3D Surface Features Scanning System with UAV-Carried Line Laser

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Abstract. As one of the newest spatial information gathering methods, three-dimensional laser scanning technique is widely adopted in various fields due to its attributes of high accuracy and non-contact. However, currently, most systems of this kind are costly and with complex data post-processing requirements, which makes them not welcome enough for public usages. To deal with this, a novel terrain scanning system using line laser based on trigonometric survey is proposed. The system is capable of terrain data collection, data pre-processing, and 3D display. The data collection circuit is designed under Labview and PCL is applied for interface design. Collected data will be imported to the interface after pre-processing, thus providing the measured 3D terrain information. The experiment results show that the proposed system is capable of large area terrain scanning and display at a high speed and with low cost, and is more portable comparing to existing systems.

Keywords: 3D laser scanning · Trigonometric survey · Data collection
Point cloud · 3D display

1 Introduction

Recently, geospatial data is playing a more and more important role in social and economic development. As one of the newest spatial information gathering methods, 3D laser scanning is capable of obtaining 3D model of terrain and complex objects with attributes such as high accuracy, high initiative, high speed, and non-contact, which greatly reduce time and money costs [1, 2]. Most importantly, it achieves the digitization of real objects, thus allowing a transformation from analogue quantity to digital quantity and solving many digital information collections problems [3].

Currently, multiple companies has developed commercialized 3D laser scanning system, including Cyra, Leica, Riegl and I-SITE [4, 5], etc. As for airborne laser scanning systems, TopScan and Optech [6] are much stronger. Products from these companies are widely adopted for business usages. However, they are not only costly for the device and data post-process, but also heavy and complex to operate. In order to overcome these drawbacks, a novel airborne 3D line laser scanning system based on triangulation is proposed.

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The proposed system can be divided into three parts: point cloud collection, data pre-processing and 3D display interface designing. Images with laser projections are captured by CCD and transmitted to the ground base station through wireless image transmission. The signal will be processed by capture card and transformed into computers as digital signals. After using Labview and VS2015 to collect the data and display, the 3D model of object is then obtained.

One of the main contributions of the proposed system is to reduce the scanning cost and make the system more portable. Meanwhile, three-dimensional display interface is integrated to the system so that no extra processing software is required for observation. With the rapid development of unmanned aerial vehicle, the system provides an easier operated and cheaper system for 3D object modeling by combining the scanning system to the UAV.

2 UAV-Carried Scanning System

2.1 System Design

Considering that line laser scanning is faster than point scanning in imaging while reaching a further distance comparing to surface scanning, the proposed system applies trigonometric survey and line laser to obtain the depth image of a target object [7]. Figure 1 is the schematic diagram.

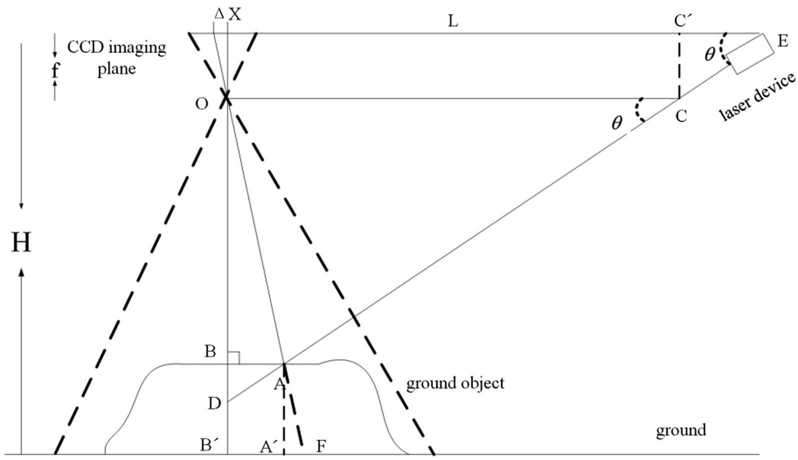


Fig. 1. Schematic diagram of trigonometric survey applied in the system.

Line ED is the light transmitted from the laser device. It is reflected by the surface of object A and imaging on the CCD imaging plane through the lens center O. Distance between point A on the image plane and the midcourt line of the image plane is Δx, level inclination of the laser device is θ, distance between the laser device and the midcourt line of the image plane is L, focal length of CCD lens is f, and height of the image plane from the ground is H. According to similar triangles, we have

$$\begin{cases} \frac{\Delta x}{BA} = \frac{f}{OB} \\ \frac{L}{BA} = \frac{L\tan\theta}{BD} \\ OB = L\tan\theta - BD \end{cases} \quad (1)$$

$$AA' = BB' = H - f - OB = H - f - \frac{fL\tan\theta}{f + \Delta x\tan\theta} \quad (2)$$

where AA' is the required object surface height. Using this method, the whole 3D model of the scanned object can be easily obtained.

