

LiDAR in Mapping

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Abstract

Light Detection And Ranging (LiDAR) is a modern technology, which has received wide acceptance and popularity around the world recently, due to its usefulness in the terrain mapping. Since the introduction of LiDAR in the mapping industry, its applications in Geographic Information System (GIS) have multiplied. In this study, LiDAR is compared with other compatible terrain data collection technique i.e. photogrammetry, in terms of amount of time and labor involved for generation of Digital Terrain Model (DTM). The aim of this study is to demonstrate how the fusion of photogrammetry and LiDAR is ideal for most GIS applications.

1. Introduction

LiDAR is an acronym for Light Detection And Ranging, sometimes also referred to as Laser Altimetry or Airborne Laser Terrain Mapping (ALTM). The LiDAR system basically consists of integration of three technologies, namely, Inertial Navigation System (INS), LASER, and GPS. The Global Positioning System (GPS) has been fully operational for over a decade, and during this period, the technology has proved its potential in various application areas. Some of the important applications of GPS are crustal deformation studies, vehicle guidance systems, and more recently, in LiDAR.

Geo Spatial Information is an important input for all planning and developmental activities especially in the present era of digital mapping and decision support systems. LiDAR is much faster than conventional photogrammetric technology and offers distinct advantage over photogrammetry in some application areas. Its development goes back to 1970s and 1980s, with the introduction of the early NASA-LiDAR systems, and other attempts in USA and Canada (Ackermann, 1999). The method has successfully established itself as an important data collection technique, within a few years, and quickly spread into practical applications. Early 1980's, second generation LiDAR systems were in use around the world but were expensive and had limited capability. With the enhanced computer power available today, and with the latest positioning and orientation systems, LiDAR systems have become a commercially viable alternative for development of Digital Elevation Models (DEM) of earth surface.

2. Technology in a glance

A pulsed laser ranging system is mounted in an aircraft equipped with a precise kinematic GPS receiver and an Inertial Navigation System (INS). Solid-state lasers are now available that can produce thousands of pulses per second, each pulse having a duration of a few nanoseconds (10^{-9} seconds). The laser basically consists of an emitting diode that produces a light source at a very specific frequency. The signal is sent towards the earth where it is reflected off a feature back towards the aircraft. A receiver then captures the return pulse. Using accurate timing, the distance to the feature can be measured. By knowing a speed of the light and the time the signal takes to travel from the aircraft to the object and back

to the aircraft, the distances can be computed. Using a rotating mirror inside the laser transmitter, the laser pulses can be made to sweep through an angle, tracing out a line on the ground. By reversing the direction of rotation at a selected angular interval, the laser pulses can be made to scan back and forth along a line. When such a laser ranging system is mounted in an aircraft with the scan line perpendicular to the direction of flight, it produces a saw tooth pattern along the flight path.

The width of the strip or "swath" covered by the ranges, and the spacing between measurement points depends on the scan angle of the laser ranging system and the airplane height. Using a light twin or single engine aircraft, typical operating parameters are; flying speeds of 200 to 250 kilometers per hour (55 to 70 meters per second), flying heights of 300 to 1000 meters, scan angles generally ± 30 , to ± 20 degrees, and pulse rates of 2000 to 50000 pulses per second. These parameters can be selected to yield a measurement point every few meters, with a footprint of 10 to 15 centimeters, providing enough information to create a Digital Terrain Model (DTM) adequate for most applications, including the mapping of storm damage to beaches, in a single pass. The primary factor in the final DTM accuracy is the airborne GPS data. Errors in the location and orientation of the aircraft, the beam director angle, atmospheric refraction model and several other sources degrade the co-ordinates of the surface point to 5 to 10 centimeters (Shrestha and Canter, 1998). An accuracy validation study showed that LiDAR has the vertical accuracy of 10-20 centimeters and the horizontal accuracy of approximately 1 meters (Murakami et al., 1999).

