Potential of novel UAV-borne green lidar to characterize vegetated rivers: comparison with traditional airborne lidar

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1. Introduction

Topo-bathymetric and riparian vegetation attributes act as major features in riverine environment. They are difficult and costly to quantify but are crucial for river engineering planning and management tasks. However, to obtain such information across river reaches, traditionally or manually used approaches are expensive, time-demanding, and challenging to repeat because of physical work requiring high-level engineering proficiency. To address the shortcomings of traditional methods, particularly for clear and shallow water bodies, several leading researchers have demonstrated a variety of advanced remote sensing techniques, including synthetic aperture radar images, airborne laser scanning, and airborne lidar bathymetry (ALB) (Yoshida et al., 2020)[1)], etc. Such approaches are usually applied to represent the underwater terrain and vegetation distributions over the long river reach. Aside from these techniques, more recently, as a cost-effective and high-resolution surveying tool, unmanned aerial vehicle (UAV)-borne green lidar system (GLS) (TDOT GREEN, 2020)[2)] developed by the Japanese company Amuse Oneself Inc., has promisingly pulled into consideration of river and coastal engineers to characterize an underwater terrain and land use classification. The overarching advantage of the cost-effective GLS over other lidar-based techniques (*i.e.,* ALB) is to simultaneously obtain both homogeneous laser point clouds of around 100 points/m^2 and high spatial resolution aerial images. Although ALB is more effective on a larger scale (Yoshida et al., 2020)[1)] because of its higher laser power, the major drawbacks of airborne approaches compared to UAV-lidar include higher expenses in data acquisition, higher flight altitude, difficulties in handling aircraft with mission safety, weather/flight conditions, etc. For these reasons, it is usually difficult to perform an immediate measurement using airborne lidar. Contrarily, using GLS, data can be easily extracted in a shorter reach due to its lower data acquisition cost, drone-based operation, data measurement flexibility, and repeatability. Hence, special attention should be paid to the new advanced GLS in light of its measurement shortcomings.

To date, a vital issue of concern is to select the most reliable remotely sensed approach considering their efficacy and drawbacks. No report of the relevant literature describes comprehensive research that gives an accurate performance evaluation of the recently emerging GLS for in-stream environments appraisal. As a case study in this research, the riverine environment of 1.6 km reach of the vegetated lower Asahi River, Japan, was assessed using both the GLS and ALB techniques. The findings were depicted based on agreement between the depth-averaged simulated flow values, lidar-derived information, and ground-truth evidence. Ultimately, the current study would support decision-makers as they prepare a realistic scenario for river planning and management initiatives worldwide by advancing our understanding of the newly launched remote sensing technique in assessing a vegetated river.

2. Study site and Methods

(1) Study site

The research was carried out in the lower reach of the Asahi River, which flows down through Okayama prefecture into the Seto Inland Sea, as depicted in Fig.1; kilo post (KP) numbers denote the longitudinal distance, in kilometer (km), from the river mouth. The domain is 1.6 km long, ranging from 14.6 KP to 16.2 KP, roughly 300 m wide open channel having a mean bed slope of about 1:670, locally known as "*Gion area*." Although this river reach originally had gravel bars, forestation in the targeted river reach has recently become a concern for effective flooding risk and ecosystem management tasks due to the potential for several difficulties.

