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# 3D Mapping by Photogrammetry and LiDAR in Forest Studies

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**ABSTRACT**

Aerial imagery have long been used for forest Inventories due to the high correlation between tree height and forest biophysical properties to determine the vertical canopy structure which is an important variable in forest inventories. The development in photogrammetric softwares and large availability of aerial imagery has carved the path in 3D mapping and has accelerated significantly the use of photogrammetry in forest inventory. There is tremendous capacity of 3D mapping which has been recognized in research, development and management of forest ecosystem. The aim of this article is to provide insights of 3D mapping (photogrammetry including Lidar) in forest-related disciplines. We utilizing the satellite stereo pair and LiDAR point cloud as a case study for producing the anaglyph map and Canopy Height Model (CHM) respectively. The study also revealed the area verses canopy height graph. Present study has some strength because it was demonstrated the use of advance software module of ARC/GIS and Erdas Imagine for 3D mapping using Photogrammetry and LiDAR data sets which is highly useful in forest management, planning and decision making.
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***Keywords*:** Stereo-Image, Photogrammetry, Lidar, Point cloud, Anaglyph, Canopy Height Model

## 1. INTRODUCTION

The prime objective of forest mapping is to generate, manipulate and update various thematic datasets representing forestry attributes. These maps can be generated and utilized in forestry disciplines in forest research and education for forest management. Quantitative

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estimates of certain forest inventory attributes, such as mean tree height/ canopy height models (CHM) or timber volume, biomass, are crucial for sustainable forest management plan.

Photogrammetry is the "art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena" (American Society of Photogrammetry 1980). Photogrammetry can be used to obtain the information from hardcopy photographs or images. Sometimes the process of measuring information from photography and satellite imagery is known as metric photogrammetry. Interpreting information such as identifying and discriminating between various tree types from photography and imagery is known as interpretative photogrammetry (Wolf 1983). Satellite photogrammetry has little bit different compared to photogrammetric applications associated with aerial frame cameras because they utilize the sensor consisting of Charge-coupled device (CCD). A stereo satellite scene is obtained when two images of the same area are acquired on from different perspectives.

The main advantages of digital photogrammetry in forestry

1) Digital photogrammetry includes various modules for image processing can execute various photogrammetry process (triangulation, orientation, orthoprojection) are fully automated whereas it facilitate stereoscopic measurement.
2) Digital automatic aero-triangulation facilitate the orientation of blocks of photos using least ground control points (GCPs)
3) After generation of stereo models it can be used for 3D-digitigition of various themes are significant for forest application and can be combined with various ancillary datasets.

Few decade before, much information was generated by the photogrammetric evaluation of aerial photos by visual interpretation widely used in forestry application (Taniguchi 1961). Subsequently, 3D information of forest canopy was extracted using photogrammetric techniques (Korpela 2004) using analogue stereo-plotters and the measurement of tree heights were executed from image stereo-pairs (Baltsavias 1999) manually. Digital photogrammetry provides highly accurate output and subsequently economical, which overall reduces the price of the final products. Much photogrammetric software have been developed subsequently and provided the huge opportunity to generate 3D information from any kind of overlapping imagery. The Digital photogrammetric software began to be developed in the late 1980's - early 1990's (Lohmann et al. 1989, Leberl 1994, Baltsavias 1999). The advancement of high resolution satellite stereo pair imageries such as Spot, IKONOS, WorldView-2 and GeoEye2 stereo pair has greatly facilitated the analysis of 3D mapping up to the scale 1:5000 with enhanced image quality.

The advent of digital imagery authorizes the automation of photogrammetric workflows to the concept of the point cloud. Although airborne laser scanning (ALS) data have many advantages (e.g. direct measurement of height, penetration of vegetation), aerial imagery still represents an essential data source for forest inventory. Therefore, nowadays aerial imageries are acquired frequently for vast areas for orthophoto production in developed countries. Photogrammetry and LiDAR could provide comprehensive spatial structure and tree species of forest, and have incomparable advantages in the long-time monitoring of forest environment at individual tree or stand scale (Liu et al. 2017). A general flow diagram of photogrammetry/ LiDAR for forestry application is given in Figure 1.

