
Accuracy	0.1 to 10m:±30mm, 10 to 30m:±50mm^{*1}
Angular Resolution	0.25°(360°/1,440 steps)
Scan Time	25msec/scan
Interface	USB2.0 (Full Speed) for field setting by PC
Weight	Approx. 370g (with cable attachment)

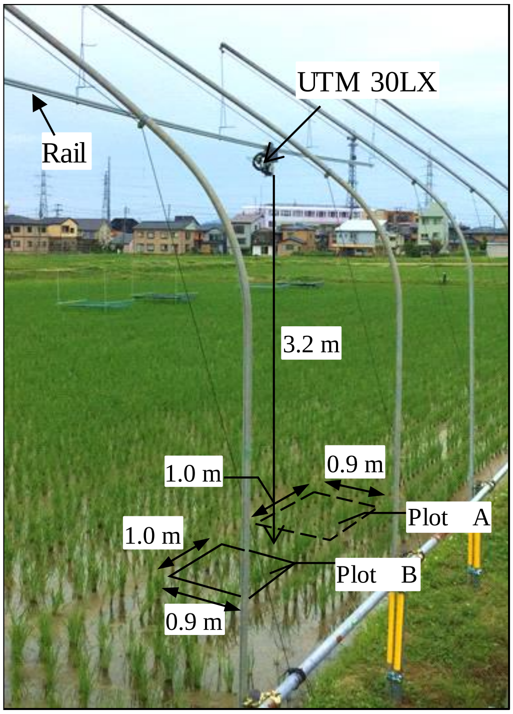

Figure 2: Field observations collected by laser scanner UTM 30LX in 2016. The scanner was hung approximately 3 m above the paddy field surface, and it could move along a rail under motorized power. Test plots A and B were identified within two rectangles, respectively

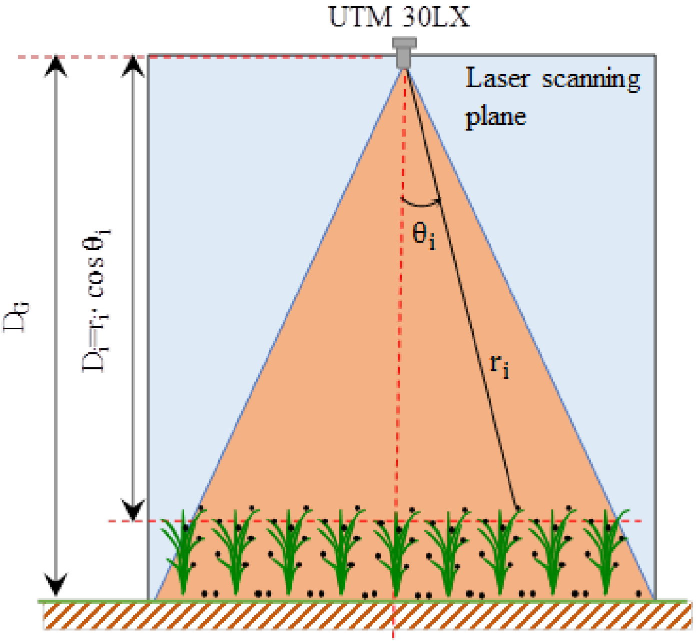

Figure 3: Laser scanning plane (Modified from Phan et al., 2016)

The histogram distribution of vertical distance of plot B is shown in Figure 4. The red lines show the position of ground surface (D_G), which is determined from the extra laser observation performed immediately after harvesting. The change in the shape of the histogram shape provides information on rice growth. In the two first observations, the paddy was covered by water, and most of laser pulses could not reach the ground surface (Figure 4a, 4b). Therefore, the histogram peak implied the level of water surface.

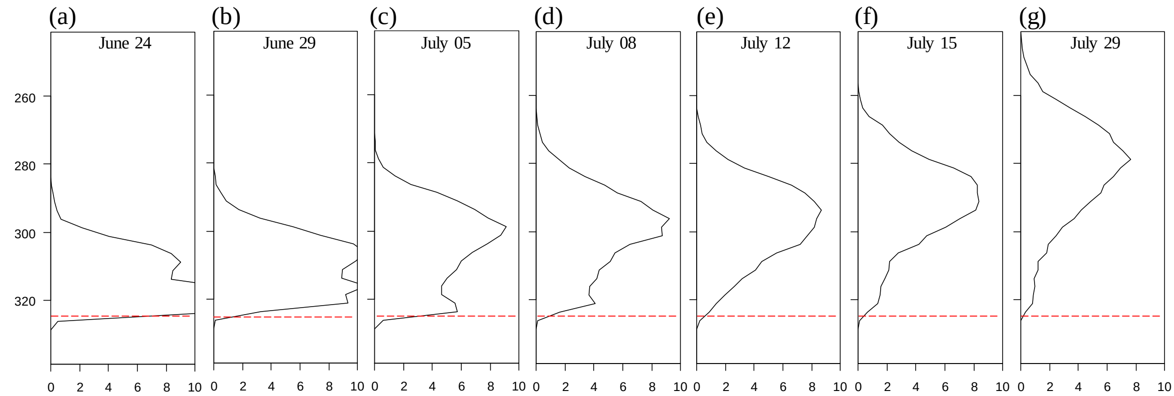

Figure 4: Histograms of the point cloud data from plot B. The dashed lines show the ground position after harvesting the crop

