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A Comparative Study of UAV Lidar, UAV, and GNSS RTK on Infrastructure Survey

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Abstract. The advancement of the latest techniques allows surveyors to have various approaches to solving survey tasks. The paper is an experimental study on collecting terrain data using different techniques including Lidar on a UAV, normal UAV, and GNSS-RTK. The study uses the point clouds extracted from Agisoft for data from Phantom 4 RTK, and Copre for data from Lidar. The lidar method uses AA450, the first lidar product line of the CHC brand in Vietnam with a Livox Avia scanner. UAV phantom4 RTK uses a 1" CMOS camera, with 20M effective pixels. Both Lidar and UAV methods use the PPK processing technique, and flight altitude is 80m and 100m respectively while GNSS-RTK uses the single-base method at around 7km distance between base and rover. The study results show the deviations in coordinates are very small, and the differences in elevation of Lidar and Phantom4 RTK compare to GNSS-RTK range from 3-5cm at open positions. The differences in elevation between Lidar - GNSS-RTK and Phantom 4RTK-GNSS RTK are 5-8cm and 10-15 cm respectively at the low vegetation and sparse density positions. The differences in elevation between Lidar and GNSS-RTK method range from 8-15cm while Phantom 4RTK cannot reach the ground point at the high and dense vegetation. However, the deviations in elevation between Lidar and GNSS-RTK are 15-25cm at the low, dense positions.

1. Introduction

The development of new techniques allows surveyors to have different methods in the survey including GNSS, unmanned aerial vehicles, and lidar solutions. Regarding the GNSS method, the first applications were introduced in the 1990s [1] with different modes of communication between a base and a rover. Over time, The RTK method has had many new improvements from single base real-time kinematic to network real-time kinematic with higher accuracy and better stability [2,3] or a new processing platform. It now becomes one of the main methods in survey applications, especially in land change surveys [4]. However, the biggest disadvantage is very hard to get fix solution when measuring under trees, or near buildings although the RTK technique had more improvement in firmware and hardware [5] or cannot access in some cases**.**

Concerning the inaccessible or disallowed areas, unmanned aerial vehicles seem to be a great alternative thanks to the automation of design, operation, and data processing. The work [6] indicated that the UAV solution is an efficient solution to determine the dimension and volume of the tank when compared to the total station with a reflectorless mode. UAVs are also a good choice for monitoring the quality of road surfaces [7] or resolving land disputes at the commune level [8]. The study results also indicated that UAV solutions had been widely used for road maintenance [9] and provided very high accuracy [10,11]. It can be seen that there was a rapid increase in the number of research and applications of UAV solutions in transport infrastructure monitoring from 2007 to 2020 [12]. The work [13] believes that UAV is a potential method for monitoring and management thanks to the progress of image analysis techniques. Comparing GNSS-RTK solutions and UAV solutions, each method has different advantages and disadvantages and can be combined in each project. For surveying projects, accessing ground points is the primary purpose of surveying regardless of use with GNSS-RTK or UAV solutions. This is a new challenge for UAV solutions when the survey area has a dense plant density, and surveyors start mentioning about Lidar method.

There has been a boom in the number of research on Lidar's application in a period of ten years from 2008 to 2018 [14]. Lidar means *Light detection and ranging* [15], and its applications are mainly for the smart city [16,17] and environment monitoring [18,19]. This technique becomes increasingly popular in acquiring road surface data [20–22]. Recently, Lidar devices can be installed and operated on drones at low altitudes for survey purposes, especially, Lidar devices can be integrated with a GNSS module and operated independently.

While GNSS-RTK solutions had already become one of the main survey methods, UAV phantom 4RTK with PPK processing mode is quite new with surveyors, especially lidar solutions with PPK working mode. AA450 is a new product line, an integrated product of GNSS, camera, and scanner in the Vietnamese market from May 2021. There was no study on the ability of the AA450 and phantom 4RTK compared to the GNSS-RTK working mode. This research aims to study the ability of phantom 4RTK and AA450 Lidar with PPK processing mode in some kinds of terrain surfaces.

2. Devices, procedures, and methods of the study

2.1. Devices

In this study, there are three kinds of devices, including a Trimble R8s (figure 1), a Phantom 4RTK drone (figure 2), and an AA450 lidar (figure 3). The AA450 lidar product can be installed and operated independently on a DJI M300 drone. Therefore, the DJI M300 drone does not play a key role and will not be mentioned in the study. Trimble R8s is a multi-channels and multi-frequencies GNSS receiver, and phantom 4RTK can be used with either RTK or PPK mode.

