Topographic Mapping of Farmland by Integration of Multiple Sensors on Board Low-Altitude Unmanned Aerial System

Mengmeng Du, Noboru Noguchi, Hiroshi Okamoto, Noriko Kobayashi

***Abstract*—**This paper introduced a topographic mapping system with time-saving and simplicity advantages based on integration of Light Detection and Ranging (LiDAR) data and Post Processing Kinematic Global Positioning System (PPK GPS) data. This topographic mapping system used a low-altitude Unmanned Aerial Vehicle (UAV) as a platform to conduct land survey in a low-cost, efficient, and totally autonomous manner. An experiment in a small-scale sugarcane farmland was conducted in Queensland, Australia. Subsequently, we synchronized LiDAR distance measurements that were corrected by using attitude information from gyroscope with PPK GPS coordinates for generation of precision topographic maps, which could be further utilized for such applications like precise land leveling and drainage management. The results indicated that LiDAR distance measurements and PPK GPS altitude reached good accuracy of less than 0.015 m.

***Keywords*—**Land survey, light detection and ranging, post processing kinematic global positioning system, precision agriculture, topographic map, unmanned aerial vehicle.

I. Introduction

FARMLAND surface unevenness has been pointed out as a major issue that affected agricultural drainage efficiency, and it was also considered as potential threat that leads to crop drowning during early growing seasons, which further causes yield loss [1]. Generally, two major proven techniques that have already been put into practice for precise land leveling could be enumerated: laser-assisted land leveling and GPS based land leveling [2]-[4]. Laser-assisted land leveler works in a simple fashion. A laser receiver is attached to the scraper and measures the height deviation of the scraper to the target laser plane emitted by the laser transmitter. The scraper goes automatically up and down to cut soil over high ground and release soil over low ground in real time, according to the height deviation signals [5]. The selected location and height of laser transmitter, however, directly affect land leveling efficiency and accuracy. Whilst GPS based land leveler uses a GPS antenna to measure actual three-dimensional (3D) coordinates (latitude, longitude, and altitude) of the scraper in real time to calculate cut/fill ratio. Either way, whether it should be a laser-assisted land leveler or a GPS based one, topographic survey is prerequisite before land leveling operation, in order to locate the laser transmitter or to provide cut/fill ratio map of each field. And land leveling accuracy as well as efficiency is in high accordance with the delicacy of each topographic map, as it determines the exact volume of soil that would be moved.

Topographic map describes terrestrial or 3D land surface features in a two-dimensional way. New technologies include 3D laser scanner and aerial photogrammetric image processing; nowadays GPS and total station still remain the primary methods used in land surveying for generating topographic maps [6]. 3D laser scanner and aerial or satellite imagery photogrammetry are widely used in urban ecology modeling, forest monitoring, and etc. by providing Digital Surface Model (DEM) or 3D point could [7], [8]. However, the geospatial accuracy as well as vertical accuracy of such kind of DEMs is reported from several decimeters to tens of meters. Land survey using the conventional total station or handheld GPS device is usually used in construction site, streambank monitoring, etc. which is both time-consuming and highly dependent on professionals. Therefore, in this study, we introduced a low-altitude UAV equipped with a high precision one-dimensional LiDAR to conduct topographic land survey in a simple and totally autonomous manner. The research objective is to integrate data from LiDAR, micro electro mechanical systems (MEMS) gyroscope, and PPK GPS coordinates to create a topographic map at farmland level for applications of land leveling.

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II. Materials and Methods

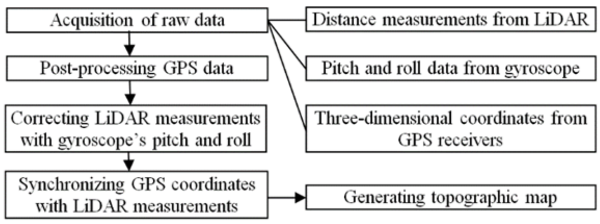

Fig. 1 Overall approach of generating topographic map using low-altitude UAV-LiDAR system

The overall approach consists of five steps: acquisition raw data from LiDAR, MEMS gyroscope, and GPS receivers; processing PPK GPS coordinates; correcting LiDAR distance measurements with attitude information from MEMS gyroscope; synchronizing PPK GPS coordinates with corrected LiDAR distance measurements; and generating topographic map, shown in Fig. 1.