As a result, it was higher than the histogram peak in the third observation. According to Figure 4a–4c, the data can be divided into two groups. The lower group provides information related to the paddy ground surface and the upper group contains information about the rice plant. In the fourth observation, the rice plant has already achieved its maximum stem number value, and the ground surface is hidden by the rice plant themselves. Therefore, from this point forward, the bio modal of the histogram turns into skew normal distribution. A similar result was also found in our previous study.

2. Rice Plant Height Estimation

Rice height is measured as the distance from the ground surface to the longest rice leaf edge. When a rice plant reaches maturity, the rice leaves bend, making it difficult from above to locate the rice leaf edge. Therefore, the study period focused on the vegetative phase and early reproductive phase of the rice plant when rice plant leaves are not bent in the rice plant height estimation method applied in our previous study, the key was to locate the positions of the top and the bottom of the plant. In this study too, we applied the same data processing procedure as before and performed a percentile analysis to identify the percentile ranks that were close to the top (p^t) and bottom (p^b) of the plant. In the previous study, p^t was identified with the 1st percentile rank (p^1), and p^b was identified with three percentile ranks, Rice height is measured as the distance from the ground surface to the longest rice leaf edge. When a rice plant reaches maturity, the rice leaves bend, making it difficult from above to locate the rice leaf edge. Therefore, the study period focused on the vegetative phase and early reproductive phase of the rice plant when rice plant leaves are not bent In the rice plant height estimation method applied in our previous study, the key was to locate the positions of the top and the bottom of the plant. In this study too, we applied the same data processing procedure as before and performed a percentile analysis to identify the percentile ranks that were close to the top (p^t) and bottom (p^b) of the plant. In the previous study, p^t was identified with the 1st percentile rank (p^1), and p^b was identified with three percentile ranks, namely, 70th, 80th, and 95th (p^{70}, p^{80}, and p^{90}). The most suitable bottom position (D^b) was identified using the vertical distance corresponding to p^{95} (D^{95}), which was closest to D_G. In the present study too, p^t is expected to correspond to the 1st percentile rank. This helped us ignore the noisy points caused by wind, insects, or small airborne particles during rice crop monitoring. According to the results of searching procedure shown in Fig. 5, the vertical distances corresponding to the 1st percentile rank (D^1) in the two test plots were slightly different. Thus, D^1 was chosen as the top position of rice plant (D^t) in this study. Figure 5 shows that the vertical distances at the 70th and 80th percentile ranks (D^{70} and D^{80}) differ greatly from D_G. For the 95th percentile rank, the vertical distance approximates D_G in the first 40 or 50 DAT but diverges from D_G with time. However, D^{99} is the closest to D_G. Therefore, besides the three chosen bottom positions D^{70}, D^{80}, and D^{95} as in the previous study, D^{99} was also chosen as the expected bottom position of the rice plant.

Finally, the relative vertical distance (rD) was calculated by obtaining the difference between D^b and D^t. This value is expected to correspond to H. As observed in our previous study, rD was always smaller than H, and rD was strongly correlated to H in all cases with a root mean squared error ($RMSE$) of 1.0 cm (Figure 6). The correlation coefficient and the regression line slope depend upon the chosen bottom position. The slope of the regression lines was close to 1 for p^b = 99 with r^2 = 0.96 (Figure 6).