Figure 1. Trimble R8s.

Figure 2. Phantom 4RTK.

AA450 Lidar, an integrated product includes a Livox AVIA scanner, a 26 MP camera, and a GNSS multi-band, all constellations.

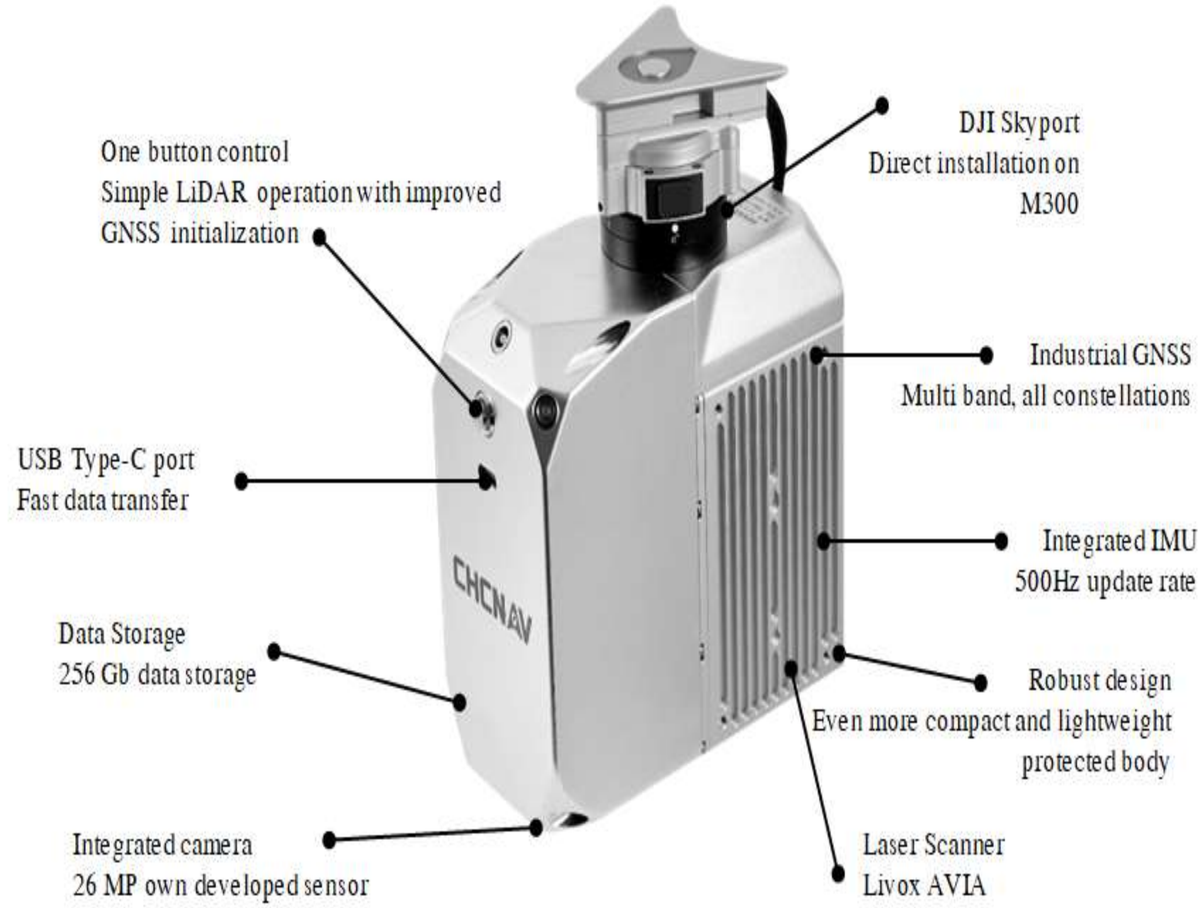

Figure 3. AA450 Lidar [23].

AA450 Lidar can be carried on an M300 drone and operated independently. The M300 drone plays a role as an AA450 carrier in the sky following the designed flight mission via a controller. The specifications of the three devices are below.