A. Field Site and Equipment

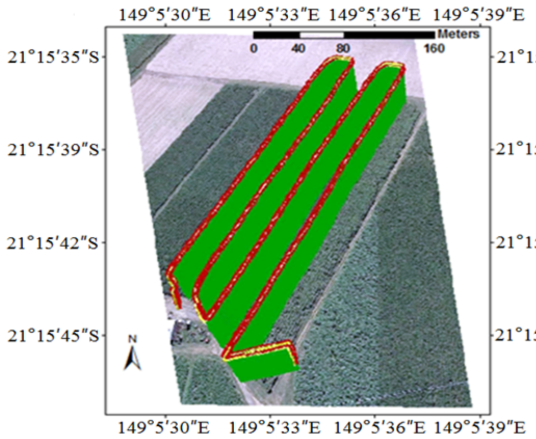

Fig. 2 Sugarcane field under study (after harvesting)

Fig. 3 UAV-LiDAR system used in this study

Experiment was established over a harvested sugarcane farmland located in Mackay, Queensland, Australia (around 21.259794°S–21.263142°S and 149.091325°E–149.094109°E), shown in Fig. 2, which accounts for about 3 hectares. A small hexarotor (ENROUTE CO., LTD., Fujimino, Japan) was used as platform of the UAV-LiDAR system [9], shown in Fig. 3. High precision one-dimensional LiDAR (JENOPTIK, Jena, Germany) was used as distance measuring device with the ranging capability from 0.5-300 m under natural reflection, which was fixed under the hexarotor pointing vertically downwards, shown in the left image of Fig. 3. Distance measurements of the LiDAR are ready to be corrected by using attitude data from gyroscope incorporated inside the hexarotor's flight controller. Two GPS modules (Emlid Limited, Hong Kong) were used to calculate centimeter-precision 3D position of the UAV-LiDAR system, with one GPS module being installed on the top of the hexarotor as a rover receiver shown in the right image of Fig. 3, while the other one is fixed nearby the field as a base receiver to provide correcting reference in PPK method.

Autonomous flight was conducted in December 7th 2016 at the ground speed of 5 m/s and altitude about 30 meters above ground level. Trajectory of the flight also was shown in Fig. 2 as red dots. As the output frequency of LiDAR measurements and GPS was synchronized at 10 Hz, along track interval of each surveying point was about 0.5 m, and the track interval was set every 20 m.

B. Correcting LiDAR Distance Measurements

In order to eliminate such effects of continuously changing attitudes of the UAV during flight on the LiDAR distance measurements, attitude data from gyroscope were utilized and expressed as (1).

$$h_{LiDAR} = D \times \cos\beta \times \cos\delta \quad (1)$$

where h_{LiDAR}, D, β, and δ indicates the corrected distance measurements of LiDAR above ground level, the raw LiDAR distance measurement, and the attitude data of pitch and roll, respectively.

We removed superfluous data during the process of taking off, turning round, and landing by visual inspection. And the total number of surveying points within the field under study amounted to 1948 in total. Continuously changing attitude data of pitch and roll are shown in Fig. 4 in sequence, while corrected LiDAR distance measurements were shown in Fig. 5.

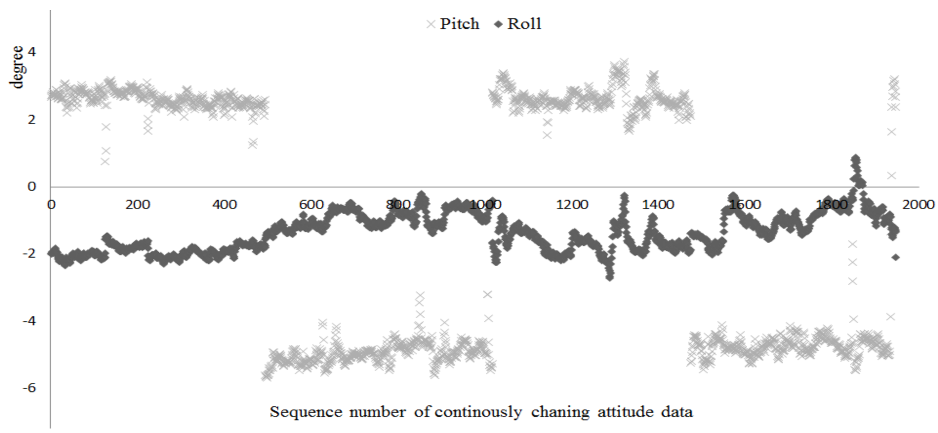

Fig. 4 Attitude data from gyroscope (removing measurements during the process of taking off, turning round, and landing)

