What laser scanning can do today : Current Techniques

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ABSTRACT

The main goal of this paper is to give an insight in what is going on in the field of laser remote sensing with a particular focus on airborne scanning techniques. We shall give an overview of different laser scanning techniques used in remote sensing. A classi-fication proposal will be introduced. The performances of some airborne laser scanners will be shown in a table. A brief comparison between two main representatives from laser scanning techniques will be done. The results will be shown in the corresponding tables.

INTRODUCTION

In fact, the laser has become widely used since the 60's. We can see a wide range from a compact (pocket-size) laser pen used for pointing by a teacher up to the eye surgery and satellite navigation. The recent develop-ments in the field of the laser technology have resulted in its increasing application in a variety of human activities: imaging, machinery, medicine, geodesy, multimedia etc.

A particular area of applications is Remote Sensing. In general, Remote Sensing is defined as a technique which allows to perform indirect measurements of any features of an object which is far away from an observer. From the point of view of the remote sensing data user, it is usually desirable to obtain required information as rapidly as possible from areas as large as possible. Laser beam scanning techniques are used for such purpose. Their number has been increasing in the last ten years.

Unfortunately, there has been delay in the wide employment of laser scanners for remote sensing purposes. They began to appear on the market only a few years ago. It is obvious that the interest in commercial application of laser scanning in different areas has been significantly increasing in the last ten years. There have been various research projects carried out by both academic and commercial organizations throughout the world.

1. THE CLASSIFICATION

There is a number of laser scanning techniques which found their applications mostly in the airborne sector, and even more simple would be used on-board a spacecraft.

The laser scanners used can be divided in two main categories, depending on the measurement principles. These categories and corresponding names of scanning techniques are shown in Figure 1:

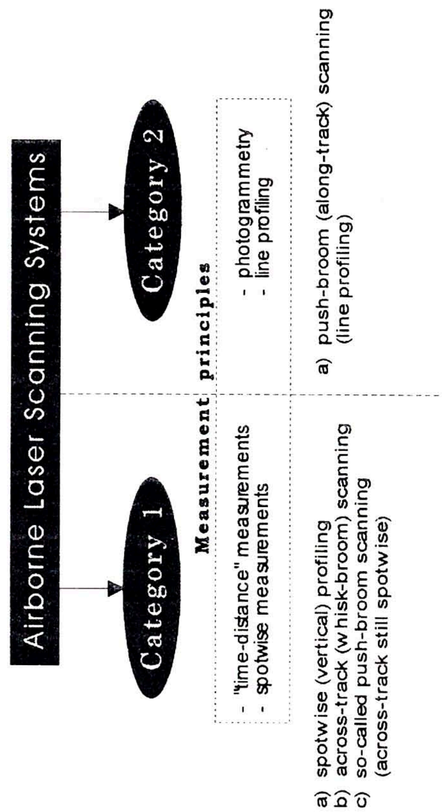
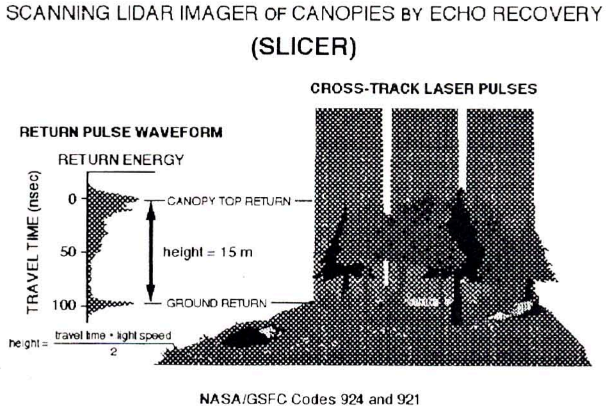


Fig. 1. *The classification of airborne laser scanners used in remote sensing today*

Thus, there are two main categories of airborne laser scanners. The operation principle of Category 1 is based on laser radar technology. It is based on the "time-distance" measurement. A laser light source shoots a pulse toward a target. The distance between the target and the transmitter is defined by the time the pulse travels between the carrying platform and the object. It is illustrated by Figure 2.