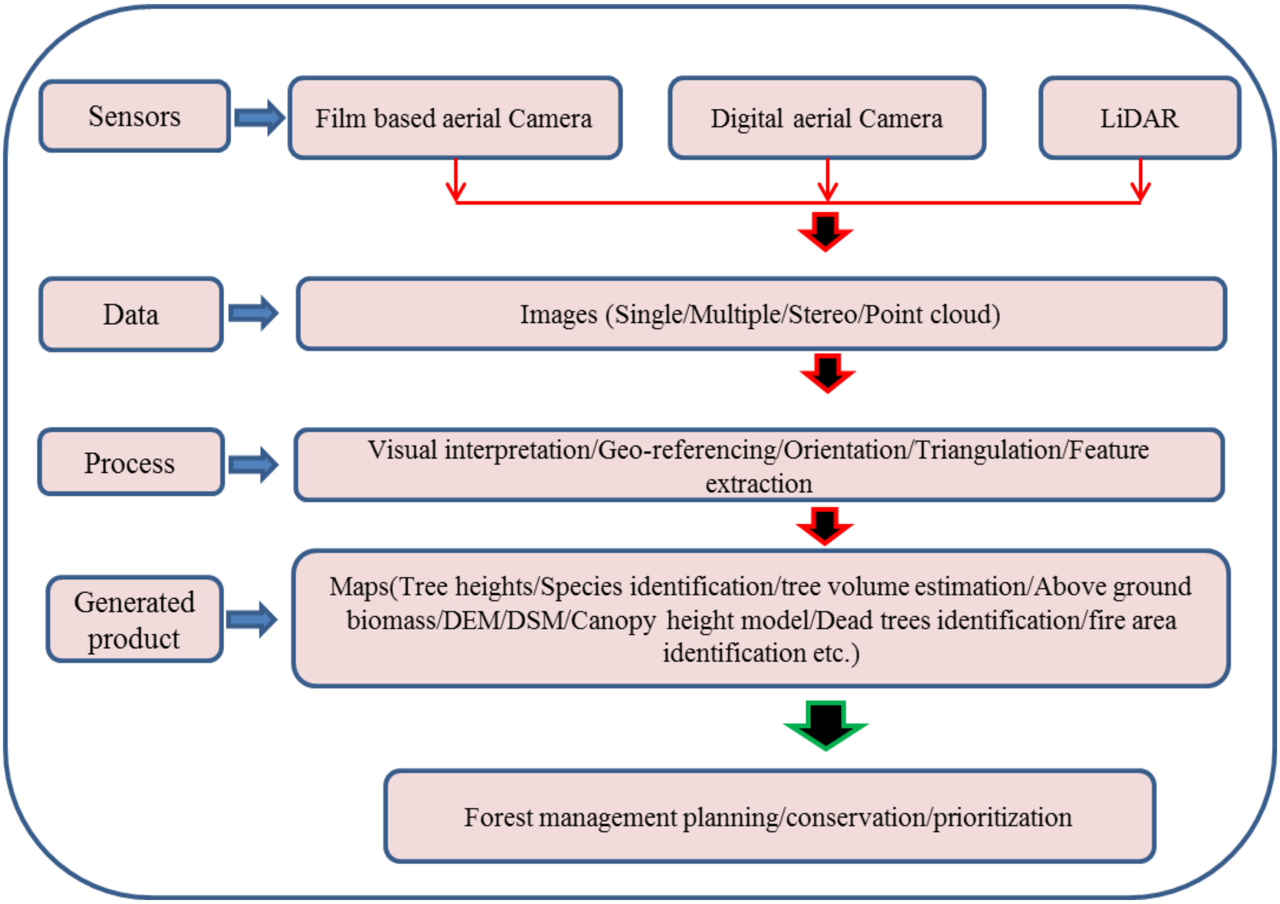


**Figure 1.** A general flow diagram of photogrammetry/LiDAR for forestry application.

One more emerging 3D mapping technology is Light Detection and Ranging (LiDAR) – applied science can produce the distance measurements based on the return time of emitted light. LiDAR systems mounted on aircraft can be a cost-effective means to obtain three-dimensional (3D) information on forest attributes for diversified geographical areas with very high spatial resolution and unprecedented accuracy (Behera & Roy 2002). Such information is potentially more practical for forest inventories than the information from other remote sensing techniques (Lefsky et al. 2001; Coops et al. 2004; Maltamo et al. 2006). The new terminology UAV photogrammetry describes a photogrammetric measurement platform, which maneuvers remotely and is equipped with a photogrammetric measurement system, including, but not limited to a small or medium size still- camera, thermal or infrared camera systems, and airborne LiDAR system.