Figure 2 is the structure diagram of the entire scanning system, which consists of data collection circuit, data pre-processing circuit, and 3D display interface. The first part is designed on Labview and achieved using hardware part, while the later two parts are mainly designed on Labview and Visual Studio respectively. Figure 3 is the flow chart of the hardware part of the entire system and Fig. 4 is that of the software design.

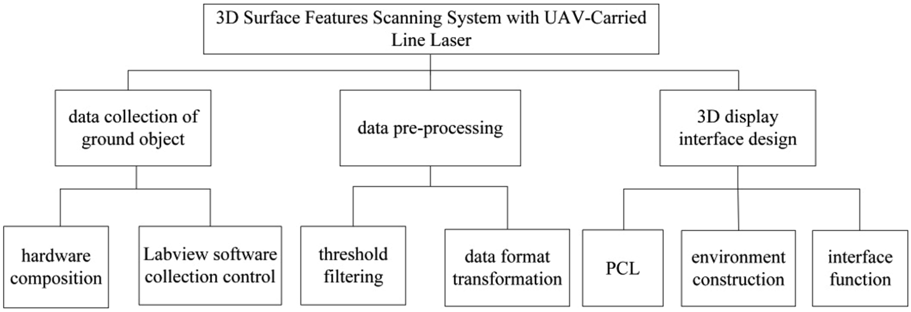


Fig. 2. Structure diagram of the entire 3D scanning system.

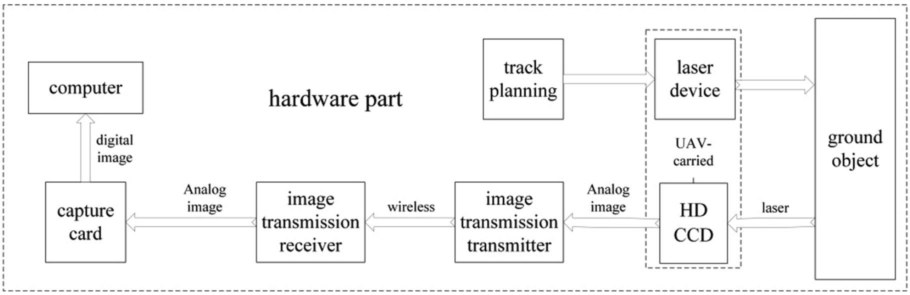


Fig. 3. Hardware part diagram.

CCD is installed on the UAV according to trigonometric survey and then is connected to the transmitter. The receiver is connected to the capture card and the computer. When the UAV is scanning according to the designed track, all pictures with laser lines captured by the CCD are live transmitted to the computer.

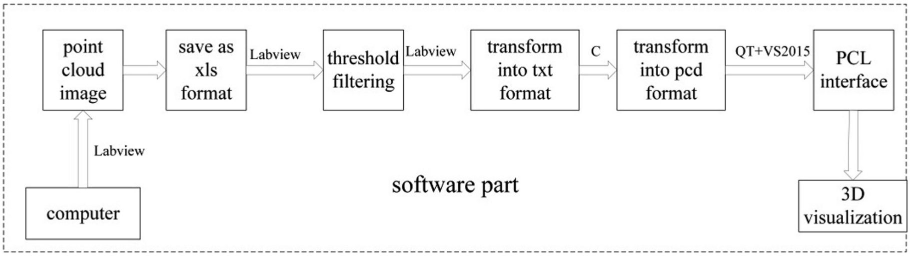


Fig. 4. Software part diagram.

After receiving the imported images, the system starts to move forward to the software parts which includes three parts: (a) Transform images into xls format point cloud based on Labview; (b) point cloud data pre-processing; (c) Display interface design using PCL. The whole processing part achieves the system function of 3D display of the scanned object.

2.2 Data Collection

The first part of the data collection procedure is the hardware of the scanning system, which is divided into two groups: onboard ones and on-the-ground ones. The former part includes UAV, one-wavelength laser, HD mini camera, optical filter, image transmission system (transmitter), and several 12 V lithium batteries. The later part contains image transmission system (receiver), capture card, and computer. Figure 5 is the system hardware part sketch map.