Trimble R8S [24]	Satellite signals: GPS, GLONASS, Galileo, Beidou, SBAS. Accuracy: 8 mm + 1 ppm for the horizontal direction; 15 mm + 1 ppm for the vertical direction.
DJI Phantom 4RTk [25]	Satellite signals: GPS, GLONASS, Galileo, Beidou. Accuracy: 10 mm + 1 ppm for the horizontal direction; 15 mm + 1 ppm for the vertical direction. Flight time: approximately 30 minutes
AA450 Lidar [26]	GPS, GLONASS, Galileo, Beidou. Accuracy: 0.010 m RMS horizontal; 0.020 m RMS vertical. IMU update rate: 500 Hz Flight time: approximately 20 minutes on DJI M300 drone Max returns supported: 3 times

2.2. Procedure of operation

For GNSS-RTK working mode, to reduce the influence of distance to survey results [2,27], a 10 Km distance between the base and rover is used, and the correction transmission mode is 4G mode. Because AA450 lidar cannot be used with RTK mode [23] like phantom 4RTK, both will be used with PPK working mode. Trimble R8s uses a single base solution for surveys following the below procedure in Figure 4

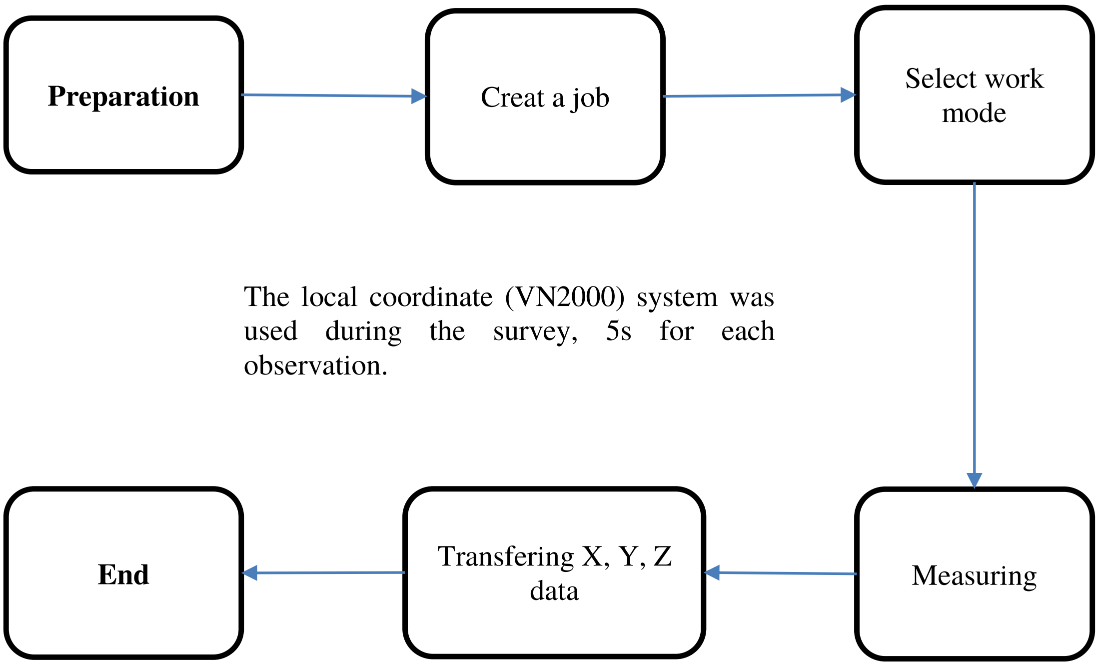

Figure 4. The procedure of RTK working mode.

AA450 is the first lidar product of the CHC navigation group and is for the low-end market (figure 5). Waypoint is the only method for flight mission design. The biggest difference between the flight mission of AA450 and phantom 4RTK is that AA450 must carry out an 8-flight mission with about 320m in length for IMU calibration [23]. The 8-flight mission is a special thing of AA450 compared to the L1 DJI. 8-light mission helps to improve the data accuracy but image and scan data from 8-flight cannot be used. This is a huge waste in terms of data and battery as well.