C. Synchronizing PPK GPS Coordinates with LiDAR Distance Measurements

In this study, we adopted two identical GPS modules, as a rover receiver fixed on the UAV-LiDAR system and a base receiver, respectively, to get high-precision 3D coordinates in a post-processing kinematic manner. PPK GPS data were acquired by using an open-source algorithm in RTKLIB software, after measuring absolute geo-spatial coordinates for GPS base receiver as correction reference using RTK GPS module. Subsequently, using LiDAR measurements and PPK GPS altitude on the point of taking off as a benchmark, we synchronized two sets of height data from different sources so that each LiDAR distance measurement could be geo-coded for generating a topographic map. The synchronizing result of corrected LiDAR distance measurements with PPK GPS altitude was shown in Fig. 5.

Based on the synchronized results of corrected LiDAR distance measurements with PPK GPS 3D coordinates, ground height of each surveying point relative to that of GPS base receiver (setting GPS base receiver's ground height as 0) could be calculated as (2). The calculation of ground height of each survey point was also illustrated in Fig. 7.

$$H = h_{gps} - h_{fix} - h_{LiDAR} \tag{2}$$

where H, h_{gps}, h_{fix} indicates the ground height of each surveying point, the PPK GPS altitude, the height difference between GPS rover receiver's antenna and LiDAR's laser lens (0.36 m), respectively. Thus, high precision 3D coordinates (latitude, longitude, and ground height) of each surveying point were acquired. The spatial variations of ground height of each surveying point were shown in Fig. 6.

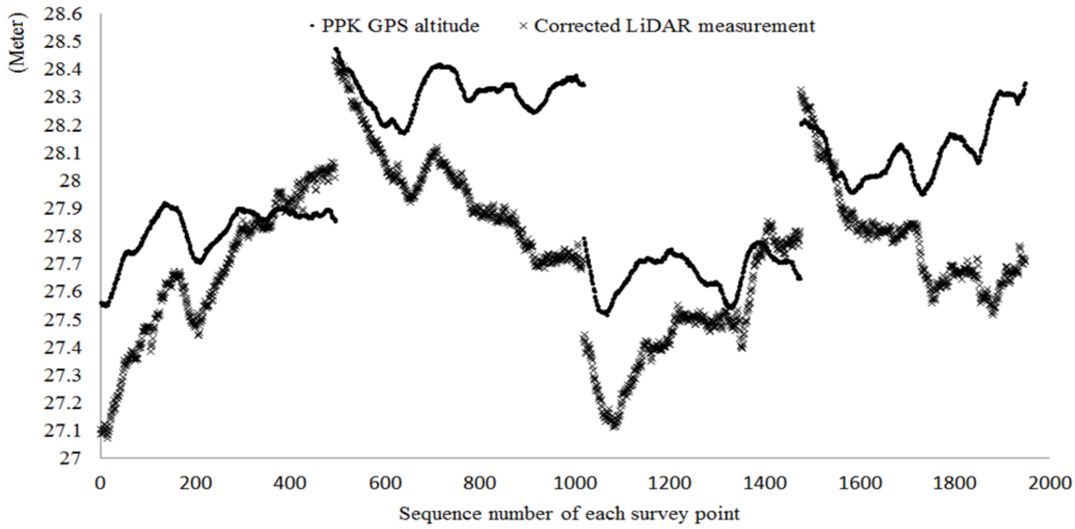

Fig. 5 Synchronizing of corrected LiDAR distance measurements with PPK GPS altitude (removing measurements during the process of taking off, turning round, and landing)