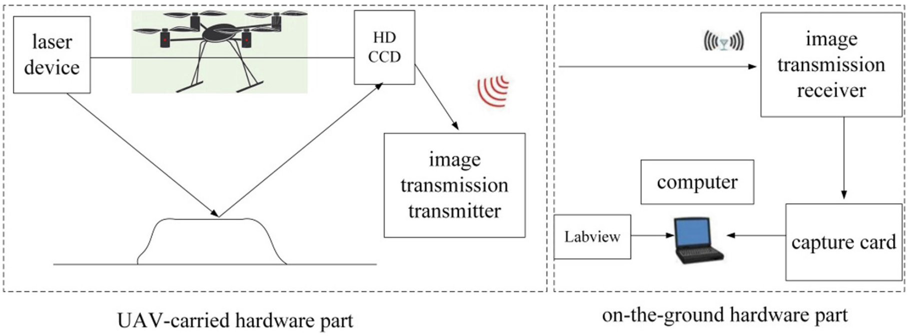


Fig. 5. System hardware part sketch map.

Data collection also involves software control which is reached by upper computer programming on Labview in the proposed system. Figure 6 is the flow chart of the whole procedure of image collection, processing and point cloud storage.

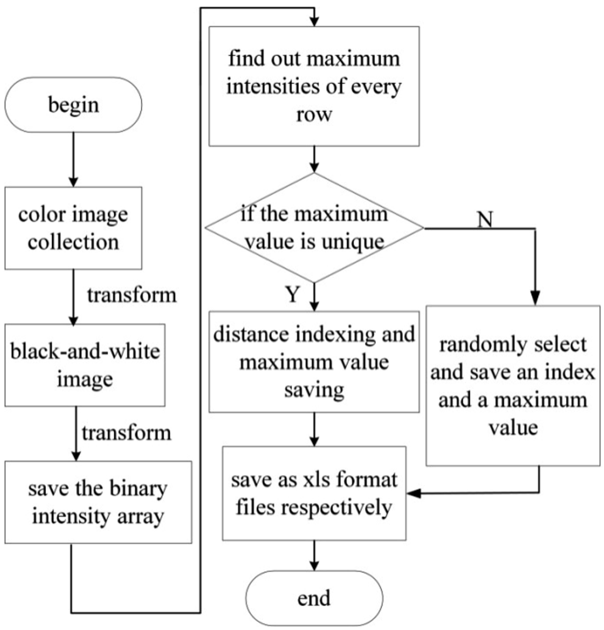


Fig. 6. Flow chart of image collection, processing, and point cloud storage.

For image capture part, color frames captured by CCD will be transformed into black-and-white images, and then be stored into queues as two-dimensional arrays. Object surface parts that are lightened by laser lines ought to have stronger intensity values comparing to the surroundings. As a result, pixels with maximum intensity values of each row are found frame by frame. If the maximum intensity of a row corresponds to more than one pixel, then one of them will be randomly selected and stored. This can be handled in the threshold filtering procedure. Finally, newly obtained arrays are stored in the format of xls as distance files and intensity files respectively.

Reasons for choosing the xls format are as follows: (a) Labview contains functions to specially process xls files, which makes the designed 3D scanning program much simpler and easier to achieve; (b) Data size of xls files are smaller than txt files of a same quantity of stored information which benefits online data storage, thus saving all experiment data without deadlocks caused by capture program; (c) xls format files can be transformed into txt files and help saving the point cloud in a format of (x, y, z), which is more convenient for further processing.

2.3 Data Pre-processing

Collected data contains information of all scanned surfaces and threshold filtering can be used to eliminate extra ones while saving the interested data. Size of the interested part can be altered by changing the threshold. Figure 7 is the Labview program for this part.

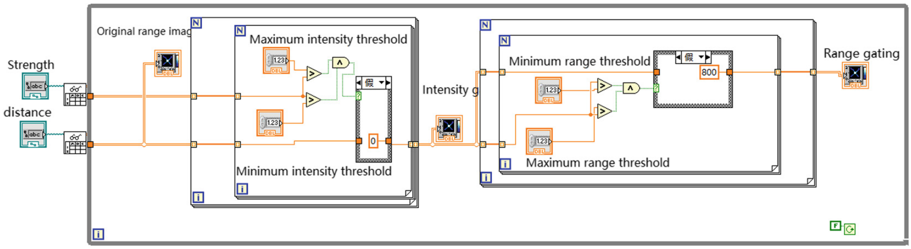


Fig. 7. Threshold filtering program diagram.