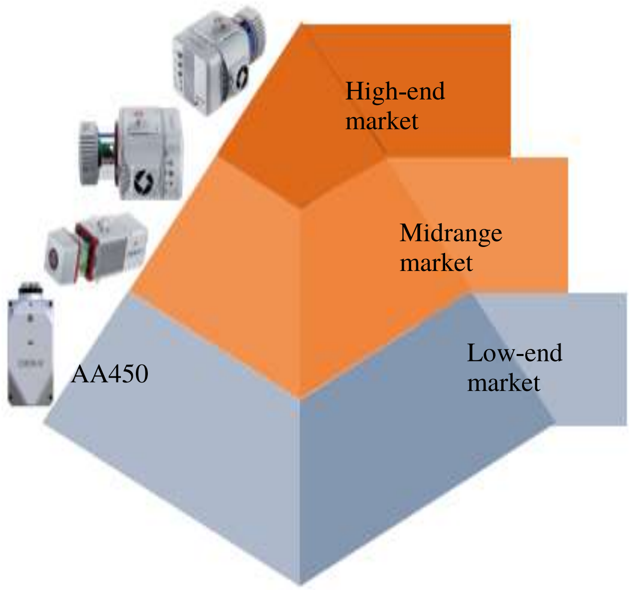

Figure 5. Lidar pyramid [23].

AA450 is operated by the power of an M300 drone, and the operation procedure can be divided into three steps, as in Figure 6. In the processing stage, the output data is adjusted images and point clouds under the *.las format. The processing stage is carried out by the Copre software.

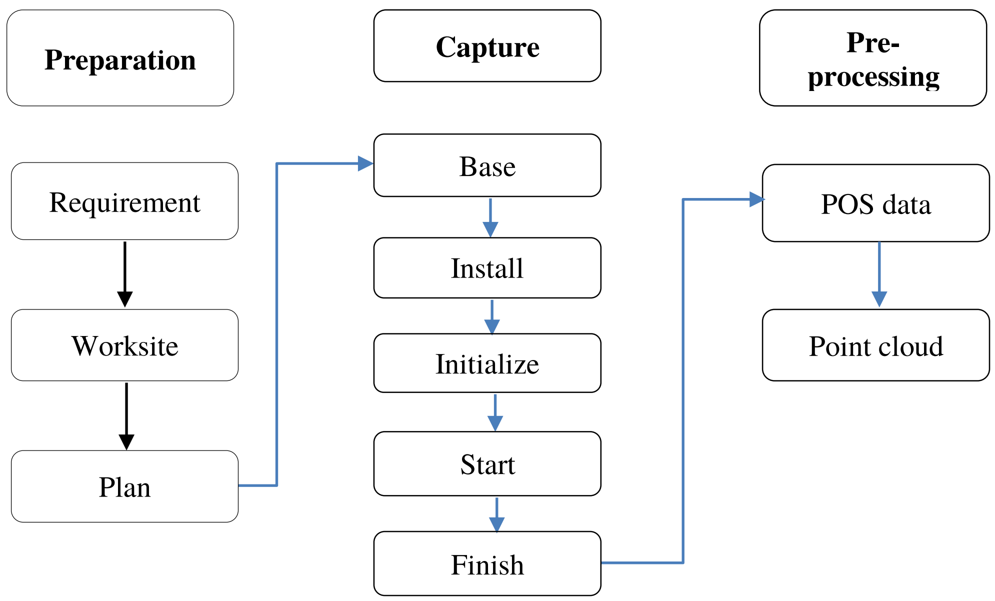

Figure 6. Operation procedure of AA450.