(http://ltpwww.gsfc.nasa.gov/eib/slicer.html)

Fig. 2. *The principle of a pulse distance measurement*

Category 2 is realized in only one system today which was initially called *Airborne 3-D Profilometer* [1]. The main idea of this remote sensing instrument is to use a laser-CCD camera combination on board a helicopter/ aircraft.

The laser illuminates a line on the ground beneath the carrying platform. The video/CCD camera is installed at a distance from the laser and used to acquire images of the reflected laser line (see Fig. 9). Applying conventional photogrammetric equations, the pictures are corrected and rectified by integrating with GPS/INS data. After that the line is extracted directly from the images and its shape represents the shape of the object which would be measured automatically. This will be explained by illustrations below.

2. AN OVERVIEW OF DIFFERENT AIRBORNE LASER SCANNING TECHNIQUES

The first airborne laser scanners were quite simple. Actually, a laser rangefinder was installed on board a helicopter/aircraft which emitted the pulse downward to the ground surface. Such scanning technique was called *spotwise vertical profiling,* also simply known as *laser profiling*. Figure 3 shows a corresponding pattern which the laser footprints form on the Earth's surface.

One example of the acquired information is shown in Figure 4 which illustrates the vertical profiles of canopies and ground topography.

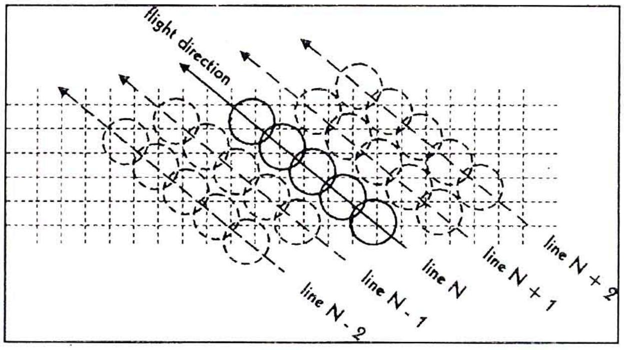
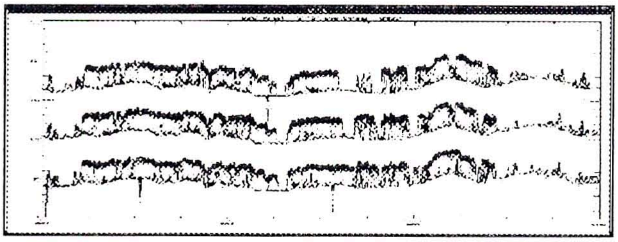


Fig. 3. *The ground pattern of illuminated spots in the case of spotwise vertical laser profiling*



(http://ltpwww.gsfc.nasa.gov/eib/slicer.html)

Fig. 4. *A sample data plot showing the topography and canopy density*

However, the end user still wants to survey large areas, while the laser rangefinding profiler provides only a single line below the aircraft. To speed up the survey systems have been designed and made in which the laser beam is swept across the flight line. This is *across-track* or *whisk-broom scanning*. This type of scanner is mostly used in remote sensing today. It is routinely used for surveying, mapping and hydrological purposes.

By scanning the laser beam across the flight line, a narrow swath is created. Figure 5 shows an example. Usually, the scan width is in the order of ±5° - 20°, equivalent to ±20 - 300 m, depending on flight altitude and on the acceptance of shadowing effects.

The laser footprints are geolocated by combining the measured distance with aircraft position, obtained from a (differential) GPS (Global Positioning System), and directional pointing knowledge, obtained from an Inertial Navigation System (INS). The most significant representatives of this type of the airborne laser scanners are ALTM-1020 (Canada), and TopEye and HawkEye (Sweden).

Further developments in this area resulted in an advanced airborne laser scanner which appeared on the market only few years ago. This is so-called *push-broom scanning* or, in the other words, *across-track still spotwise*. It is still based on the "time-distance" measurement principle. Its operation idea is illustrated in Figure 5.

