COMBINING LIDAR AND PHOTOGRAMMETRY FOR URBAN AND RURAL LANDSCAPE STUDIES

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ABSTRACT

There is a growing availability of data from airborne laser ranging (LiDAR) as the potential use of these systems is more fully exploited and appropriate applications are discovered. The basic product from LiDAR is a digital surface model (DSM), the surface being defined by the point of reflectance of the laser beam. DSMs have been a standard product from photogrammetry for many years using analogue, analytical and digital techniques. Analytical photogrammetry enabled semi-automated methods where as digital photogrammetry has produced fully automated techniques of DSM measurement, once the stereo pair of photographs are appropriately orientated. Photogrammetry and LiDAR are different technologies and have different measurement characteristics and therefore have different potential uses. They can be seen as independent systems and in some instances, can produce an equally useful DSM for certain applications. Alternatively they can be combined to enhance each other's DSM and provide additional capabilities for particular applications. The relationship between LiDAR and photogrammetry has not been fully exploited and there is significant interest from a wide range of environmental scientists and engineers in this area of research. This is reflected by the fact that the authors of the paper come from surveying, engineering and geographical backgrounds.

1 INTRODUCTION

With all new technologies their role and relationship with existing perhaps, well established techniques has to be determined. Photogrammetry is a well established technique for digital surface modelling. Analogue photogrammetry provided methods for DSM generation by the observation of strings of 3D points, random distributions of height points, and grids of height points. In addition it provided a very efficient method of contouring perhaps, the most common and traditional form of showing variations in the shape of the land surface. Analytical photogrammetry provided potential increases in productivity and quality of these products. Certain tasks also became semi-automatic or even automatic. Image correlation techniques using patches of digital images from the analytical plotter optics enabled the development of automatic heighting techniques. The availability of digital images soon brought developments in automated DSM, many methods of image correlation were developed and are still being refined. This automation has brought very significant productivity gains and much research has taken place to not only develop the optimum algorithms but also test the quality of the final DSM (Smith et al., 1997).

Airborne laser ranging for surface modelling has really only been achievable to high accuracy with developments in determining position and orientation of the laser. The positioning and orientation of the laser has been dependant on the quality of GPS positioning and inertial measurement units (IMU) ability to measure position and attitude. The integration of these systems has further enhanced the quality of these measurement techniques. The advances in this field have been stimulated by the reduced cost of suitable equipment making it a more economically attractive and viable system.

Fundamentally the DSM measurement techniques by photogrammetry and by LiDAR are different. Digital photogrammetry uses images captured on photographic film/emulsion. These images are then measured and computations are performed using stereoscopic and perspective geometry to enable a height value (3D coordinates) for a point on the ground to be determined. LiDAR works on the direct measurement of range using a laser, from a known point in a known direction determined by GPS and IMU techniques.

Before, the DSMs from either technique are used, it is important to assess the quality of the measurements. To do this it is important to understand the principles of each technique. A fundamental question to be answered is "what surface is being measured?" In addition to the determination of heights it is important to compare what other information is available for example, a photographic image is available for interpretation if photogrammetry is used.

This paper will present a brief background to the technique of automated DSM creation by digital photogrammetry with particular reference to the influences on the quality. This will be followed by a description of LiDAR as this is perhaps less well known. A discussion is given on the possible quality of a LiDAR DSM with reference to some examples of applications. Some conclusions will be drawn and future plans for this project will be proposed. The poster presentation will show results obtained so far from the trials undertaken at Nottingham where a test site has been established.