Finally we can conclude the continuous progress and improvement in remote sensing data/ methodology/ software/ algorithms carved the path for forestry applications can be harnessed in large area at national level due to digital cameras to far visibility mapping range up to near infrared and thermal range and can be integrated into common working environments for efficient analysis in 3-D (Ginzler & Waser 2017). The modeling of image-generated 3D- digital surface models (DSM) utilizes high-resolution aerial images with stereo pair coverage (Hirschmugl 2008, Leberl et al. 2010, Liang et al. 2016).

Stereo photogrammetry is a type of the measurement of its three-dimensional position relative to a reference datum when any feature is scanned/imaged from two different perspectives. The use of digital aerial cameras which captured the image in digital format with an overlap images that are obtained for forest related inventory and monitoring. The progress in technology from film in early ages -to-digital format (CCD chip) has magnified by improvements to the radiometric properties of the images. The technological progress in resolution (radiometric and spatial) improving the characterization of detailed structures thus provide high quality of DSMs which strengthens the forest related application. The image quality in term of information determined by digital image resolution is defined by the ground sampling distance (GSD) largely depends on flying height and the camera (instrument specifications) used. Flying height is an important determinant for forestry applications, resulting in GSDs (e.g., Hirschmugl 2008, Bohlin et al. 2012, Jarnstedt et al. 2012, Nurminen et al. 2013) thus decide the scale of mapping (Zihlavniket al. 2007) and accuracy (Balenovic et al. 2017).

The Bohlin et al. 2015 utilized the aerial images of three seasons for deriving the canopy height models (CHM) in deciduous forest of Sweden. Nasi et al., 2015 conducted a study in an urban forest located in the South of Finland by utilizing photogrammetric and hyperspectral images and identified the tree suffering from infestation. They classified the trees into classes of healthy, infested and dead, with overall accuracy were 76% (Cohen's kappa 0.60), and the results were very significant. Lehmann et al. (2015) investigated the utility of UAV-acquired VNIR images to provide reliable remote-sensing data for producing maps of pest infestation and dead oaks to support intervention decisions in the management of forests located in the northwest Germany by utilizing photogrammetry, GIS and Image processing software. Aicardi et al. (2016) utilized 8 years DSMs from the year 2008 to 2015 obtained from LiDAR and UAV digital images (2015) to detect changes in a secondary forest of Scots pine with sporadic larch, Norway spruce, downy oak (*Quercus pubescens* Will.), European aspen (*Populus tremula* L.), and silver birch (*Betula pendula* Roth), located in northwest of Italy, affected in 2005 by crown fire.

They identified a 135 m long profile within the burned areas. The analysis of the profiles highlighted that the increase in height of forest stand was mostly caused by post-disturbance regeneration of vegetation. Balenovic et al., 2010 used the aerial photographs by the process of photointerpretation and photogrammetric measurements in forest management in Croatia and delineated trees and stand attribute. Hoxha, B. 2012 evaluated lowland mountainous forests in Europe using aerial photographs in 3D (three-dimensional) methods and identified crown cover, height of dominant trees and density. Kardos, 2013 utilize the digital photogrammetry methods and their products in Slovak forestry in the field of forest mapping by image data using the technique of interpretation and classification of forestry features. They meet the accuracy requirements within the forest mapping standard. Bohlin et al., 2012 evaluated the tree height, volume of stem, and basal area for forest stands using canopy height, density, and texture measurement derived from photogrammetric matching of digital aerial images and a high-resolution DEM at a coniferous hemi-boreal site in southern Sweden.

Three different data-sets of digital aerial images were used in the analysis. The study concludes that photogrammetric process of digital aerial images has outstanding capacity for operational use in forestry.