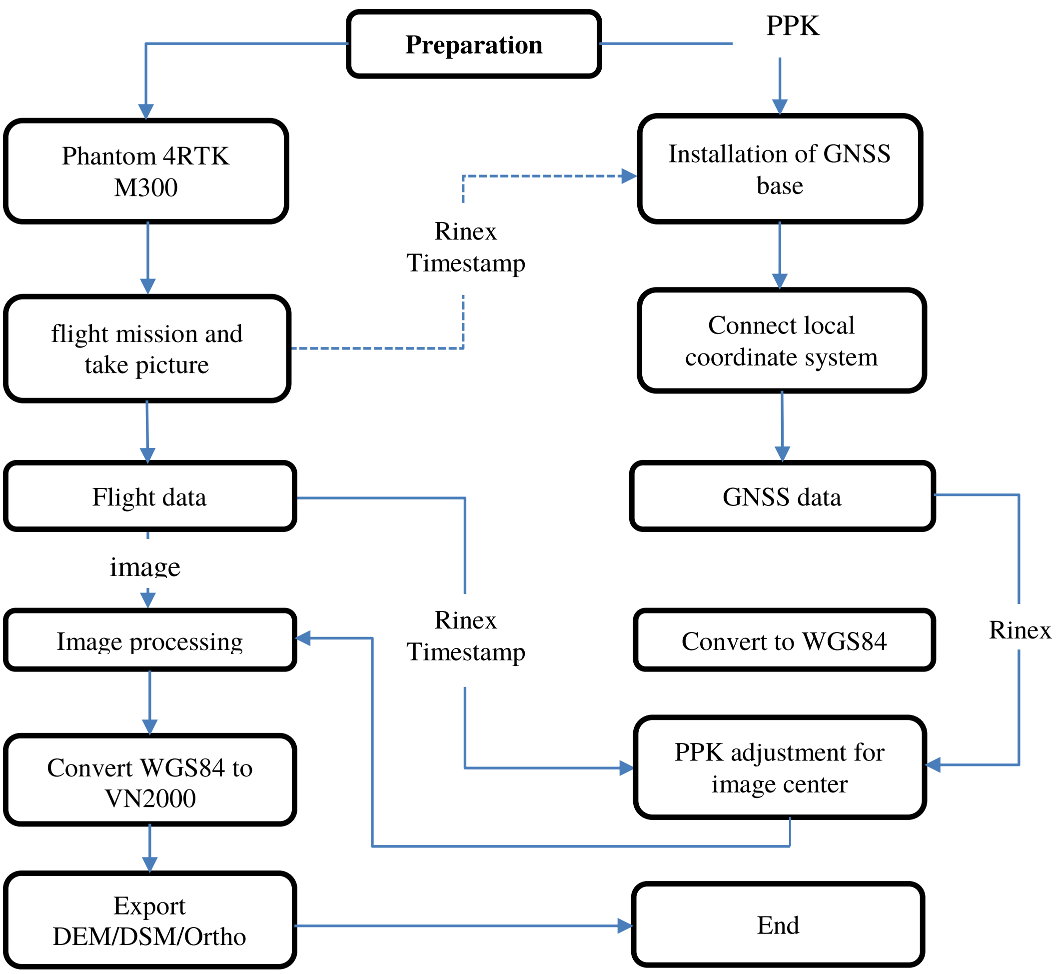

Figure 7. Operation procedure of Phantom 4RTK.

In Figure 6, the preparation segment is about 3-5 minutes, the time of the four first stages in the capture segment is about 10 minutes and about 20 minutes for each flight mission.

For phantom 4RTK, the procedure can be seen in Figure 7. GNSS static recording for the base station is a 5hz sample interval, the same as GNSS raw data in phantom 4RTK.

Preparation process including position collection, boundary area, and weather conditions…. Flight missions were carried out by DJI pilot on the controller at 2D flight for both Phantom 4RTK and AA450 Lidar on the M300 drone.

Captured data processing can be performed by Pix4D Mapper or Agisoft with data from phantom 4RTK. Comparing Pix4D and Agisoft, Agisoft seems easier than Pix4D [28,29]. However, Copre is an obligation to process scan and camera data from AA450

2.3. Methods of the study

Firstly, the UAV Phantom 4RTK solution is carried out at 100 m flight altitude, 2D flight mission, 80% is the overlap and side lap, and flight speed is 7 m/s. The image center coordinates are processed by the PPK method using CHC-CGO software and the image data are processed using Agisoft. The output data consist of ortho image, DSM (Tif format), X, Y, and Z data.

Secondly, the AA450 lidar is operated independently and carried on an M300 drone with waypoint design mode for flight missions, at 70 m flight altitude, overlap, and side lap is 40% for each, and the flight speed is 7 m/s as well. Scan and captured data are transferred to a computer using copy function of Copre software. The input data to process in Copre includes scan data, captured data, and GNSS base data. The output data of Copre consist of the adjusted image and point cloud data (Las format). The las files are input data for Coprocess data. The key role of Coprocess software is classification and filtering ground points.

Finally, Trimble R8s with single-base RTK solution are used to measure ground points in different positions in the survey boundary. Coordinate and elevation from GNSS-RTK mode will be as the original data to compare with X, Y, and Z data from UAV Phantom 4RTK and AA450 Lidar solution.

3. Experiment results

After processing image data from Phantom 4RTK and scan, camera data from AA450 Lidar, ortho, and point cloud were exported. (Figures 8, 9, 10, 11).