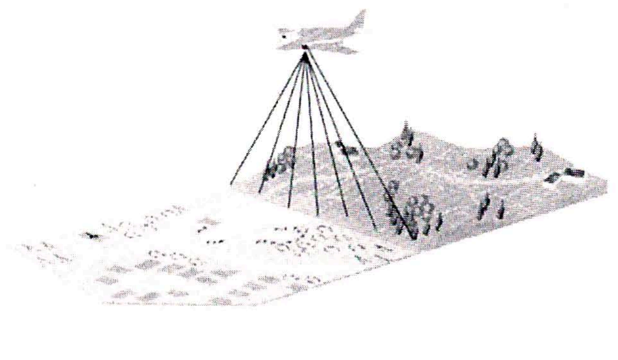


Fig. 5. *So-called push-broom (along-track) scanning (Courtesy of TopoSys)*

This system produces singular, non-repeatable distance measurements. A corresponding ground pattern is shown in Figure 6.

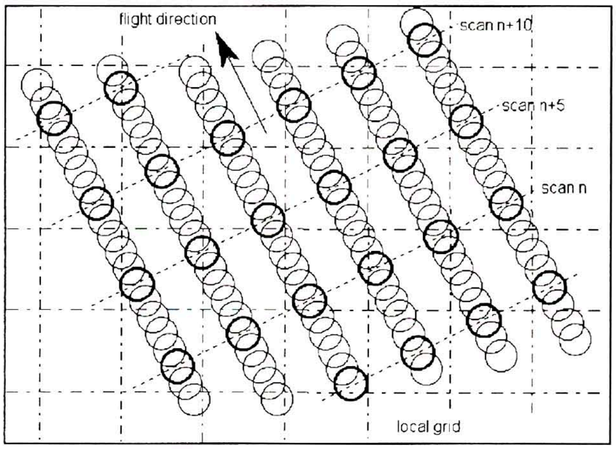


Fig. 6. *The ground pattern made by TopoSys system which represents so-called push-broom or, in the other words, spotwise still across-track scanning technique (Courtesy of TopoSys)*

Furthermore, the hardware configuration differs from that which is used in the traditional across-track scanners. It was designed so in order to provide robust image geometry. One of the main departure points of the designers was the question where a signal reflection comes from (i.e., a tree's branch, a lamp pole or the ground). It is difficult to interpret the results if the measurements are distant from each other. Thus, In the case of the TopoSys the distance between neighbouring scans is only about 0.15 m resulting in an average of four measurements per m². In addition, the high measurement density (currently up to 80.000 pulses per second) allows the extraction of break lines and other surface features.

In many cases these airborne laser scanners are capable of delivering sufficient information from wide areas, even covered by vegetation. They would be employed for Digital Elevation Model / Digital Terrain Model production, 3-D city modelling, urban planning, power line survey and planning, shoreline control etc. One such example is given in Figure 7.

Fig. 7. *Outlines of the buildings (Courtesy of TopoSys GmbH, Germany)*

As has been mentioned above, one particular area of laser scanning applications is 3-D city modelling. With the above mentioned airborne laser scanners, the end user still acquires a large number of separate spots.

It has been reported by Dr. Lohr from TopoSys GmbH, the "with respect to their geometric orientation the measured spots are independent from the local geodetic survey system and still have to be transformed into the target co-ordinate system. This transformation requires a data resampling which might be done either by an interpolating technique or by the nearest neighbour method. Depending on the density of the measurement spots and the width of the target grid, the resampling will cause position and elevation errors which can only be ignored for plain and unstructured surfaces. For high quality DEMs resampling errors must be minimized - which means that there should be at least two times more measurements available than needed for the target grid."

For this reason, in order to provide highly reliable 3-D terrain models and based on a pilot system [1], an Airborne Laser 3-D Imaging System (ALII-3D) is proposed [2]. ALII-3D is a further development of a scannerless (no moving mechanical parts) airborne laser scanner which still belongs to Category 2. The idea is illustrated in Figure 8 below.