The study of LiDAR data were used in early days for assisting traditional forest inventory limited to the height, basal area and volume (e.g. Naesset 1997; Hyyppa and Inkinen 1999; Means et al. 2000). This can be used for biomass estimation (Lefsky et al., 2005), forest canopy modeling, ecosystem modeling (Antonarakis et al., 2011), assessing biodiversity patterns of species at local scales are often examined as a function of habitat characteristics by evaluating vegetation structure and composition (e.g. Lassau et al. 2005; Flaspohler et al. 2010; Muller et al. 2010). Feng et al., 2008 utilized the LiDAR data for tree height and stand volume measurement. The LiDAR based measurement was 8.68 meter whereas actual value was 8.67 which showed very positive correlation. They drew the conclusion that estimating forest stand volume using different coefficient methods by utilizing LIDAR data sets. They concluded that the LIDAR technology can save amount of field work time and improve the work efficiency. Ahmad et al 2017 utilized the LiDAR data and determined the canopy height in rural areas of the USA. The analysis derived the canopy height models (CHMs) and area tree height graph. Study manifest the 22 meter tree height highly occupied (greater than 12 hectare) in the study area. The objective of the present research is to demonstrate the 3D capability utilizing the satellite stereo pair and LiDAR point cloud and subsequently generating the anaglyph map and Canopy Height Model (CHM) respectively.

## 2. MATERIAL AND METHODS

The analysis used free stereo pair of Geoeye-1of Poshiana, India in the form of 4-band bundle (https://www.digitalglobe.com/resources/product-samples/stereo-satellite-imagery) having forest area. The data have pan and multispectral images with acquisition dates 8$^{th}$ September 2014 having the spatial resolution 50 and 200 cm respectively. We have utilized the Imagine photogrammetry module of Erdas Imagine for processing the stereo images. We have created new block file and selected the appropriate geometrical model utilizing the GeoEye RPC option. The block projection systems were defined (UTM and zone 43). The stereo PAN image is added and the interior and exterior orientation was performed by selecting appropriate RPC coefficient of both left and right images. We have utilized point measurement tool and manually given 25 tie points uniformly over the left and right image.

The block triangulation was performed based on these tie points. The DTM was generated. We have finally generated anaglyph image of the area can be viewed by Anaglyph 3D viewing glass (http://bestdealsnepal.com.np/wp-content/uploads/2016/10/3d-glasses.jpg) shown in Figure 2(A,B).

We have downloaded the free LiDAR data (point cloud) from the USGS website (https://earthexplorer.usgs.gov/) was in LAS file format. We have followed the methodology of Ahmad et al 2017 and generated the Canopy Height Model (CHM), derived the area and canopy height graph in ARC/GIS (Figure 3). The LiDAR point cloud was viewed in 3D by the Erdas Imagine for better understanding and knowledge (Figure 3).

