Research article

Comparison of Crop Surface Models and 3D Point Clouds by UAV Imagery on Estimating Plant Height and Biomass Volume of Pasture Grass

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Abstract Plant biomass is considered an important parameter for crop management and yield estimation, especially for grassland. Aerial photogrammetric techniques have been used for vegetation data gathering of the areas of dense vegetation fields with high research interest. Recent advances in computer vision include structure from motion and multi-view stereopsis (SfM-MVS) techniques, which can derive 3D data such as digital surface models (DSMs) and orthomosaic from overlapping photography taken from multiple angles. The difference between the DSMs of a planted field and the digital terrain model (DTM) has been referred to crop surface model (CSM). Ever since SfM-MVS has been adopted to derive plant height (PH) and above-ground biomass using CSMs at 2013, this method has become the most explored and verified approach to simulate the structure of crops all over the world. However, the complexity of crop structure is thought to be not well represented in DSMs because the DSMs have only one Z value at each 2D pixel. Besides, lacking a DTM representing the bare ground is another problem when adopting the CSM method. On the other hand, the 3D point cloud where DSMs are derived from UAV may provide the structure information in a faster and more detailed way. This research tested the capability of 3D point cloud in estimating plant height and biomass volume of pasture grass, and compared the results with CSMs. UAV photography were conducted at the experimental field of Obihiro University of Agriculture and veterinary Medicine, Hokkaido, Japan, 2019. The biomass volume estimated by DSM and point cloud have no significant difference, showing that DSM and point cloud have the same performance at estimating biomass volume of grass. In the case that only the simple value data is required, the point cloud data is recommended.

Keywords biomass volume, CSM, DSM, plant height, point cloud, UAV

INTRODUCTION

Proper planting of biomass fuel plant has become one of the main challenges of carbon neutral. In recent years, attention has been paid to the use of pasture grass as biofuel. Gramineae grass has a vigorous regenerative power and can be cut multiple times a year. Some species can be continuously cultivated for more than five years (Nakagawa et al., 2009). Furthermore, pasture grasses can adapt to most kinds of ground surface environment and provide high yields where the edible crops can hardly grow, which avoids the competition between biofuel and food production.

At the site of grassland management, plant height and biomass production monitoring during the growing stage is one of the most important measurements. In the last decade, with the advancement in new platforms such as unmanned aerial vehicles (UAVs), methods based on remote sensing for biomass production estimation are gathering popularity. As a result of the fusion of UAV remote sensing and digital photogrammetry technology, a flexible and automatic approach of progressing aerial imagery has been developed, which is known as the structure from motion (SfM) technology. Based on the multiple overlapping images, characteristic feature points are detected of which the three-dimensional (3D) coordinated are reconstructed during the bundle adjustment progress afterwards. After the bundle adjustment, a detailed scene geometry made by a sparse point cloud is built and all pixels are used in this step to reconstruct finer scene details. Based on this sparse point cloud, the dense point cloud, orthomosaic and the digital surface model (DSM) are exported. As an intermediate production to construct the DSM, the characteristic of the dense point cloud is that it is not filtered, meaning that it contains all the outliers and noise point (Agisoft LLC, 2013). On the other hand, DSM is exported in a common image format such as *.tif with a particular coordinate system, with the pixel size of more than one centimeter, meaning that one pixel represents the mean value of all 3D points inside it. Furthermore, filters such as noise filter and surface smoothing filter are applied to the DSM, which make the DSM unable to represent the detail of the small features on the ground precisely, such as the leaves of plants (Cubero-Castan et al., 2018).

The difference between the DSMs of a planted field and the digital terrain model (DTM) has been referred to crop surface model (CSM) (Hoffmeister et al., 2010). Ever since Bendig et al. firstly adopted SfM-MVS to derive plant height (PH) and above-ground biomass using CSMs at 2013, this method has become the most explored and verified approach to simulate the structure of crops all over the world. Most studies showed that the plant height estimated by CSMs tend to be lower than the plant height measured on the ground, because of the average and smooth surface of CSMs (Bendig et al., 2014). Based on this background, there is thought to be a possibility that point clouds can represent the plant height of crops more accurately than CSMs.