3. Comparison with photogrammetry

LiDAR is useful for collection of elevation data in case of dense forests, where photogrammetry fails to reveal the accurate terrain information, due to dense canopy cover. Not limited by the environmental conditions restricting aerial photography, airborne LiDAR is emerging as an attractive alternative to the traditional technology for large-scale geospatial data capture. Because it is an active illumination sensor a laser system can collect data at night and can be operated in any weather and at low sun angles that prohibits aerial photography. Rural and remote areas can be surveyed easily and quickly because each XYZ point is individually geo-referenced, aerial triangulation or orthorectification of data is not required (Flood and Gutelius, 1997).

Photogrammetric methods for DTM generation are very time consuming and labor intensive. In photogrammetric method of DTM generation using stereoplotters, firstly photogrammetric model needs to be formed into stereoplotter using interior, relative and absolute orientations. Stereo-compiler manually digitizes geomorphic features such as, drainage, road edges, sides and bottom of ditches in one layer. These lines are called as "hard break lines". The undulations in the topography are mapped by so called, "soft breaklines" (shown in yellow colour). Then spot heights are added up at regular interval (cyan colour) manually by keeping floating mark on the ground (in model). Later on the DTM is generated from these breaklines and spot heights by using sophisticated softwares currently available in market. On the contrary, on an average, 90-100 sq. km. area can be measured in one hour using LiDAR system. Typical post-processing time for LiDAR are, two to three hours for every hour of recorded flight data with additional processing time required for more sophisticated analysis for target classification (Lohani, 2000). Studies showed that LiDAR requires only 25 to 33% of the budget needed for photogrammetric compilation (Petzold et al., 1999)