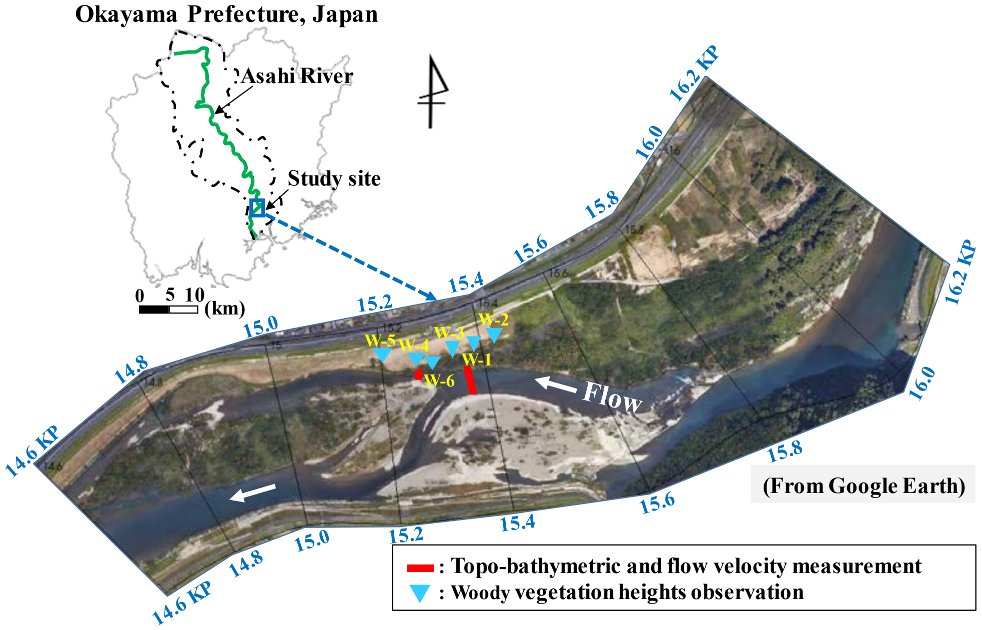

Fig.1 Targeted domain of the lower reaches of the Asahi River, along with field-surveyed points

(2) Methods

With a normal water level, ALB (February 2019) and digital drone-mounted GLS (March 2020) were used to conduct river topo-bathymetry and vegetation attribute measurements. Herein, for performing a depth-averaged numerical simulation (Yoshida et al., 2014)[3], the missing data found in the UAV campaign were updated using the existing ALB data. However, the numerical mesh in the hydrodynamic model consisted of 432 × 81 cells with an approximate size of 4 m on average, representing 432 cross-sections in the longitudinal direction and 81 nodes in each cross-section. Furthermore, to verify the lidar-based data and to validate simulated values, ground-truth measurements were carried out (Fig.1).

3. Results and Discussion

(1) Topo-bathymetric and flow velocity assessment

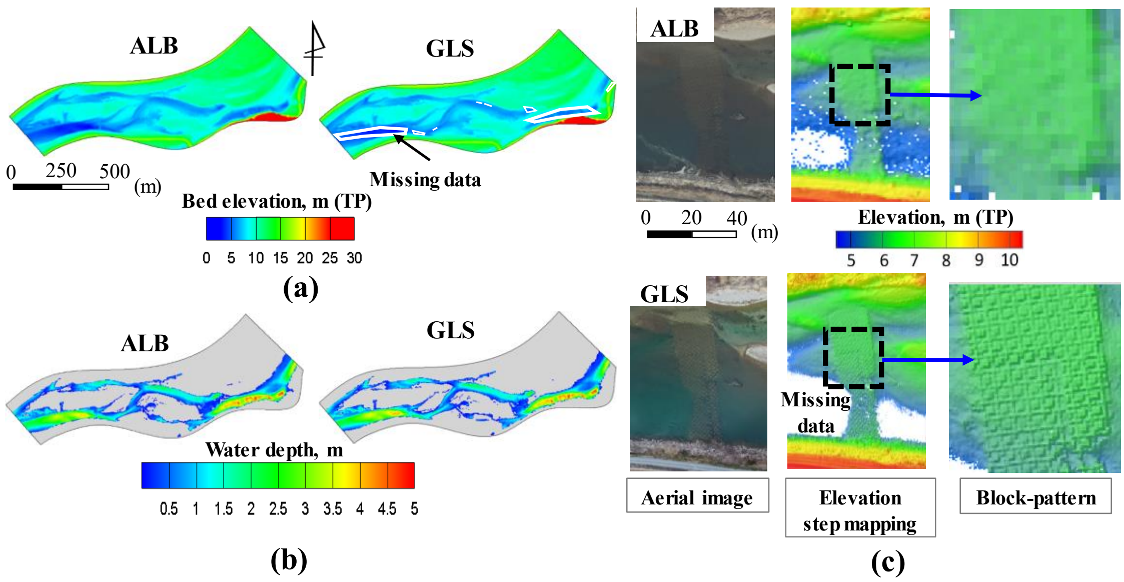

Fig.2 (a) Bed elevation, (b) numerically simulated water depth mapping, and (c) reproducibility of submerged infrastructure; herein, Tokyo Peil (TP) denotes the average sea level in Tokyo Bay, Japan

Findings retrieved using lidar-based digital terrain data (Fig.2a) revealed no flood with substantial bed deformation during the measurement time of 2019–2020. Furthermore, it was found that the GLS laser was unable to capture a few water areas because almost all lidar-based techniques, including transparency, are highly limited to deepwater. However, in GLS, the white-marked parts indicate missing data (Fig.2a), which could have been caused by insufficient laser power. The maximum water depth (Fig.2b) was approximately 4.96 m (1.79 FTU, turbidity) and 2.08 m (0.80 FTU, turbidity), respectively, for the underwater measurements using the ALB and GLS (before updating missing data). It was saliently featured that the GLS point clouds over the present ALB illustrated the submerged artificial infrastructure (Fig.2c) of the river in detail, including its shape, patterns, and eroded parts, which could be helpful in maintenance and construction tasks, if necessary.