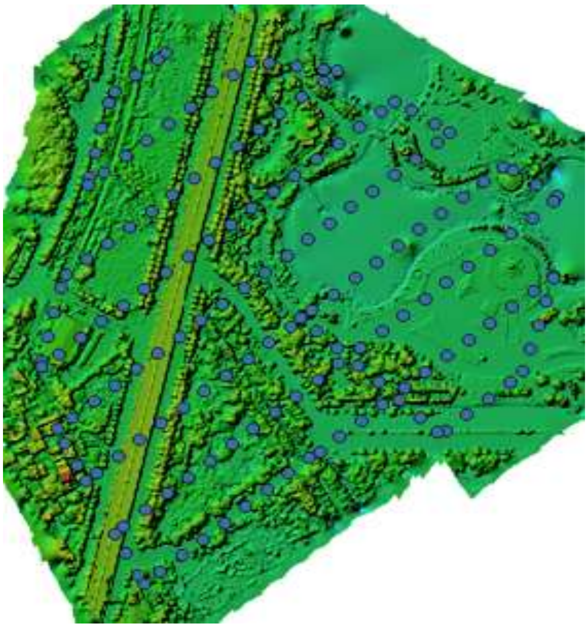

Figure 8. Flight mission on DEM.

Figure 9. Ortho from Phantom 4RTK.

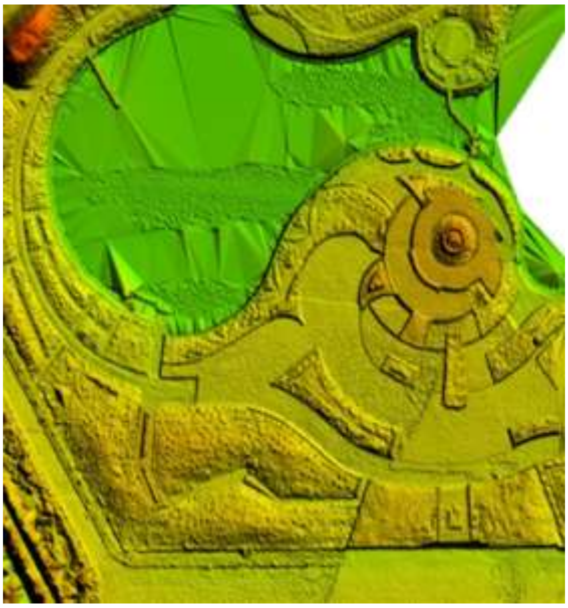

Figure 10. DEM from AA450.

Figure 11. Ortho from AA450.

The elevation of the GNSS-RTK points is compared to the elevation extracted from UAV and lidar solution as in the below figures.

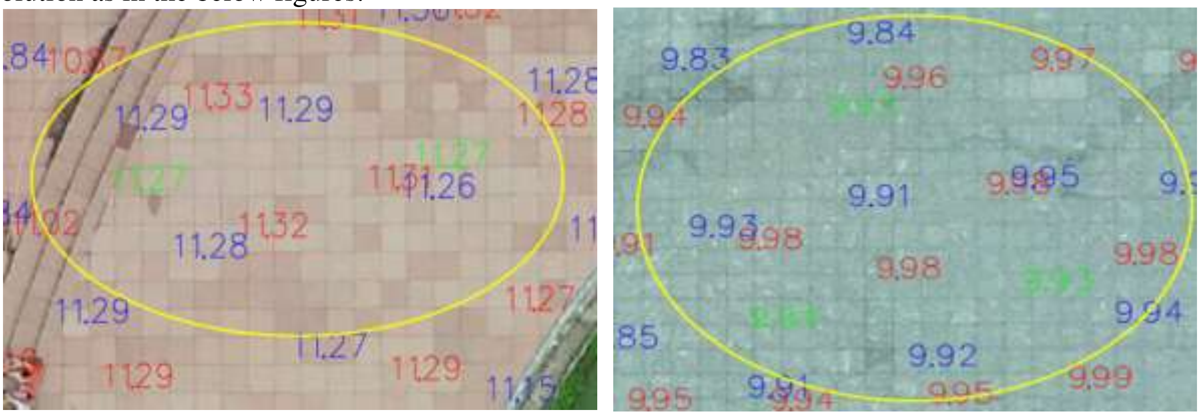

Figure 12. Elevation on the brick and concrete area.