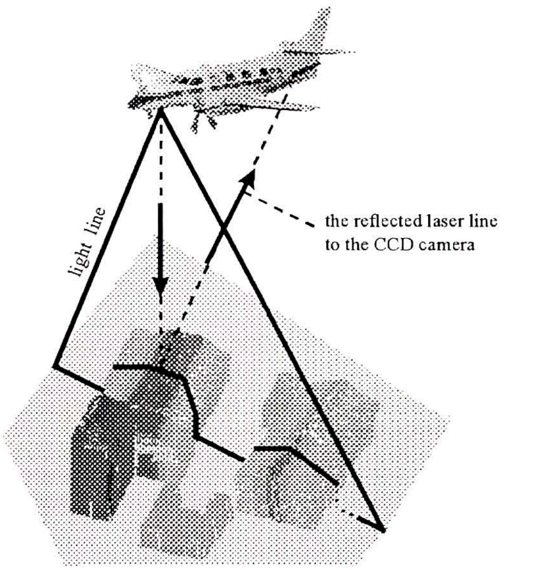


Fig. 8. *Such a remote sensing system is a combination of the laser line generator and the video/CCD camera installed on board a flightcraft. They are apart from each other so that the required imaging geometry is defined. (The 3-D city model shown was generated by Olli Jokinen, HUT / IPARS, from the data collected with the IPARS's digitizing system and using Matlab)*

Instead of the previous systems, this instrument creates the lines on the terrain if we look beneath the aircraft (Fig. 9).

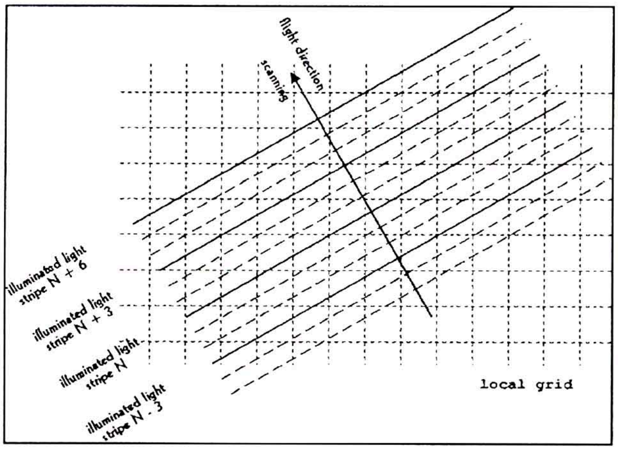


Fig. 9. *The footprint pattern is formed by the laser lines in the case of ALII-3D*

Data processing is illustrated by Fig. 10.

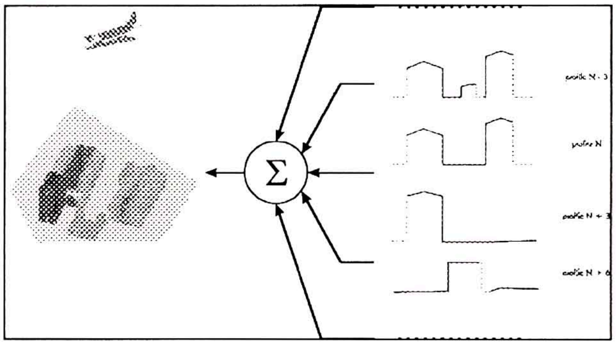


Fig. 10. *The 3-D object model is made from the successful profiles collected from three different directions. Matching and filtering is used.*

As the 3-D terrain model is considered and two different elevation data acquisition methods would be applied for the model making, it is desirable to compare these methods. Usually GPS/DGPS is used to determine the position of the aircraft in the defined coordinate system. It means that we know exactly only those geolocated laser footprints which have been recorded at the same time when a GPS pulse was transmitted/ received. Therefore, the position of the other shots is unknown. They have to be interpolated. In turn, the final accuracy of the measurements and terrain models is very dependent on how many laser footprints are defined in the terms of GPS. The following tables give some numbers that may be of interest.