However, there is no study yet discussing the difference at the performance on estimating plant height and above-ground biomass volume of pasture grass. The objectives of this study are 1) to compare the estimation results of plant height and biomass volume obtained by point clouds and CSMs respectively, and 2) discuss the characteristics of each of them on representing three-dimensional structure of the crop.

METHODOLOGY

The study site was a grass field inside the experimental field of Obihiro University of Agriculture and Veterinary Medicine, Obihiro City, Hokkaido, Japan. The specie of the pasture grass was reed canary grass. The surveys by UAV were conducted weekly from 31st May to 3rd September 2019 (15 times in total), with Phantom 4 Pro (DJI). Before the UAV flights, seven ground control points (GCPs), of which position information was measured using RTK-GNSS (HiperV, TOPCON), were settled all over the experimental field. The flights were carried out automatically by Pix4D Capture (Pix4D). During each flight, the flying height was 50 m above ground. Both the top-overlap and the side-overlap rate were 80%. The ground sampling distance (GSD) of the raw aerial imagery was 1.32 cm. Ground surveys in order to obtain the plant height of the grass were conducted from 17th July to 3rd September (totally 8 times), on the same dates as the UAV surveys. During each time of the ground surveys, six measuring points were settled all around the grass field and marked with marking tapes which could be seen at the aerial imagery. Sampling of these six measure points was made during every time of the ground survey. A self-made plant height measure was used to obtain the optimal height value of the grasses. According to Bendig et al. (2014), “the PH_{CSM} represents the mean plant height of all pixels in a pixel. As a result, not only the top of the plant, for example the ears, is measured, but also the lower parts, like the leaves. Consequently, the detail of PH_{CSM} is higher than PH_M, because PHCSM contains more than on pixel per plant and, the method of the PH_M reference measurements in the field should be discussed.” Based on this opinion, which is most reasonable, the method of method to measure plant height with tape measure or staff ruler, which has been used in many studies, can defiantly not obtain the obtain value standing for the plant height of a certain the field. In this research, a self-made plant height measure was used to obtain the reference plant height. A sliceable plastic plate (10 cm × 20 cm) was used to determine the proper height of the grass canopy. When measuring, the plate was sliced down from above, until every part of its bottom was touched by the grass leaves. The leaves should be naturally curved instead of being forced bending when the plat has stopped. This method can not only help determine the optimal canopy position, but also help the observer to read the scale efficiently. The height of the grass is usually lower than one meter, meaning that the investigator has to squat down or gravel down to the ground in order to look at the canopy from a horizontal direction.

Fig. 1 shows the workflow of the data processing. The RGB imagery obtained by UAV was progressed using Pix4D mapper (ver 4.6.5, Pix4D) to construct the dense point clouds, orthomosaic, and DSMs, of which coordinate was corrected by GCP calibration. By identifying the measuring points at the orthomosaic, the coordinates of the measuring points were extracted using ArcGIS Pro (ver 2.4.1, Esri). After inputting the coordinates into the Pix4D mapper again, the location of the measuring points was marked at the dense point clouds. The plant height obtained from point clouds (PH_{PC}) was then calculated by subtraction the altitude of the ground surface from the altitude of the grass surface. On the other hand, CSMs were made with ArcGIS Pro by subtraction of the DSM of the field without plants from the DSMs with plants. The plant height obtained from CSMs (PH_{CSM}), which was in other words the CSM value of each measuring point, was then extracted using ArcGIS Pro. Then, both PH_{PC} and PH_{CSM} were compared to the measured value of plant height (PH_M) to evaluate the accuracy of point clouds and CSMs to estimate the plant height of grasses. Finally, the above-ground biomass volume (BV) of the whole grass field instead of the particular measuring points was extracted from point clouds and CSMs (BV_{PC}, BV_{CSM}), respectively, and compared to each other to unravel the characteristics of point clouds and CSMs on estimating above-ground biomass volume of pasture grass. The calculation of BVCSM used the geo-metry function of ArcGIS, and the calculation of BV_{PC} used the Volume Tool of Pix4D mapper.