Threshold filtering contains intensity filtering and distance filtering. The intensity filtering do comparing between stored intensity values and the threshold. If the intensity value is greater than the threshold, the same position information as the original array will be saved; otherwise, the corresponding position will be set to a distance of zero. After gating the new distance array, the required object image is successfully obtained. Figure 8 is the scanned object, and Fig. 9 is the corresponding filtering result.

Fig. 8. Original image of the scanned object.

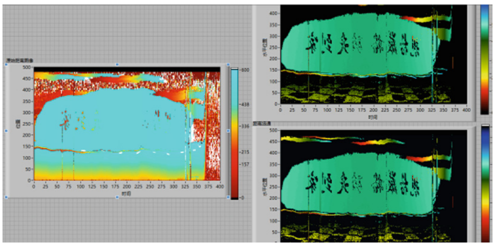


Fig. 9. Filtering results.

The left image is the original distance image; the upper right one is the intensity gating result and the bottom right one is the distance gating result after intensity gating. It is clear that filtering results are better than the original image.

The designed software requires pcd format inputs. As a result, the collected and filtered xls format data need to be transformed before using the interface. First, xls format data is transformed into txt format. Figure 10 is the transformation Labview program. Each case in xls refers to a distance value z. If the rows and columns are stored as x and y, then all data will be restored into a format of txt as (x, y, z). The new txt file is two times larger than the original xls file. Secondly, the txt file is transformed into a final pcd file using PCL functions based on VS2015 [8].

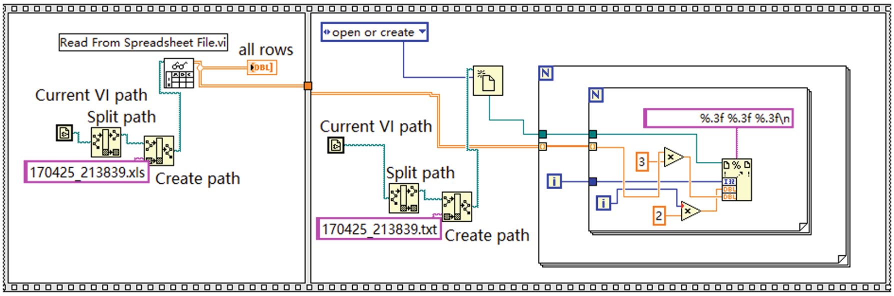


Fig. 10. Transform program from xls format to txt format.

2.4 Display Interface

Point Cloud Library, along with VS, QT, and VTK, is used for display interface design. VTK is applied for point cloud 3D display, PCL for core algorithms and data input/output, and QT for interface layout design. The programming language is VC++ under VS2015. The combination of those greatly improves the performance of the designed interface. It can read point cloud, do filtering, achieve curve planar reconstruction and human-machine interaction. The interface frame is shown in Figs. 11 and 12 is the display result of the mentioned object.

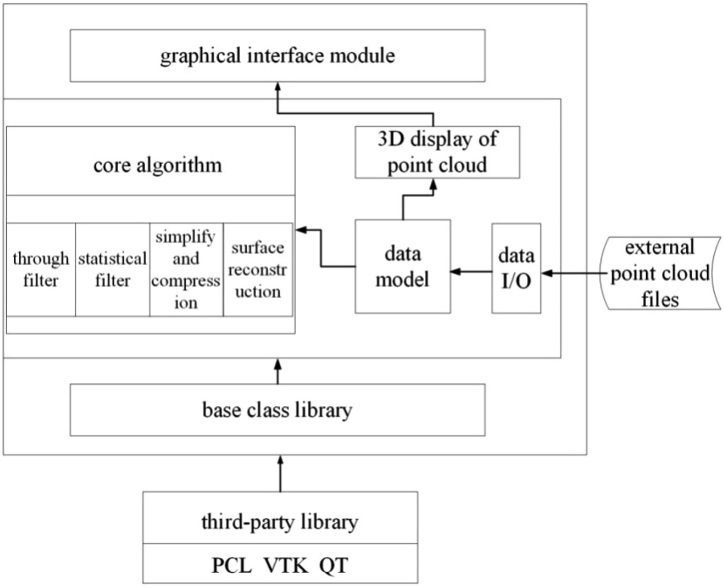


Fig. 11. Designed interface frame.