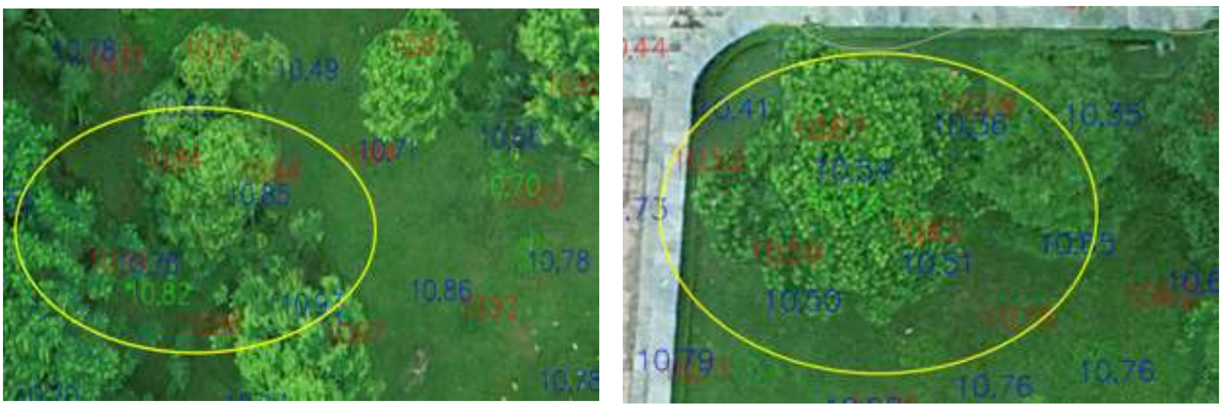

Figure 13. Areas of high canopy trees, sparse, no lower shrubs, no thick grass, visible bare ground.

Figure 14. Areas of high and thick canopy, no lower shrubs, no thick grass, visible bare ground.