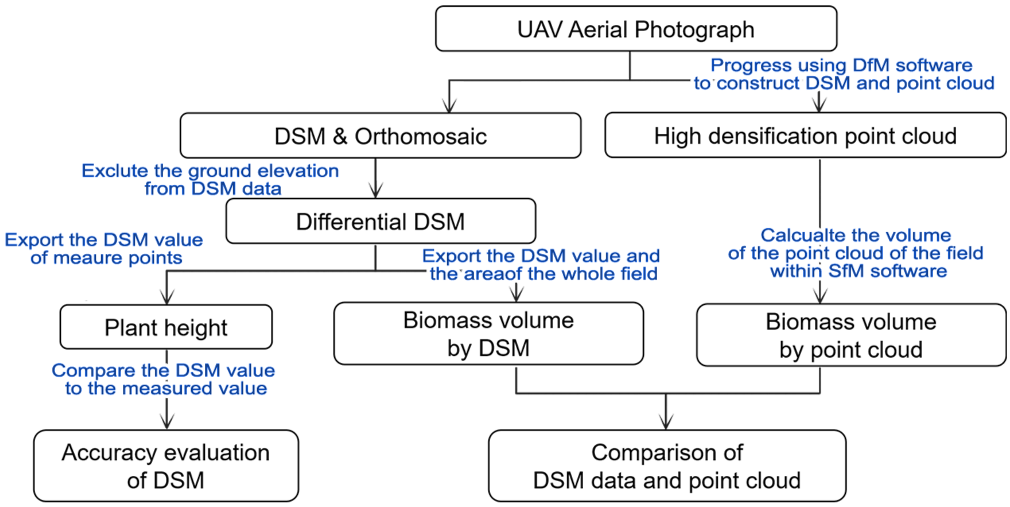


Fig. 1 Workflow of data analysis

RESULTS

1. Time Series of the Plant Height Estimated by Point Clouds and CSMs

Fig. 2 shows the Time series of measured value of plant height (PH_M), plant height obtained from point clouds (PH_{PC}) and plant height obtained from crop surface model (PH_{CSM}). From 17th July to 3rd September, all the three time series lines remained approximately parallel to each other. However, the line of PH_{CSM} stayed lower than the reference line all the time, while the PH_{PC} line was almost laying over the reference line. This indicated that both CSMs and point clouds could reflect the growth trend of grass, while there was a constant difference existing between the plant height estimated by CSMs and the reference value.

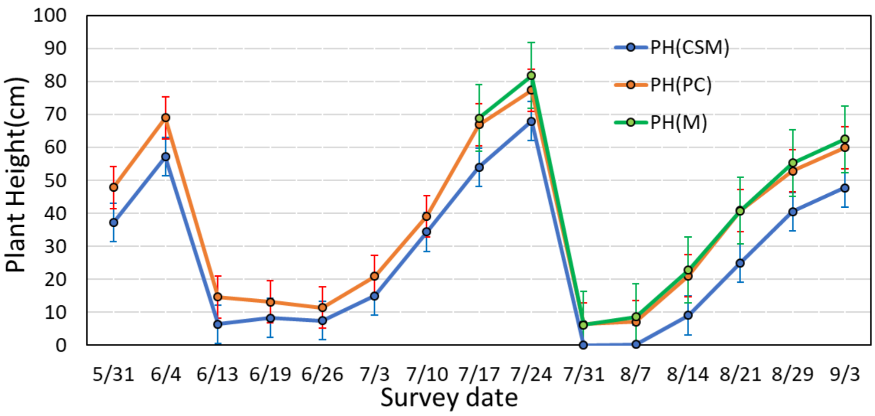
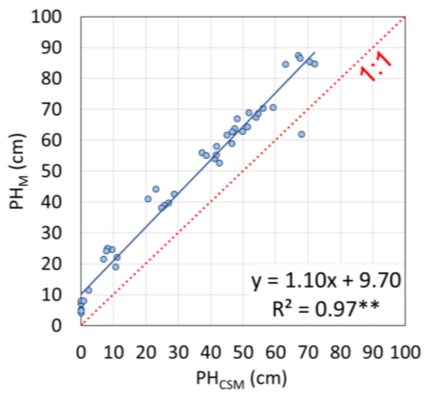