2 DIGITAL PHOTOGRAMMETRY

2.1 Digital images and DSM generation

Although there are scanners that can provide digital images they have often been developed as a multi-spectral sensors for remote sensing applications, not for the more traditional mapping purposes. The push broom type scanners create images with perspective geometry across track and the accumulation of scan lines along track. These sensors have had their mapping potential improved by the integration of GPS and Inertial Navigation System (INS) (Shukla, 2000). However, most digital images for photogrammetric applications use scanned standard aerial photography. The DSM that is created from this imagery is defined by what is captured on the traditional film. This in turn is dependent on the type of film used. This is normally film capturing the visible spectrum as opposed to for example, infra red film. The type of film is the first of numerous influences on the quality of the resulting DSM. The choice of camera, if there is one, will be partly dependent on the lens principal distances available. The automatic generation of a DSM by digital photogrammetry is then going to be dependant on the choice of a number of parameters some are basic and are like the choice of film and camera, they are perhaps going to affect all image matching algorithms. Other parameters are dependent on the type of matching algorithms used. The following is a list of some of the basic parameters which influence the quality of DSM:-

Camera	Scale of photography
Film	Image band used (red, blue or green if using colour photography)
Scanning resolution	DSM grid spacing
Type of terrain	Image quality

The parameters that directly control the image matching algorithms for example in ERDAS IMAGINE OrthoMAX (1995) include the following :-

Minimum and maximum template size	Minimum precision
Maximum parallax	Rejection factor
Minimum threshold	Noise threshold

The parameters affect the DSM in different ways for example, a number of these parameters have an effect of smoothing the DSM created (Smith et al., 1997). Even with a very fine grid spacing some of the sharpness of features will not be retained. This could be particularly important in urban studies where building outlines are important. However, the DSM is not the only information that is available as there is also the image itself which can be processed to extract further information. These various forms of information can be analysed by the use of image processing tools or GIS to assist in understanding the landscape.

3 LIDAR TECHNOLOGY

LiDAR stands for "Light Detection And Ranging". The use of this technology from aircraft for ground height measurements goes back to the 1970's. However, it hasn't been involved in commercial applications until the last few years. It has both sounding and ranging remote sensing applications. In the sounding application, the back scattering properties (reflection) of laser can be applied in atmospheric studies (Rees, 1990). However, the ranging method is involved in measuring the distance between the sensor and an object by determining the time delay between the transmission of a light signal towards the object and the reception of it by the sensor on its return from being reflected by the object. LiDAR employs Laser light for profiling and is based on the ranging method. It can be operated from the ground and from moving platforms such as a boat, a helicopter, and an aircraft as well as from a spacecraft. The output from airborne use of this technique is a digital surface model (DSM) which is useful in many environmental applications.

3.1 Laser Background

Laser is an established technology and acquired its name from the first letters of the expression “Light Amplification by Stimulated Emission of Radiation”. It is light but more intensive and more concentrated than any natural light. While white light from different sources such as the sun, lamps or flash light spreads out as it travels, a laser does not disperse much as it travels. Also, laser is a monochromatic light with a theoretical unique wavelength and refers to a specific colour of the electromagnetic spectrum. It can be focused to a very thin beam of diameter reaching 0.001 inch. Moreover, it can be controlled as a continuous beam or pulses with widely varied abilities ranging from boring holes in the hardest materials to being used in performing very soft surgery operations (NASA, 1999).

Lasers are classified in different ways (Measures, 1984). They can be distinguished with respect to the duration of emission into pulsed or continuous lasers. They are also, categorized by their wavelength into infrared lasers, visible lasers and ultraviolet lasers. In addition, they vary due to the power of the beam. Moreover, a traditional classification is due to the type of the material of the gain medium, the energized substance that can amplify the light beam. This leads to having solid state lasers, gas lasers, liquid or dye lasers and semiconductor lasers.

3.2 Airborne Laser Scanning

Airborne laser scanning exploits the LiDAR technology in measuring ranges from an airborne platform to ground objects which reflect the emitted laser beam. The laser pulse used can be sufficiently sensitive to pick up tops of trees and the ground surface, sending back a ‘double’ pulse that has obvious advantages in some applications such as forestry. The system includes a scanning unit, which has the ability to change and control the direction of the emitted laser that pulses a large number of times per second. There is also a timer unit with the system which has the capability to measure the time of delay of each signal starting from the moment of emission of the laser pulse till the moment of the reflected signals reception. This time is accurately measured with a resolution of 1.0nsec. For the profiling purposes, the ground object co-ordinates have to be determined and this is needed at every time of pulsing. This process requires the laser position and the attitude angles of each laser pulse to be accurately measured. Therefore, the system has to include a positioning unit and a unit for measuring attitudes beside the laser system. The whole system comprises of the following main units (figure: 1):

1) A Laser scanning and cooling unit.
2) Global Positioning System (GPS) receivers with antennas mounted on the platform and at ground stations.
3) An Inertial Navigation System (INS) unit.
4) Data storage and processing unit.