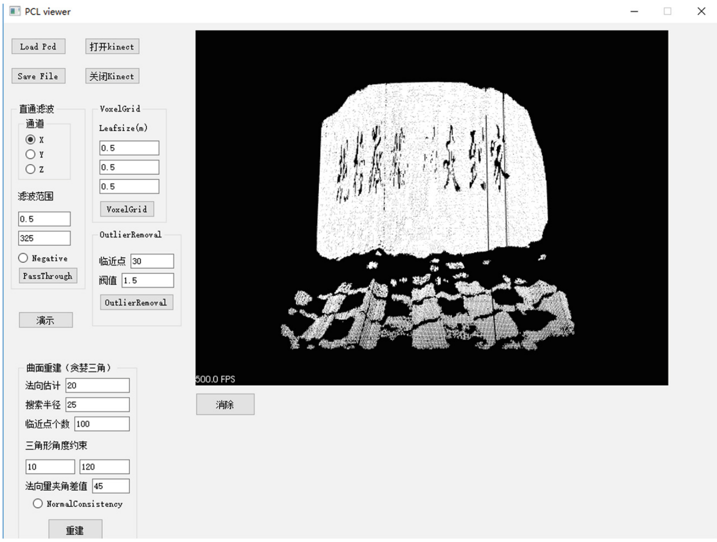


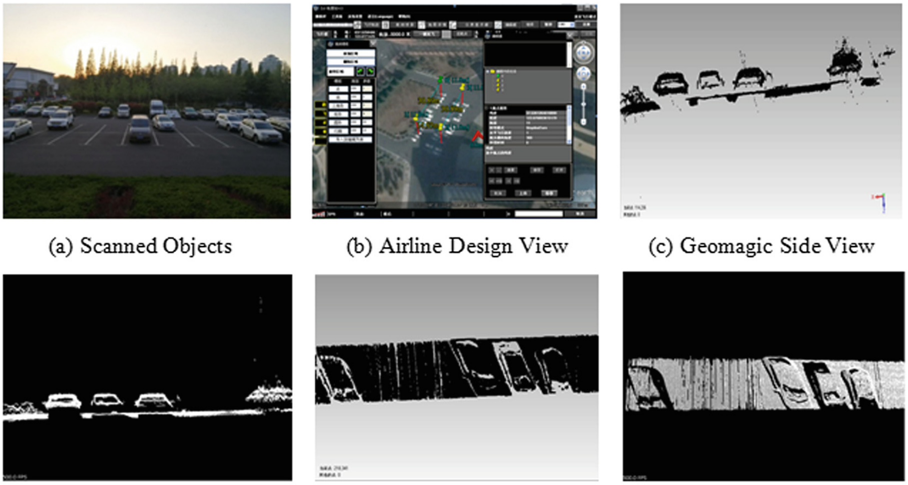
Fig. 12. Display result.

3 Experiment

The laser device used in experiments is 200 mw 532 nm green line laser. Lens focus of the HD mini CCD is 6 mm. Other hardwares are 5.8G image transmission transceiver and drive-free capture card. The experiment is carried out at night in a school parking and the scanned object is the parked vehicles. There was a south wind of force 2 to 3. Designed air lines are two parallel lines at a height of 11 m. Figure 13 shows the scanning results.

It is clear that point cloud collected by the proposed system is capable of revealing the outlines of the scanned vehicles, especially for details like the rearview mirrors and the car windows. This indicates that the proposed system performs desirably in high-quality data collecting. As for the point cloud display, comparing to Geomagic, the proposed PCL interface describes the object features more clearly and intuitively, and its displayed images are more similar to the original appearance of the scanned objects. As a result, the proposed PCL interface is betterin collected data display.

Above experimental results shows that the proposed UAV-carried 3D line laser scanning system is capable of wide range ground object information collection and 3D display of the collected data. The experiment results verified the correctness and rationality of the proposed system.



(a) Scanned Objects (b) Airline Design View (c) Geomagic Side View

(d) PCL Side View (e) Geomagic Plan View (f) PCL Plan View

Fig. 13. Experiment results.

4 Conclusion

As a modern non-contact high accuracy sensor technology, airborne 3D laser scanning technology can directly obtain the 3D information of various real objects and surroundings, thus having more advantages that cannot be achieved by traditional surveying instruments. In this paper, a novel triangulation-based UAV-carried 3D laser scanning system for ground objects is proposed, which can achieve both data collection and display. Comparing to existing methods, the proposed system is capable of wide range scanning and is smaller, lighter, simpler, cheaper and easier for post-process. The experiment results indicate that the system can also be enhanced by applying CCD with higher resolution ratio and wireless image transmission. These improvements will be done in the future.

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