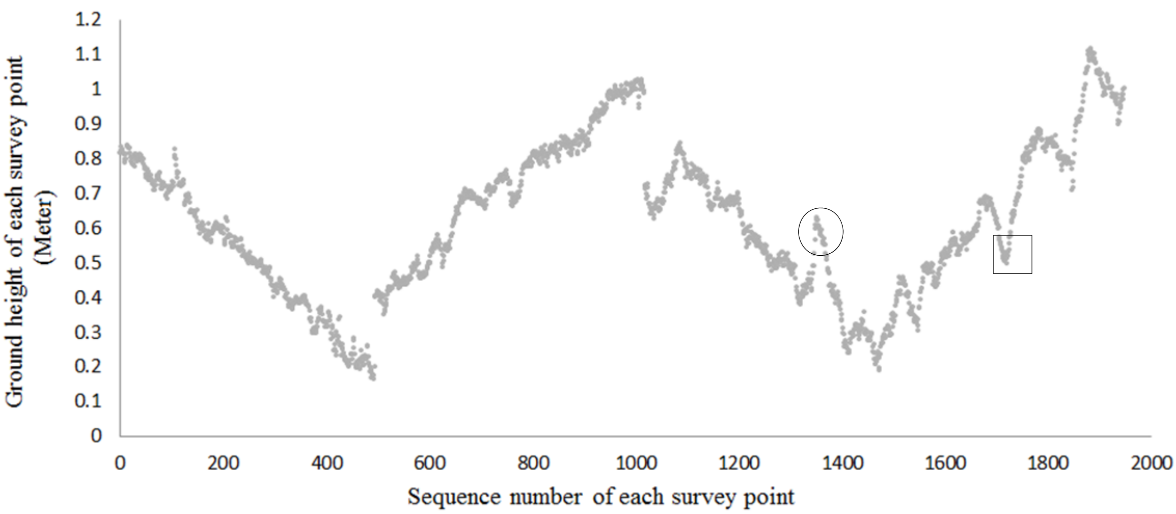

Fig. 6 Ground height of each surveying point

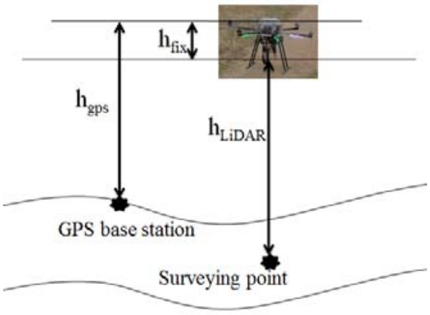

Fig. 7 Illustration of calculating ground height of each surveying point

In order to confirm UAV-LiDAR system's working capability and topographic map's precision, several bumps and hollows were artificially built inside the field by using a plough, shown in Fig. 8.