3.2.1 The Laser Scanning and Cooling Unit. The main function of this unit is to generate and emit laser pulses with a specified frequency. A timer is included in the unit to assess accurately the time difference between pulsing of laser and receiving the reflected signal as described previously. By recording this time (t), from sending out the laser pulse to receiving the return, the distance or range (R) to the object can be computed using:

$$R = c \cdot (t/2.) \qquad (1)$$

Where: c = the light speed in air, which is known.

A typical scanning unit contains a mirror, mounted in front of the laser-emitting point. This mirror rotates with a frequency equal to the laser pulsing rate through a scanning angle similar to the field of view angle in the case of the imaging systems. The pulses of few nanoseconds duration are directed by the mirror, through an opening or a window, towards the ground. Additionally, a cooling system is provided to absorb the temperature released from the lasing action.

When the laser scanner is mounted on an aircraft with a scan line perpendicular to the direction of flight, a saw tooth pattern of scanned objects is formed within a strip covered by the flight. The width of the strip (sometimes called swath) and the space between the object points depends on the flying height, the domain limit of the scanning angles and the flying speed. These factors vary due to the type of the scanner used and the design of the scanning flight. Typically, the flying speed ranges from 200 to 250 kilometres per hour and the flying height varies between 350 and 1000 metres. Also, the pulsing rate can be within 2000 and 5000 pulses per seconds. In addition, the limit of the scanning angle is of the order ±20°. A laser scanning process with these parameters and of reasonable measuring accuracy may yield to a measured point every few metres. This is enough to create a DSM suitable for many environmental applications (Sherstha et al., 1997).

The continuous development of the system aims at increasing the pulsing rate and improving the capabilities of the system. In the near future scanning systems with high pulsing rate will be seen in commercial applications. Ackermann, (1999) states that the measuring rate of most of the existing systems range from 2000Hz to 25000Hz. The same reference mentions that there is one system with a measuring rate reaching 80000Hz. Also, some of the scanning systems may allow a higher flying height up to 5000m above the mean sea level. However, this development should not ignore the safety condition of the system. An important factor of the safety of the system is the power of the emitted laser pulse towards the ground. This power must be controlled by the acceptable safety limit for the human eye. This is a factor, which is directly related to the flying altitude.