## 3. RESULT AND DISCUSSION

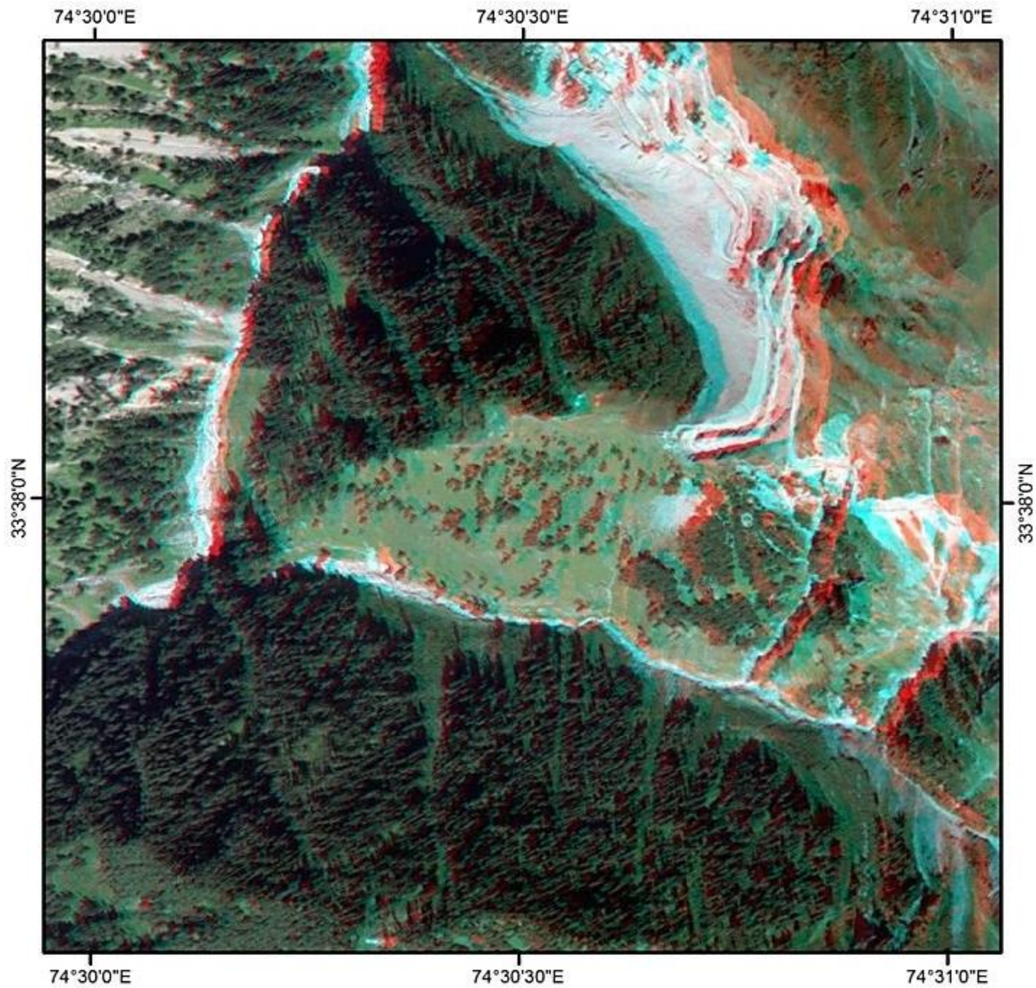


**Figure 2A.** Anaglyph natural colour image

**Figure 2B.** Anaglyph 3D viewing glass

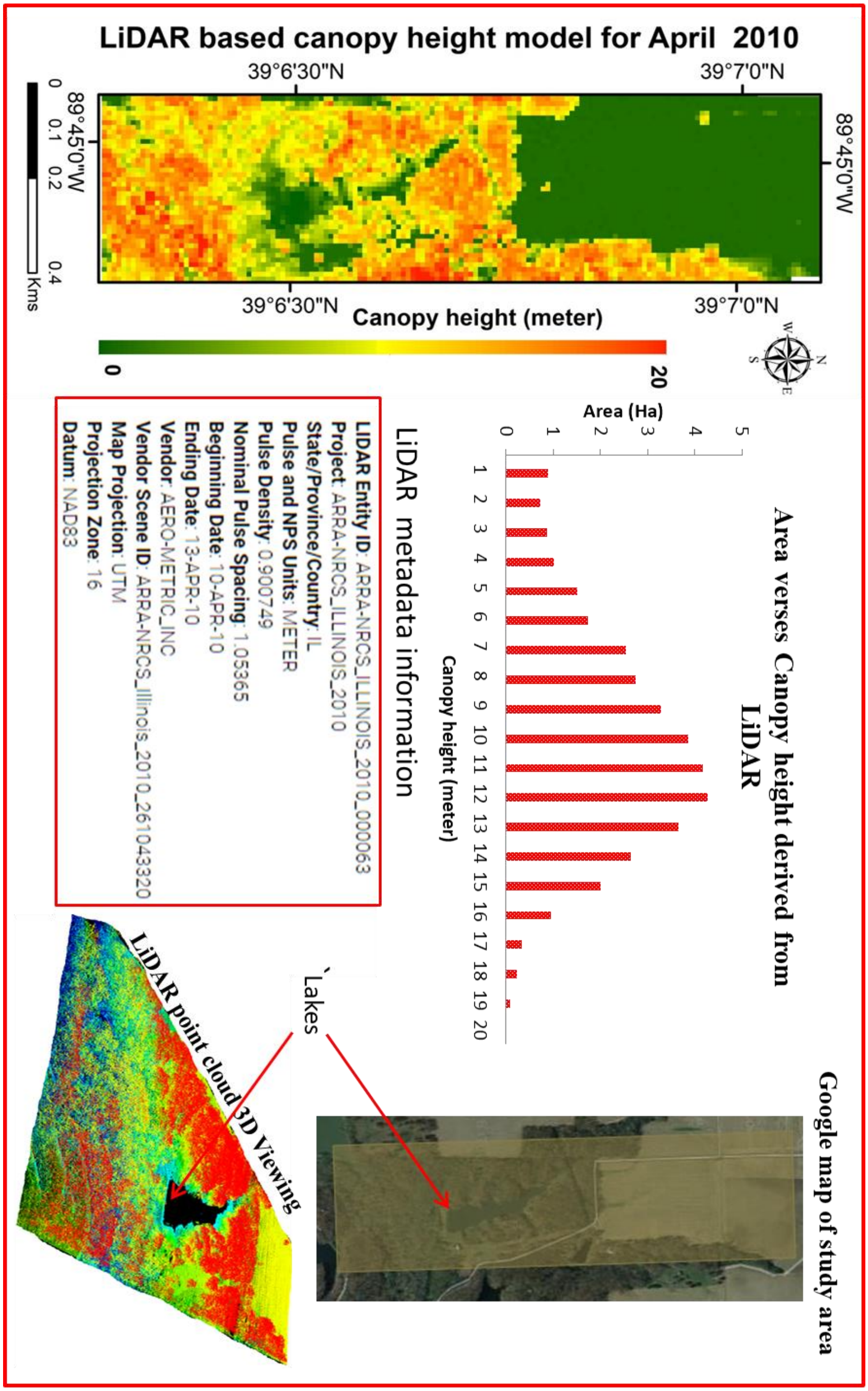


**Figure 3.** Work flow showing Canopy Height Model (CHM), Area vrs. Canopy height graph, Google Image of the study & LiDAR point cloud 3D Viewing

We have showed our capability of using such advance technology using ARC/GIS and Erdas imagine software. The free available satellite stereo pairs were used and generated the DTM. The part of the area is produced for Anaglyph natural colour image (Figure 2A) can be viewed 3D by special glass (Figure 2B). Similar natural colour Anaglyph image has been produced by Zhang 2002.

We have also analyzed the LiDAR point cloud and quality was evaluated. We have generated the Digital Elevation Model (DEM) and Digital Surface Model (DSM) for generation Canopy Height Model (CHM) by utilizing the formula CHM = DSM – DEM. The area verses canopy height graph was drawn. The study also reveals the maximum canopy height is 20 meter whereas, among all canopy height, 12 meter canopy height occupied the largest area. We have also generated 3D viewing from the point cloud; the red colour shows the tree canopy cover with maximum heights (Figure 3). Similar finding was observed by Ahmad et al., 2017.

Finally we can conclude 3D mapping using photogrammetry and LiDAR has huge potential in forestry application because data attributes are significantly discriminated and delineated with excellent accuracy and speed by involving limited manpower which is less time consuming and relatively economical.