Fig. 8 Building bumps and hollows using a plough

III. Results and Discussions

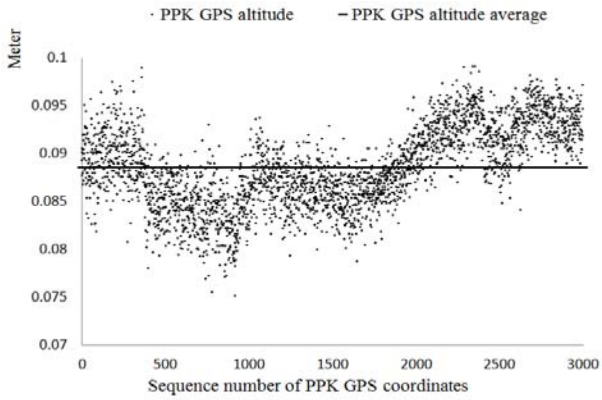

Fig. 9 Accuracies of PPK GPS altitude

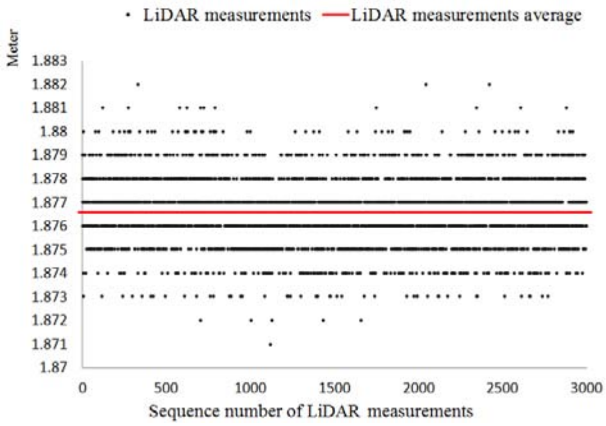

Fig. 10 Accuracies of LiDAR distance measurements

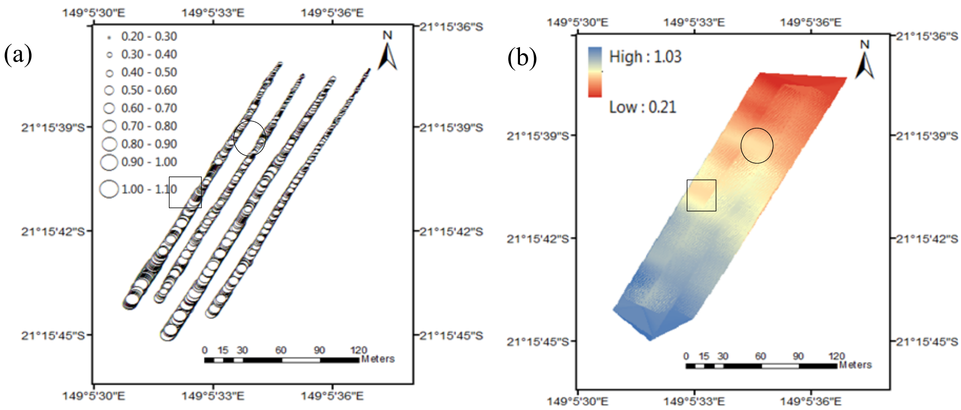

Fig. 11 Topographic maps (image (a) was shown in graduated symbols, whilst image (b) was shown by using natural neighborhood interpolation method)

To validate the accuracies of PPK GPS coordinates as well as LiDAR distance measurements, we extracted 3000 sets of PPK GPS altitude data consecutively five minutes before taking off when the GPS rover's antenna was hold stationary, shown in Fig. 9. Another 3000 static LiDAR measurements were also acquired and shown in Fig. 10. From Fig. 9, we can conclude that altitude measurements of PPK GPS changed along with time, ranging from 0.08m to 0.095 m due to usage of different combinations of satellites over time, and the accuracy could be confirmed as about 0.015 m, comparing to standalone GPS's 5-10m, differential GPS's 1-2 m, and real-time kinematic GPS's 0.05-0.15 m. The horizontal accuracy of PPK GPS is also confirmed better than the altitude accuracy, as the same law applies to all of the GPS positioning modes mentioned above. From Fig. 10, we could conclude that LiDAR distance measurements remained substantially constant over time mostly ranging from 1.873-1.881 m, and the measuring accuracy was confirmed within 0.01 m.

The high precision topographic map was generated by using GIS (Geographic Information System) software ArcMap (ESRI Inc., Redlands, AB, Canada) as Fig. 11, from which we can visually understand the general low-north high-south terrain of the field under study, with the ground height (relative to the ground height of GPS base station) varying from 0.21 m to 1.03 m. Bumps and hollows in the middle of the field artificially made by using a plough among other irregular terrestrial features could also be easily spotted by visual interpretation both in Fig. 6 and 11, marked in rectangle and circle.

IV. Uncertainties, Errors, and Accuracies

The innovative approach of generating topographic maps by using a low-altitude UAV-LiDAR system indicated good accuracy concerning each surveying point; however, spatial resolution also matters when surveying points were interpolated in GIS software to generate a raster map. In this study, bumps and hollows along the UAV-LiDAR system's flight path were precisely spotted, which proved the feasibility and applicability of using this UAV-LiDAR system for generating high precision topographic map when flight paths of the UAV-LiDAR system were scientifically preset.

V. Conclusion

Topographic survey using conventional equipment is proven to be extremely time-consuming to take enough samples manually, and the execution is highly dependent on professionals. In this study, we designed an innovative topographic surveying method by integrating LiDAR distance measurement with PPK GPS coordinates, using a low-altitude UAV as a platform. The topographic mapping system is of high precision, efficient in time and cost, and simple in structure, which is also highly flexible in designing and executing autonomous flight for each specific farmland.

The experiment in a small-scale sugarcane farmland was conducted in Queensland, Australia. Based on the synchronization of LiDAR distance measurements, which was further calibrated using attitude information from gyroscope, with PPK GPS data, 3D coordinates (latitude, longitude, and ground height) of each survey points were acquired, and accuracy was confirmed less than 0.015 m. Subsequently, we generated a topographic map by interpolating 1948 sets of survey points' 3D coordinates using GIS software, from which we can visually understand the general low-north high-south terrain of the farmland, with the ground height (relative to the ground height of GPS base station) varying from 0.21 m to 1.03 m. Bumps and hollows in the middle of the field artificially made by using a plough among other irregular terrestrial features could also be easily spotted by visual interpretation of the topographic maps.

Most kinds of plants are vulnerable to stagnant water throughout germination period to early growth stages, and after irrigation or natural rainfall puddles are very likely to ensue inside farmland over lower areas, leading to crop drowning as well as occurrence of infestation and plant diseases due to high humidity. Therefore, the topographic map generated using the proposed approach could practically provide reference for laser-assisted land leveler to locate laser transmitter, and also could be used to produce cut/fill ratio map for GPS based land leveler, for facilitating surface drainage, improving crop establishment, reducing occurrence of infestation and plant diseases, and increasing crop yield.

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