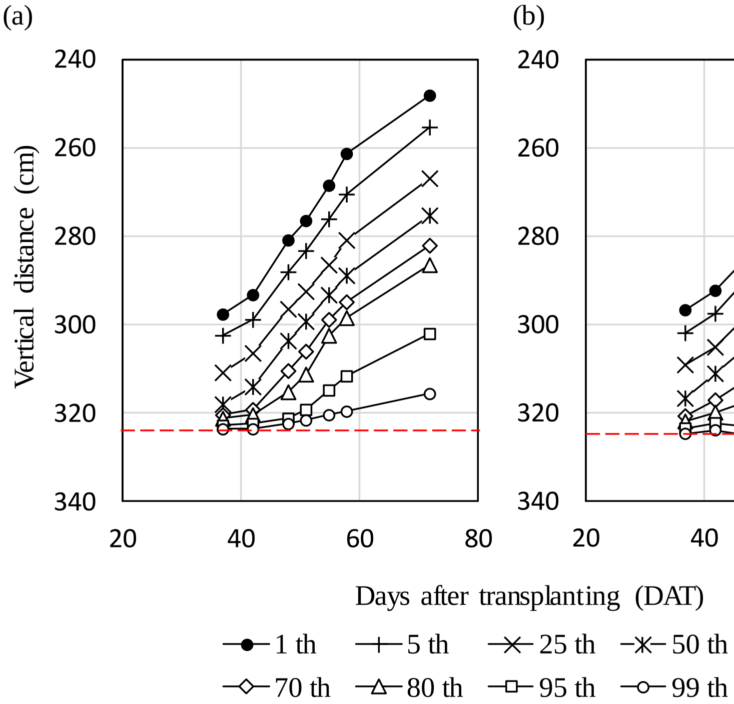

Figure 5: Vertical distance at various percentile ranks in (a) plot A and (b) plot B. The dashed lines show the position of the ground surface after harvesting the crop

5. Discussion

In this study, a small and lightweight laser scanner with rectangular footprint was chosen for observing rice plants. The rice plant height is estimated from the laser data by applying the method described in our previous study. Specifically, the top and bottom of rice plant are determined from laser scanning data. Subsequently, rDs values are computed and the relation between rDs and Hs is determined.

According to the results, D^t corresponds to p^1. The D^1 values of the two plots differ slightly because of the uniform planting geometry in the two plots. Although the effect of the ground inclination angle is ignored by narrowing the target areas to an inclination less than ±8 deg, D^1 also depends on the rice plant structure and footprint size. In fact, the rice leaf tip and the individual rice leaves cannot be detected over large footprints. Therefore, if the footprint is larger, the D^1 is closer to the ground surface. Since Hokuyo UTM 30LX has a 4-cm long rectangular footprint, D^1 was closer to the ground surface in this study than it was in our previous study using the SICK 200 laser scanner. As a result, the ratio between rD and measured rice plant height in this study was 60%, whereas its value in the previous study was 80%. According to the results, the computed rDs values in this study were smaller than they were in the previous study, although the rice variety in both studies was Koshihikari. Moreover, with the 4-cm long rectangular footprint, the Hokuyo UTM 30LX's laser pulse has more difficulty reaching the ground surface than in the case of the laser pulses of the SICK LMS 200. According to Figure 4, the amount of laser pulses reaching the ground surface decreases with time. In the last observation, the laser pulses barely reached the ground surface. Furthermore, the results indicated that D^{95} diverged from D_G from 50 DAT and D^{99} provided the closest ground surface position, which meant that approximately 1% of the laser pulses reached the ground surface compared to our previous study, where 5% of the laser pulses reached the ground surface. Although the laser scanner with rectangular footprint is small and lightweight and the selected target areas in this study were larger than they were in our previous study, good results were achieved as rD strongly correlated with H in all cases of the identified p^b ($r^2 \geq 0.86$). Similar to the results of our previous study, all regression line slope values were greater than 1.0. Based on these results, the greater the difference between D_G and D^b, the steeper the slope of the regression line (Figure 6). In other words, the further the ground surface was from the identified rice plant bottom, the steeper was the slope of the regression line. In conclusion, the relation between rDs and measured rice plant heights was found with Hokuyo UTM 30LX laser scanner in this study.