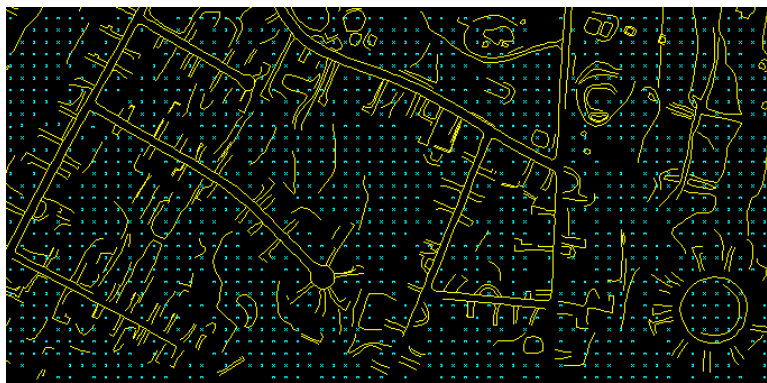


Figure 1 "hard/soft breaklines and spot heights" for DTM generation

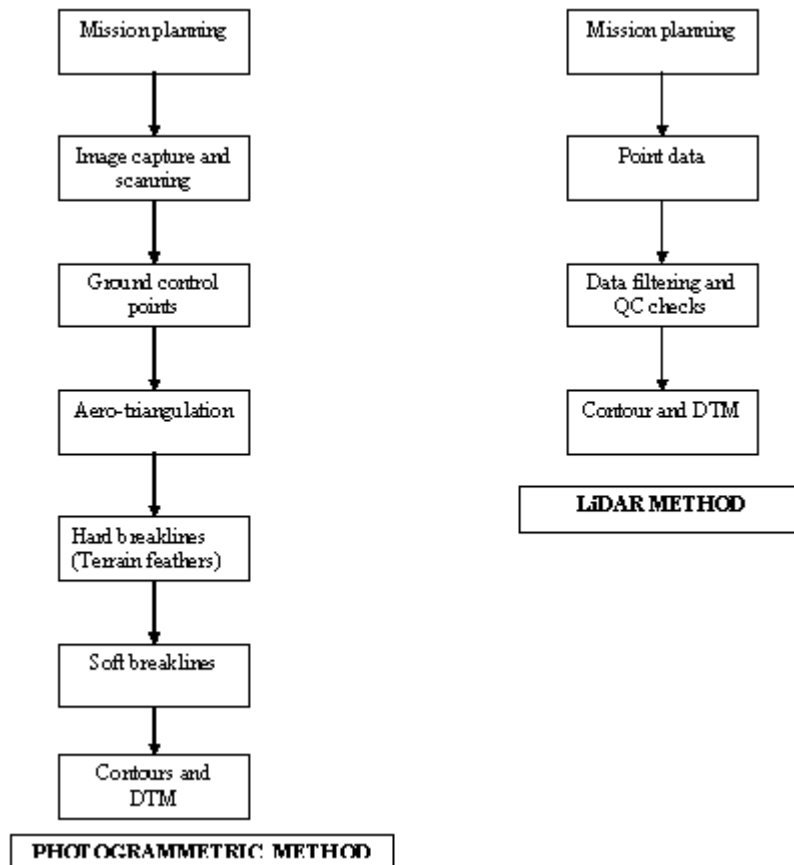


Figure 2 Comparison of various steps involved in DTM generation, Photogrammetry vs. LiDAR

4. Applications

Coastal zones, beaches and wetlands are the areas with limited contrast and texture. It is very difficult if not impossible to achieve satisfactory results in such area with traditional photogrammetry. In above case LiDAR gives good results (Flood and Gutelius, 1997).

Some application areas where LiDAR outperforms photogrammetry are (Green et al., 1997):

- Coastline and dune surface profiles with lesser relief.
- Wetland areas where no ground point can be installed due to restricted access.
- Forest areas where vegetation cover prevents visibility of the ground in aerial photographs
- Road-pipeline or powerline-planning for narrow corridor mapping.
- Openpit mining operations where the final data is needed within a few hours of collection.

5. Integration of photogrammetry and LiDAR

In the digital era today, GIS is increasing in complexity, sophistication and detail. But despite the increasing sophistication of these tools, at the heart of every GIS is the “base layer” that contains and displays the rudimentary spatial information on which all other GIS layers are built. If elevation data is available then a DTM can be created as the base layer. However collecting accurate elevation data to describe the terrain can be difficult and is most often costly and time consuming by traditional methods (Green et al., 1996). The LiDAR DEM tends to be much denser than those available through current sources. This potentially leads to more accurate orthorectification of aerial photographs. User enjoys the benefit of high spatial resolution from the imagery and a very accurate, dense DEM from the LiDAR system. The imagery can be used to add breaklines to the LiDAR data to reveal the terrain more accurately for contour interval of less than 2 feet. LH Systems ALS40 Airborne Laser Scanner claims to offer much the same swath width as an aerial film camera with a six-inch (15 cm) lens, which is ideal for

simultaneous mapping such as corridor mapping. Simultaneous recording of LiDAR data and digital imagery requires joint operation of the two sensors on board of the aircraft. In corridor surveys with narrow widths, simultaneous mapping is very useful for estimating amount of cut and fill along the alternative alignments. This helps in selecting best economical route from available alternatives. But for projects with larger areas, aerial photography and LiDAR missions needs to be flown separately because of different field of views between aerial cameras and LiDAR scanners.

The combination provides more realistic representation of the area than LiDAR data alone. If the project needs 1 foot or smaller contour interval and planimetric details, then it's good to begin with traditional aerial photogrammetry and analytical triangulation. The LiDAR data can be imported into stereoplottor for each stereomodel so as to enable stereo-operator to easily edit LiDAR data, draw breaklines and generate contours. The combination could be ideal in obscured areas in heavy vegetation where LiDAR data can be useful to fill in the obscured areas not visible in aerial photography. Pure LiDAR products are normally used when schedules outstrip the need for a traditional large-scale map product. LiDAR data filtered to a bare-earth model, or in its raw form, can be grided to create DEM files for viewing as shaded relief or color-coded elevation data. These forms of data can be useful in an emergency situation such as a natural disaster. The following figure shows the area mapped by photogrammetry and LiDAR separately. The area was mapped by flying separately once for photogrammetry and then for LiDAR. The photogrammetrically compiled base maps were then modified for creating tax maps of the area as shown in the figure. These maps are then attached to the database for creating query based maps, the one shown in figure 3. Figure 3 shows photogrammetrically compiled digital map, resulting map with spatial query, contours generated by procedure described earlier and point data imported into GIS software, respectively. Gram++, a package developed by CSRE, IIT, Bombay was used for GIS purpose.