Figs.3a-c illustrate the comparisons of field observations of the bed elevation, water depth, and velocity distribution profiles, respectively, with numerical estimates using ALB and GLS data along the two local cross-sections surveyed at the right bank of around 15.3 KP and 15.4 KP (see Fig.1). Overall, findings revealed that both the ALB and GLS data were practical and almost identical to field observations with centimeter-level outperformed accuracy, and the cross-sectional profile of the resultant flow velocity was reasonably reproduced. Despite its shortcomings in deepwater observation and root mean square error (RMSE) when compared to field measurements, the newly launched GLS would be a useful surveying tool for shallow depth and shorter reach assessment tasks, as its performance was very close to the already well-proven ALB approach (Yoshida et al., 2020)[1]. Despite the fact that the time lag of ALB and GLS measurements was taken into account during numerical simulation, the results may be influenced by the time variation of these data.

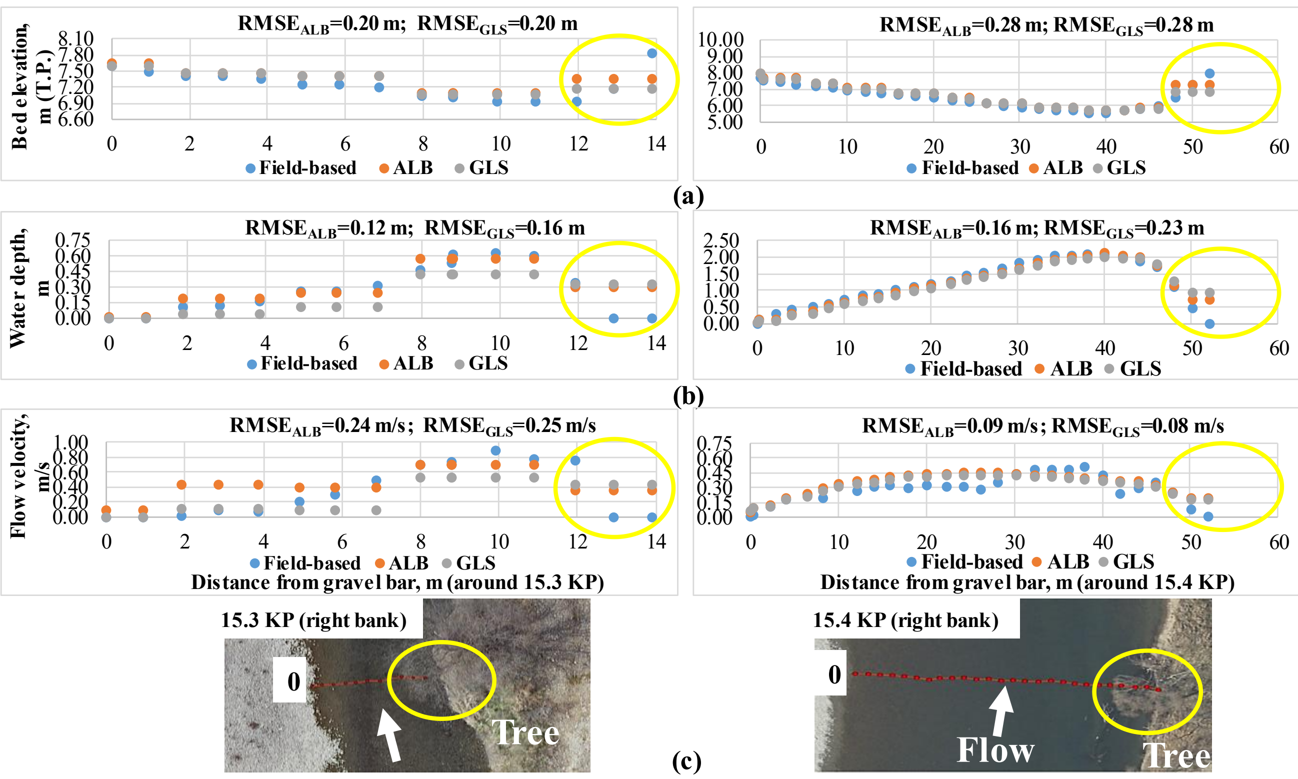

Fig.3 Comparison of field-observed (a) bed elevation, (b) water depth, and (c) flow velocity with respective simulated values at a low discharge of 26.16 m^3/s, using ALB and GLS data along the two surveyed local cross-sections

(2) Floodplain vegetation attributes assessment

Proper assessment and management of river forestation are critical factors in controlling water level during flooding. Results of vegetation attribute illustration (Fig.4) in this study revealed that GLS performed reasonably well, almost identically to the ground-truth observations and the respective high spatial resolution aerial image with a ground sampling distance of 3 cm/pixel. Herein, vegetation height elucidation partly supports the results of an earlier report (Straatsma and Baptist, 2008)[4] because willow ends were so thin that a laser device cannot precisely detect the top of the vegetation. The slight difference in height measurements could also be attributed to vegetation growth during the one year between the two lidar campaigns.