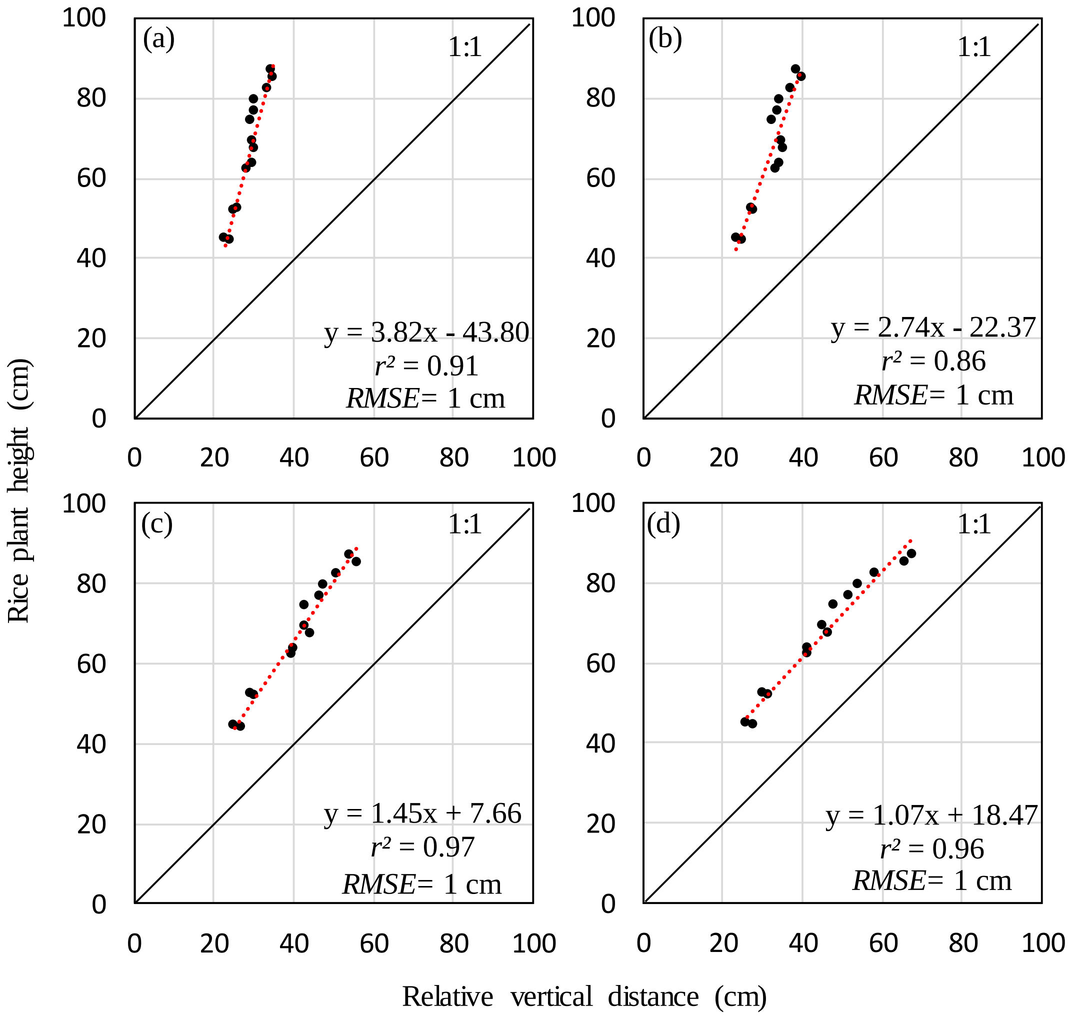

Figure 6: Plots of rD against the measured rice plant height. The results with the reference position computed at the 70th (a), 80th (b), 95th (c), and 99th (d) percentile ranks are shown. The dotted lines are the regression lines

In general, the accuracy of the method employed in this study was confirmed in the previous study with different plant density and geometry. In this study, greater accuracy was achieved because the planting geometry was uniform. The achieved RMSE in all cases is about 1.0 cm; in contrast, the plant height estimation errors reported by Zhang and Grift, 2012, Kaizu et al., 2012 and Tilly et al., 2014 and our previous study were 14 cm, ~10 cm, 5 cm, and 4 cm, respectively. Therefore, for uniform planting geometry, the results obtained using rD for estimating rice plant height are more accurate than those in the aforementioned studies.

In this study, good results were achieved with all chosen p^b. However, the regression line slope was nearly 1.0 ($r^2 \geq 0.96$) only for $p^b = 99$. H was greater than rD by 22.0 cm. Thus, using rD, H can be estimated with small RMSE values in situations where the ground surface cannot be observed with the HOKUYO UTM 30LX line laser scanners. This result shows the feasibility of using a UAV- based HOKUYO UTM 30LX line laser scanner for monitoring rice plant height in the future.

6. Conclusion

This study validates the feasibility of using a small and lightweight laser scanner to estimate rice plant height without ground surface detection. Despite the rectangular footprint of the HOKUYO UTM 30LX line laser scanner and larger target areas, the method yielded good results. The regression line slopes were steeper than they were in our previous study because of the slightly larger footprint size of the laser scanner used in this study. However, rD was strongly correlated to H with $r^2 \geq 0.86$ in all studied cases. Consistent regression lines were obtained with increasing slope as the distance between the plant bottom position and ground surface increased. We obtained better results (RMSE = 1.0 cm) than in our previous study because of uniform planting geometry. The accuracy of the results largely depends on the laser footprint size of the specific laser scanner used. Larger laser footprints correspond to larger bias between rD and H. In future studies, application of UAV-based Hokuyo UTM 30LX line laser scanner systems for rice plant height estimation using our developed method shall be further investigated. In addition, the effect of the incident angle shall be carefully considered.

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