Table 1. *The percentage of the footprints whose position is known due to the GPS measurements (vertical - the number of GPS pulses; horizontal - the number of the sent laser pulses)*

	2.000	5.000	10.000	80.000
1	**0.05 %**	**0.02 %**	**0.01 %**	**0.00125 %**
10	**0.5 %**	**0.2 %**	**0.1 %**	**0.0125 %**
20	**1.0 %**	**0.4 %**	**0.2 %**	**0.0250 %**

It is obvious that, for example, if we want to generate a 3-D city model, a better accuracy and more reliable model would be achieved by using ALII-3D which belongs to Category 2 and represents the laser push-broom scanning.

Table 2. The percentage of the footprints whose position is known due to the GPS measurements (vertical - the number of GPS pulses; horizontal - the number of the illuminated laser lines according to the frame rate of the CCD camera)

	25	50	100	200
1	**4 %**	**2 %**	**1 %**	**0.5 %**
10	**40 %**	**20 %**	**10 %**	**5 %**
20	**80 %**	**40 %**	**20 %**	**10 %**

3. THE PERFORMANCES OF THE SYSTEMS

Some information currently available on the performances of airborne laser scanners are presented in the following table.

Table 3. *The performances of airborne laser scanners*

	TopoSys	TopEye	ALTM 1020	Hawk Eye	Airborne 3D profilometer
flight altitude, m	< 1000	60 - 500	330 - 1000	300 - 900	7 - 15
pulse repetition rate, Hz	80.000	6.000	65-5000	2.000	CW
scan frequency, Hz	600	5 - 25	30 - 50	9	----
swath width, m	250 at 1.000 m	36 at 100 m	680 at 1.000 m	100 at 150m	5 at 7 m
max. Test resolution (x,y,z), m	0.3; 0.3; 0.06	0.2; 0.2; 0.2	0.2; 0.2; 0.01	1.0; 1.0; 0.3	z = 0.2
flight speed m/s	70	10 - 25	25 - 70	5-100	9 - 14
weight, kg	100	300	57	350	≈ 20

4. THE RESUME

Thus, we have considered airborne laser scanning techniques which are used today for different kinds of surveying. The airborne laser scanners have been grouped in two general categories depending on the operating principles. All laser beam scanning techniques presented in Figure 1 have been briefly discussed. Table 3 displays data about the main performance of the airborne laser systems in use today.

Table 4. *Comparison between two categories of airborne laser scanners*

	Category 1	Category 2
	an average airborne laser scanner	ALII-3D
flight speed, m/s	10 - 70	10 - 50
flight altitude, m	100 - 1.000	30 - 100
swath width, m	25 - 68 at 100m	30 - 100
Z accuracy, cm	10 - 30	10 - 30
cost, á FIM	4 mill.	< 300.000

Thus the considered laser push-broom and across-track scanning techniques have the following advantages and disadvantages.

<u>Advantages:</u>

- push-broom scanning
  - very simple configuration
  - no scanner needed
  - no moving parts
  - only off-the-shelf components required
  - easy to install and operate on board
  - the accuracy of the z-component comparable with the accuracy achievable by the laser spotwise measurements
- across-track scanning
  - the-state-off-the-art technology
  - the high flight altitude
  - the high flight speed
  - the high point density per m^2
  - the accuracy of the height is about 10 - 30 cm
  - already available on the market

<u>Disadvantages:</u>

- push-broom scanning
  - the low flight altitude
  - lower flight speed
  - still under the development
  - a huge amount of data to store and to process, because of the large size of the video frames
- across-track scanning
  - the system is complicated
  - delivers a less reliable geometrical information compared to the laser line profiling (Tables 1 and 2)
  - the high cost

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[3] **Samberg, Andrei** *et al.* Airborne scanning laser systems: generating digital terrain models in near real time. Special report for The Third International Airborne Remote Sensing Conference and Exhibition (July 7 - 10, 1997, Copenhagen, Denmark), 66 p.