Fig. 2 Time series of PH_M, PH_{PC} and PH_{CSM}

2. Accuracy of Plant Height Estimation by CSMs

Fig. 3 shows the relationship between PH_M and the estimated plant height by CSMS (PH_{CSM}). The number of samples was 48 (6 samples × 8 times of ground survey). The regression coefficient was close to 1, which suggests the regression line was nearly parallel to the 1:1 line. On the other hand, the intercept was approximately 10, suggesting there was a difference of about 10 cm between PH_M and PH_{CSM}, which stayed stable during the whole survey period since the regression coefficient was near to 1. The R^2 and *RMSE* were 0.97** and 14 cm, respectively, also sowing that PH_{CSM} has the same changing trend, however a stable difference with PH_M. These showed that CSM can represent the changing trend of the plant height of pasture grasses, but has a relatively low accuracy on estimating the value of plant height.



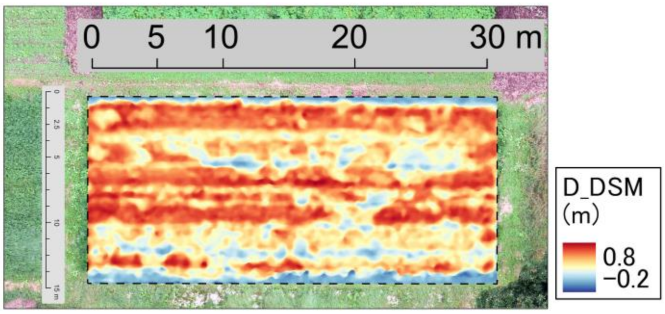


Fig. 3 Relationship between PH_M and PH_{CSM} **Fig. 4 CSM map for grass field (2019/7/24)**

On the other hand, as shown at Fig. 4, the CSM map could show the growth unevenness clearly by the estimated plant height within ArcGIS.

3. Accuracy of Plant Height Estimation by Point Clouds

Fig. 5 shows the relationship between the measured value of plant height (PH_M) and the estimated plant height by point clouds (PH_{PC}). The regression coefficient and intercept of the regression equation were 1.04 and -0.16, respectively, making the regression line extremely close to the 1:1 line. The coefficient of determination (R^2) and the *RMSE* were 0.99** and 3 cm, respectively. This result showed that point clouds can estimate plant height of pasture grass with extremely high accuracy with little need for calibration.

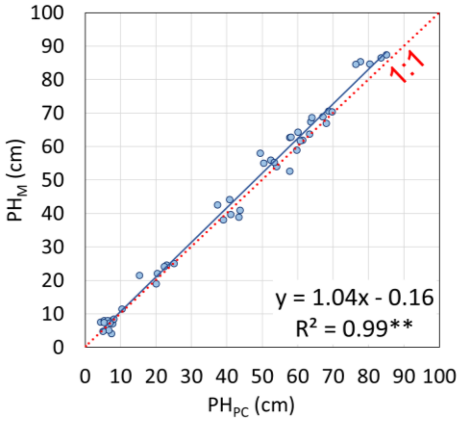


Fig. 5 Relationship between PH_M and PH_{PC}

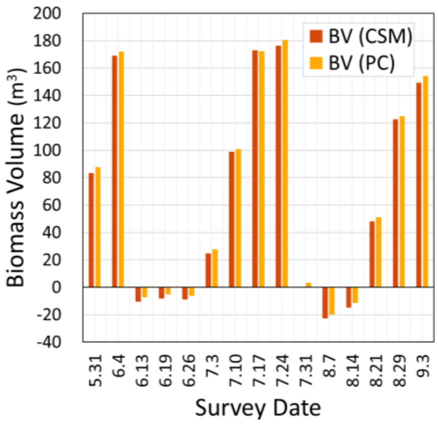


Fig. 6 Comparison of BV_{PC} and BV_{CSM}

4. Comparison of the Above-ground Biomass Volume Estimated by Point Clouds and CSMs

Fig. 6 shows the comparison of BV_{PC} and BV_{CSM} of the whole field during the whole survey period from 31th May to 3rd September. The BV_{CSM} and BV_{PC} of 13th June, 19th June, 26th June, 7th August, and 14th August showed minus value because the DSM used as the bare ground surface had included the remaining grass after the reaping. The result of t-test showed that there was no significant difference between BV_{PC} and BV_{CSM}. This result showed that despite point cloud can estimate plant height of pasture grass with higher accuracy than CSM, it gives the same value of above-ground biomass volume estimation with CSMs.