## 4. CONCLUSIONS

RS technology has been developing very fast due to the needs of increasing demand of information have created possibilities for cost efficient production of accurate, large area forest data sets, which also will change the scenario of forest inventories in the future. The fundamental objective of photogrammetry is to produce 3-D spatial and descriptive information from two-dimensional imagery that may be from aerial photograph or satellite stereo pairs or LiDAR point clouds. Such technology is in budding stage in our country whereas in developed country it has been part and parcel of the management programmes. Our case study has some strength because we have demonstrated the use of advance software module of ARC/GIS and Erdas Imagine for 3D mapping using Photogrammetry and LiDAR data sets. The developed countries policy is changing and it is more user friendly (thanks to USGS/Digital globe and other international organization for putting such data online) which greatly help in enhancing the knowledge and understanding to the researchers from various field. Furthermore, they are maneuvered themself and adopted some advance mapping technology by Unmanned Aerial Vehicle (UAV) surpassing the phase of 3D mapping using aerial photo interpretation/ analog photogrammetry/digital photogrammetry/LiDAR. It was significantly reflected by their research contribution which is available online these days. The research in forest mapping using photogrammetry and LiDAR are lacuna in our country. Surely knowing the benefits of 3D technology it should be incorporated in forest management policies so as to tap the best of the information for the benefit of mankind.

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