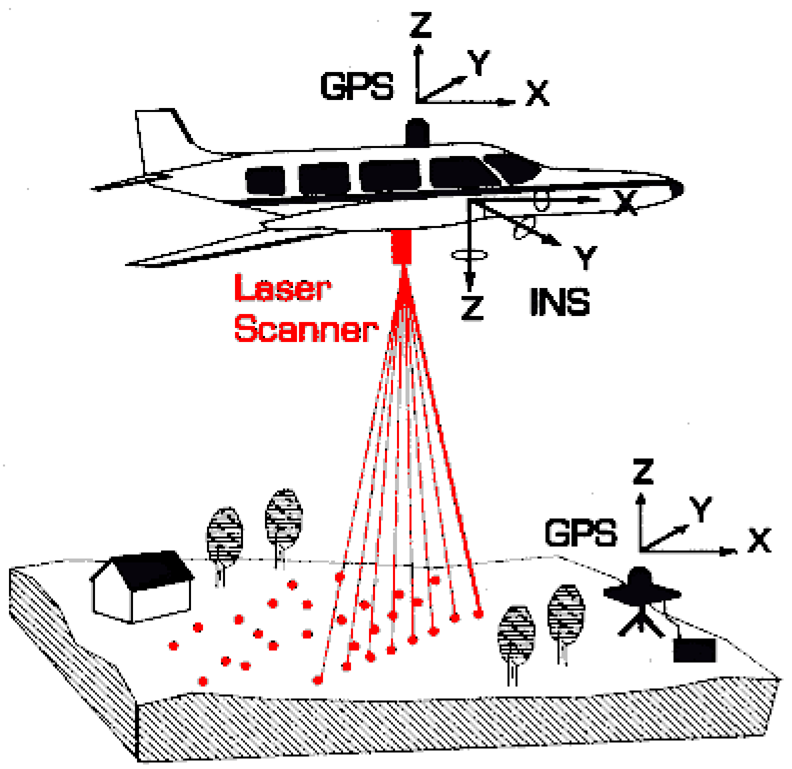

Figure 1: The airborne laser scanning system (Flood and Gutellius, 1997)

3.2.2 The Positioning System Unit. As mentioned earlier, the position of the aircraft must be known at every time of pulsing. This is essential for the calculation of the co-ordinates of the object points. The phase difference kinematic global positioning system (GPS) technique is used for this purpose (Wright et al., 1996). This is applied by fixing a GPS receiver on the aircraft. Also, another receiver is mounted at a ground station in the area to be scanned. The ground stations in the case of airborne laser scanning are known as ground bases. This is because the measurements at these bases are used to get differential GPS measurements and increase the accuracy of the system. Sherstha et al. (1997)

states that, an accuracy of 3 to 4 centimeters can be obtained if the aircraft flies within 30 to 40 kilometres from a ground base. If more than one ground base can be established, this is useful in strengthening the quality of the laser scanning process. Moreover, installing more than one receiver on the aircraft improves the positioning accuracy. However, this increases the final cost of the project.

For sometime in the past, only one GPS observation could be obtained per second, now this has been increased to be potentially greater than 10. Unfortunately, this is not sufficient for airborne laser scanning processes, since a positional measurement is essential at every time of pulsing as stated above. This means that about 2000- 5000 (depends on the pulsing rate of the system) positional measurements may be needed every second, which is outside the capability of direct measurement using present GPS technology alone. In order to help solve this problem, an INS is used which also has the ability to measure the attitude of the platform to enable the direction of the scanning pulse to be determined.

3.2.3 Attitudes of the Laser Sensor Unit. Attitudes of the laser sensor are described by the rotation angles about the main axes of movement and called; roll, pitch and yaw where (figure: 1):

a) Roll: is the rotation angle of the aircraft about the horizontal longitudinal axis (X), which takes the main direction of movement. It can also be expressed as the angle of rotation of the aircraft, which causes a wing-up or wing down movement.
b) Pitch: is the rotation angle of the aircraft about an axis (Y), which is normal to the longitudinal axis (X). Also, it may be expressed as the angle of rotation, which cause a nose-up or nose down movement.
c) Yaw: is the rotation angle of the aircraft about its vertical axis (Z) so that the longitudinal axis deviates to left or to right from the flight line.

If the laser system is rigidly fixed to the fuselage of the aircraft then these rotations correspond to the aircraft movements.

The Inertial Navigation System (INS) is a device that has the capability of determining the aircraft attitudes with high accuracy over short periods of time. The drop off in accuracy is due to the INS values drifting which can be overcome by integrating with GPS. The INS has gyroscopes for measuring the attitudes and accelerometers for determining the flying accelerations. This allows the aircraft position (X, Y, Z) to be determined with high frequency by applying double integration to the measured acceleration. Synchronization of measurements (timing) is important between the INS, GPS and the laser pulsing time.

3.2.4 Data Storage and Processing Unit. Another important component of the airborne laser scanner is a PC unit with large RAM and large hard disk capacity. The PC is connected to the different units of the system and controls their operation.