DISCUSSION

Despite the reference plant height was measured by an improved method and was as accurate as possible, there was still a 13 cm RMSE of the PH_{CSM} of the grassland. It is necessary to realize that there is a problem estimating when estimating plant height using CSMs, which is caused not by the human error or the environmental factors such as the wind, but by the characteristics of the DSM itself. There is a fact that should not be ignored that the airborne laser scanning or the aerial digital photogrammetry were aiming at generating DEMs standing for the basic topographic shape at the first place. The key point of DEM generation using aerial imagery was never about the bumpy terrain or the above-ground objects, but about the smooth terrain. This fact is so important, because it resulted in a critical characteristic of the dense matching algorithm such as SfM-MVS, which are the denoising filter and the smooth filter. Both of these filters can improve the accuracy and quality when constructing terrain models or large-scaled buildings. However, the disadvantage of using these filters is that the small-scaled or low-heighted objects may be smoothed, for example, thee leave of crop plants. As long as DSM is still raster data, which represents the ground objects with certain-sized pixels, it has a limit on estimating plant height of crops, because there are spaces between the crop leaves. This is thought to be the inherent weakness of apply remote sensing photogrammetry to agriculture.

Compared with CSMs, point clouds showed much higher accuracy on estimating plant height of grass field. The reason of the high accuracy is considered to be because no smooth filter and pixel averaging algorithm has been conducted when constructing point clouds. While CSM shows the average height of all the objects of a certain area (for example, one pixel), point cloud shows the particular height of one certain object (for example, the leaf of grass). In other words, point cloud reflects a more detailed height distribution data of the grass field. Therefore, it is considered that point cloud is more qualified than CSM to estimate grass field plant height.

However, on the other hand, when estimating above-ground biomass volume, no significant difference was found between the results obtained by CSMs and point clouds. It is because when calculating the total value of the grass above-ground volume with point cloud, not only the dense points of the canopy that were included, but also the lower parts between the grass leaves, including the ground surface. As the result, point cloud yields the same value as CSM on grass above-ground biomass volume estimation. The spaces between the leaves, which has been found an error factor and should be excluded when estimating plant height, is no longer an error factor when estimating above-ground biomass volume and should be considered in order to increase the accuracy. This led to a conclusion that point cloud is more qualified on estimating plant height of grass than CSM, but has the same accuracy as CSM on estimating above-ground biomass volume.

There have been mainly two purposes for remote sensing at agriculture field, monitoring the current status of the crop land, and predicting the final yield of the crops before harvesting. Before UAV was popularized, the former purpose could not be fully achieved, because neither satellite imagery nor laser scanning was properly suit for the purpose. The ground resolution of satellite imagery, which is usually larger than one meter, is too large for a single crop land. The laser scanning conducted by ground survey is both time and labor consuming, making it almost not realistic for the whole crop field. This is exactly why UAV is so crucial on applying remote sensing to the real agriculture sites. It is more precise than satellite imagery, and more efficient than laser scanning, making it perfectly suit the purpose of current status monitoring of crop lands. For decades, remote sensing has found difficulties on benefiting the farmers directly. With UAV becoming a trustable platform of remote sensing, it is finally possible to help farmers make better management of their own crop land, by not only the traditional CSM data, but also the precise dense point cloud data.

CONCLUSION

In this study, the abilities of dense point clouds and CSMs on estimating plant height and above-ground biomass volume for pasture grass have been validated and compared based on multiple-time surveys. Plant height was monitored by dense point cloud with very high accuracy (RMSE = 3.5 cm), while the plant height monitored by CSMs was consistently lower than the reference value. On the other hand, no significant difference exists between the above-ground biomass volume estimated by dense point cloud and CSMs. These results show that dense point cloud has an advantage on reflecting current status of crops, while has the same accuracy with CSMs on predicting above-ground biomass volume. When the purpose of the UAV survey is to monitor the precise status of the crops or identify the lodging area, point cloud is a better choice of data; while when the purpose is estimating the biomass volume of the whole field with little requirement of details, DSM data provides the estimated value with both accuracy and efficiency.

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