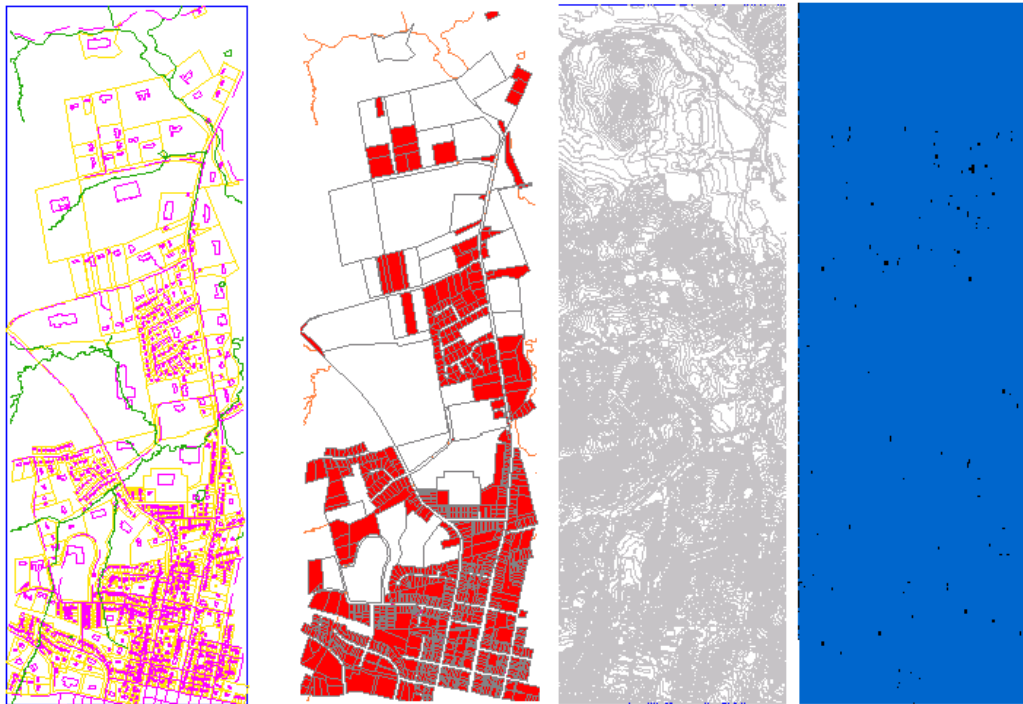


Figure 3 Combined LiDAR-Photogrammetry data product

Indian and international scenario

The technology is well tested and accepted by carrying out pilot projects in various countries around the world. LiDAR is commercially operational in various countries like USA, Canada and in Europe. So far no LiDAR project has been carried out in India. There is a proposed project that will be carried out by Survey Of India (SOI) in near future, on the pilot basis.

In India, there are lots of ongoing and proposed projects related to roadways, railways, oil and gas

pipelines, electric transmission lines, communication network, ports and harbors, for which speedy collection of accurate topographic data is an important factor, which reduces the cost of the entire project dramatically. Delays in project work due to the disadvantages of conventional data collection approaches may also be minimized (Lohani, 2000). India is prone to natural disasters of varied forms, resulting in heavy losses of life and wealth. LiDAR data have potential to be effective in many disaster management programs, including most frequently occurring floods, as in case of state of Orissa in India. The LiDAR technology can be very useful for such application in India.

Conclusions

The main advantages of LiDAR are accuracy of measurements, high automation and fast delivery times. Due to its typical characteristics, both in data collection and data type, LiDAR has opened up several new applications that are not economically feasible with the conventional techniques. In India the technology is yet to make its way and has still a long way to go. Looking at the potentials of this technology, it is obvious that LiDAR will play a major role in geospatial community in near future.

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