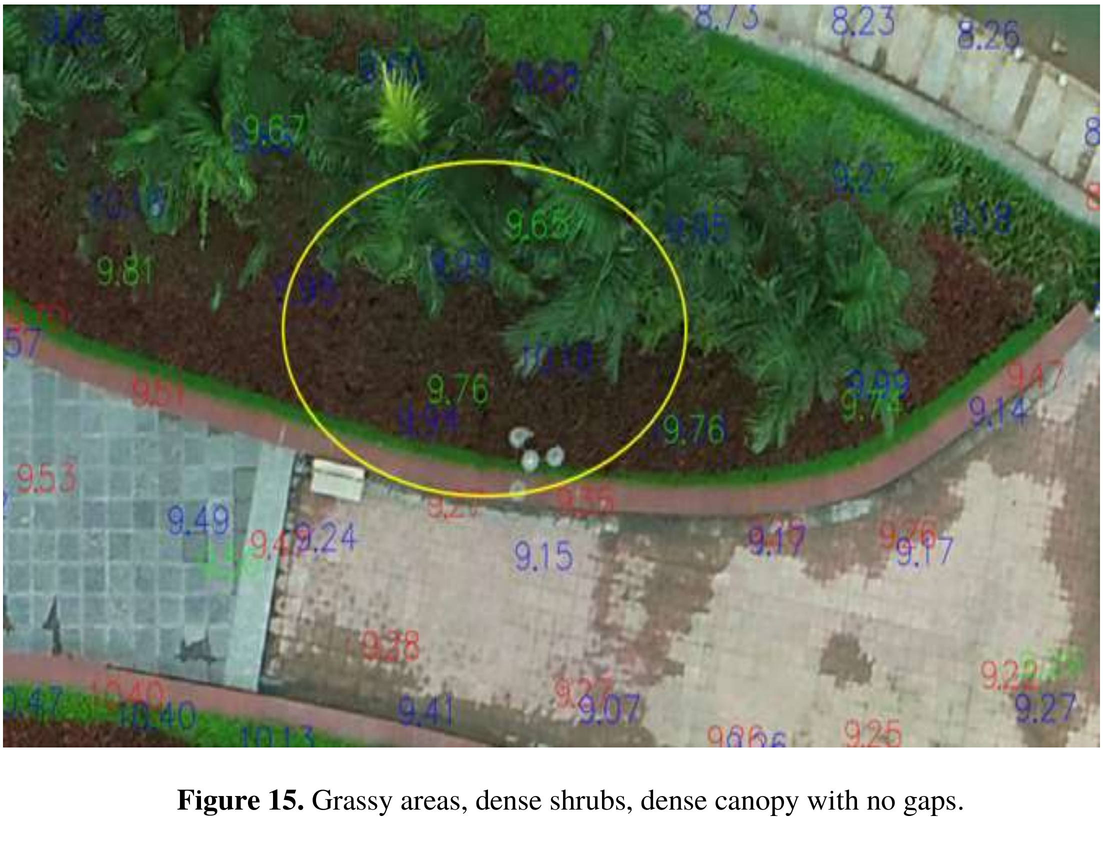

Figure 15. Grassy areas, dense shrubs, dense canopy with no gaps.

In Figures 12-15, green is the elevation of the GNSS-RTK solution, blue is the lidar solution, and red is from phantom 4RTK. As in Figure 14 and Figure 15, there is no elevation from Phantom 4RTK. Choosing the elevation of GNSS-RTK mode as the original elevation, the deviation between phantom 4RTK and AA450 Lidar are in Table 1.

Table 1. Comparing the elevation of phantom 4RTK and AA450 Lidar to GNSS-RTK.

Order	Areas	GNSS-RTK (originality)	AA450 Lidar	Phantom 4RTK
1	The open area includes concrete, brickyard, asphalt road	0	3-5 cm	3-8 cm
2	The areas of high canopy trees, sparse, no lower shrubs, no thick grass, visible bare ground	0	5-8 cm	10-15 cm
3	The areas of high and thick canopy, no lower shrubs, no thick grass, visible bare ground	0	8-15 cm	**Higher than 40 cm**
4	Grassy areas, dense shrubs, dense canopy with no gaps	0	**Higher than 30 cm**	**NAN**

4. Discussions and conclusions

The occurrence of AA450 is the hope of the surveyors to access ground points in challenging positions like under the tree or near the buildings, a new choice, and a competitor in the lidar market. In open locations, the accuracy of the AA450 Lidar is acceptable compared to its specifications. Especially, AA450 Lidar is the first integrated product line in the Vietnamese market.

There was no study on AA450 Lidar before but there was a similarity in accuracy assessment compared to the DJI L1 sensor in the previous research [30,31]. It is due to the same scanner for both AA450 and DJI L1 sensors. It is also indicated the success of the *all-in-one* solution in a mainboard (an integration of GNSS-camera-scan).

Taking a look at the results in Table 1, the results from AA450 lidar are always better than those from UAV phantom 4RTK. The difference between AA450 and GNSS-RTK may be caused by either noise from filtering ground points in Coprocess or from GNSS-RTK working mode. The GNSS-RTK method is significantly affected by the distance from the base to the rover station.

The study results provide an overview of the AA450 lidar solution in the survey and confirm that AA450 is a good replacement for normal UAV solution, an equivalent choice with the DJI L1 sensor. GNSS-RTK used single-base mode at a 10 Km distance in the experiment study, a very popular distance for RTK working mode but it takes time and is hard to get a fixed solution in some hard positions like under the trees. In general, GNSS-RTK is easy to use and fast to get coordinate information of the objects without complicated post-processing. However, it cannot provide a visual view of the entire survey area because measuring single points only.

The study also indicated the advantages and disadvantages of the existing solutions in the survey field. The UAV phantom 4RTK helps to reduce the working time in the field and provides a visual view of the entire survey area. The post-processing procedure requires a good computer and high technical manpower. There is a similar requirement with AA450 Lidar for post-processing even Copre and Coprocess need a much better computer than agisoft. The hugest advantage of the AA450 Lidar is accessing ground points in difficult areas like under the trees. The las files with million points can be classified, filtering for different purposes. Besides, the area of the study is small, and the kinds of terrain surfaces and flight altitude are not rich are the disadvantages of the study.

AA450 focuses on improving the performance of the entire project, not on ground points only. In general, these are the purposes of lidar solutions. Based on study results, the AA450 lidar accuracy is compatible with its catalog. In this study, AA450 Lidar was carried out with a 2D flight mission, the same as Phantom 4RTK. The study is the first ability assessment of AA450 Lidar in Vietnam and is the basis of product selection in surveying tasks

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