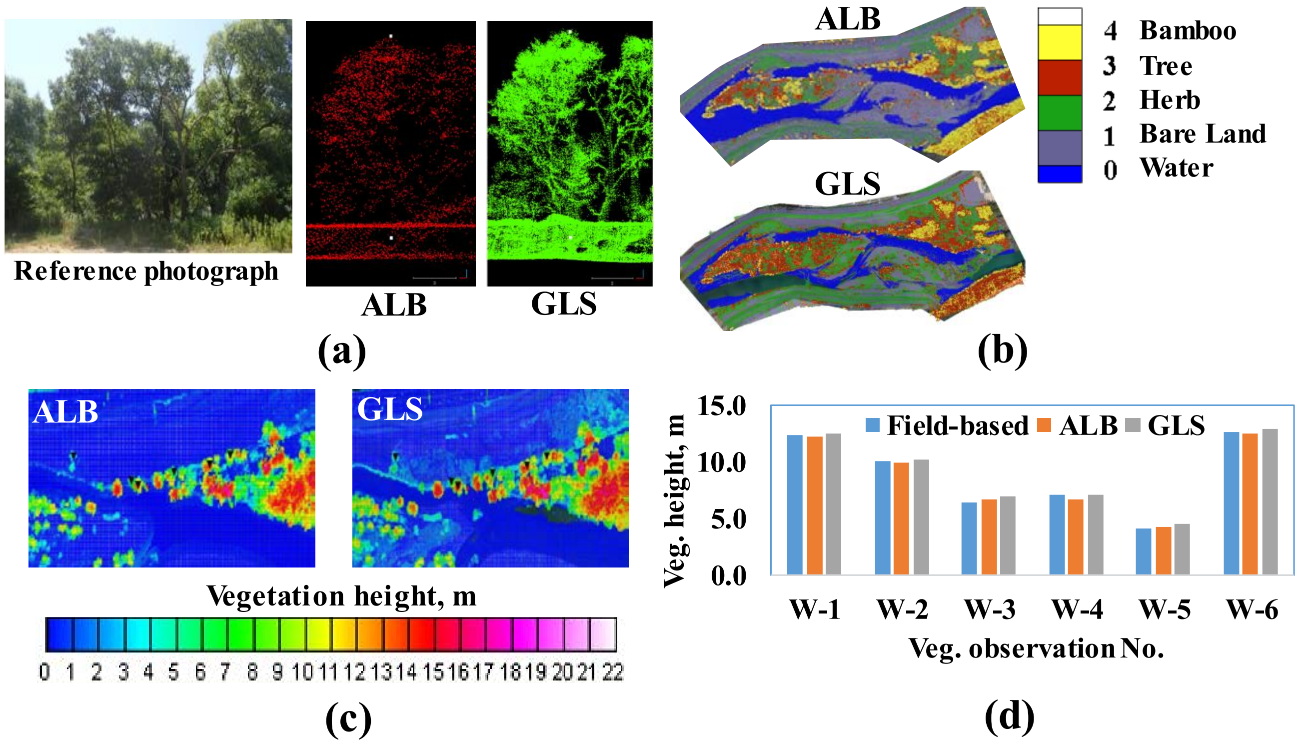

Fig.4 (a) Vertical structure, (b) land cover mapping, (c) vegetation height contour map, and (d) comparison of ground-surveyed woody vegetation heights with ALB and GLS data estimates

4. Conclusion

Findings demonstrated that the data from both systems were effective, with nearly identical accuracy to benchmark in situ measurements, especially for bed elevation observation, and the lidar-based depth-averaged numerical simulation reasonably reproduced low-water flow patterns. Based on GLS's applicability, the new advanced technology could be considered convenient and practical to manage clear-flowing and shallow streams with vegetated floodplains. Furthermore, the time lag between the ALB, GLS, and field measurements may affect the current study's results. Therefore, for further research on the comparative assessment of lidar-based techniques, it is also recommended to use data from the same period for proper estimation, which would also help select the most feasible approach for cost-effective river management tasks. In addition, assessing seasonal variation performance is highly recommended for gaining a better insight.

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