3.3 Quality of the LiDAR DSM in Different Applications

Due to continuous improvements in the airborne laser scanning system and due to decreasing cost of such new technology, there are a number of commercial companies offering a LiDAR service. This section will review a few projects that have been undertaken to show the variety of potential applications. Vaughn et al. (1996) states that a laser altimeter, profiling system can measure the ellipsoidal height with accuracy better than 10cm, if careful calibration of the laser scanner, accurate attitude measurements, precise determination of the platform trajectory by using GPS and relatively low flying height are applied. Also, Csatho et al. (1996) describes the use of NASA's laser system, which covers a swath of 130 to 200m in width for studies of the polar region. The aim of these studies was to obtain a digital elevation model (DEM) and topographic maps from airborne laser altimetry data. A dense distribution of measured points to an accuracy from ±10 to ±20 cm was obtained and used to create the DEM. Another DEM was created of the same area using traditional aerial photogrammetric methods. A comparison between DEMs indicated a strong agreement.

Flood and Gutellius, (1997) states that, airborne laser scanning surveys are more economical and more productive specially in areas where traditional surveying methods such as aerial photogrammetry and terrestrial surveying methods are impractical or impossible. The airborne laser scanning system is found beneficial if used in areas such as coastlines, wetlands, forests, power lines and transportation corridors. Also, it can be used successfully in topographic mapping and in mapping areas of high dynamic environmental changes due to episodic disturbances such as earthquake and hurricane regions. Wright et al. (1996) explains that an airborne laser scanner called airborne topographic mapper (ATM-II), developed by NASA has the capability to produce high resolution maps, was used in mapping and profiling arctic ice in Greenland, Svalbard, and Iceland in October 1996. This instrument was also used to survey a 600km baseline of the East Coast beaches between Delware and South Carolina in the USA. The results indicated that an accuracy of about 10cm in elevation data was achieved. Moreover, airborne laser scanning data have been used in the determination of mean tree height in Norway for the purpose of forest planning. The results show that using such new technology for this purpose gives results equal to or even better than those obtained by using the aerial photogrammetric methods (Næsset, 1997).

The Department of Surveying of Rijkswaterstaat in Netherlands carried out a laser scanning process to get topographic measurements in order to study the sources of errors in the system. The study indicated that errors may vary between 5cm and 200cm and mentioned that the main sources of errors are due to the uncertainty in determining the platform positions and attitudes. The same study also, predicted that some errors might result from the laser range measurements. However, the same study recommended that, by following adequate strategy in measuring to remove gross errors, would lead to an improved accuracy (Huising and Pereira, 1998).

Kraus and Pfeiffer, (1998) record the use of the airborne laser scanning technique to provide data for digital terrain modelling (DTM) of wooded areas. This data was shown to be of an accuracy equivalent to that obtained from wide-angle images of scale 1:7000 using aerial photogrammetry methods to create digital terrain models in open areas. An accuracy of ±25cm was obtained in flat terrain. However, an accuracy of ±10cm for the airborne laser DTMs is achievable. Moreover, the airborne laser scanning system can be used in wooded areas even if the penetration rate is only 25%.

Besides the previous applications, the airborne laser scanning technology has been used in hydrographic surveying applications. A Scanning Hydrographic Operational Airborne LiDAR Survey (SHOALS) system has been developed as a result of co-operation between the US army corps of engineers and the Canadian government in order to support the US army corps operations and maintenance of federal harbours. The corps received SHOALS in March 1994 after field testing in Florida. SHOALS started its final stage of development to become completely an operational airborne hydrographic surveying system (Lillycrop et al., 1996).

4 CONCLUSIONS

LiDAR has been shown to be an accurate surface modelling tool. It is starting to be used in a wide range of applications. Although there is some overlap of ability between LiDAR and photogrammetry these are different measurement systems and therefore have the potential to be complementary to each other.

This project aims to investigate the relationship between LiDAR and digital photogrammetry both from a qualitative assessment and a quantitative assessment. This will be achieved by establishing a test site, which has already been established to the North East of Nottingham, UK. LiDAR and various scales (at present, 1:10000 and 1:25000 scale) of aerial photography will be used to make comparisons of DSM and other extractable information in the assessment in rural and urban areas. The assessment will not only look at the two methods independently but what can be achieved through integration and fusion of the data. Latest results will be present in the poster presentation.

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