Generation of 3-D Large-Scale Maps using LiDAR Point Cloud Data

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ABSTRACT:

3-Dimensional geospatial data is essential for creating and utilizing real-world visualizations for analyzing infrastructure design improvements. However, techniques exist such as Total Station, Global Positioning System (GPS), and Google Earth data. Traditionally 3D maps were constructed using simple measurements of angles and distances, providing a planimetric representation of the area with a limited number of cross-sections to reflect the built-up area.

However, Terrestrial laser scanning (TLS) is an efficient technique for capturing dense point clouds to construct detailed information models for large-scale built-up areas. In recent years, advancements in the measurement of speed, reduction of size and cost, and portability of these technologies have revolutionized 3-D data collection. This article discusses the methodological framework and 3-D mapping accuracy by adopting terrestrial laser scanning to map a built-up area having different features. Point cloud data collected in the form of scans were processed and registered using Faro Scene software with an overall registration error of 14 mm (RMSE). Finally, it creates a 3-D map of the built-up area having planimetric and elevation accuracy analyses. It will be used for spatial analyses or simulating the interaction of surface and subsurface processes contributing to urban and rural planning development in a 3-D GIS environment and for smart cities.

The method presented here provides a different way for achieving large-scale maps with greater accuracy, which will be applicable in identifying and monitoring the deformations in the built-up areas and in various disaster mitigation.

1. INTRODUCTION

Due to the development in the field of science and technology, the interest in the analogic map is declining in favor of presenting its digital image displayed with computer programs. Over the last few centuries, thousands of cartographers have developed various techniques, procedures, and rules to present and communicate information efficiently. On the other hand, the increasing popularity of computers and the advent of digital maps necessitated the development of new standards and methods for cartographic presentation. (Eremchenko et al., 2015).

The concept phase gives rise to the developed object. After modeling and symbolizing spatial components, it culminates in creating a visualization. These procedures, which are familiar to the conventional 2D method, are subject to changes and provide new guidelines for producing 3D spatial research (Petrovic, 2003; Hájek et al., 2016). Individual spatial objects (Roberts et al., 2022) are subject to three-dimensional presentation, and a visualization of entire cities is generated (Mao et al., 2020). An increasingly frequent process is the creation of cadastral maps presenting the three-dimensional range of the object's occurrence and the laws of ruling in the form of the 3D cadastre (Aditya et al., 2020; Klapa, 2021).

Three-dimensional (3-D) city models or geographic information systems (GIS)-based 3-D landscape analyses are crucial for urban planning, disaster management, virtual tourism, 3-D GIS, and other applications (Lafarge and Mallet 2012; Xiao, Gerke, and Vosselman 2012; Xie et al. 2012; Sun and Salvaggio 2013; Wang 2013;).

It is crucial for 3-D city models to maintain high accuracy in portraying 3-D geometric objects. Despite the fact that significant research concerning 3-D city models has been conducted; however, it is still challenging to create accurate 3-D representations, particularly across a wide area (Byungyun, 2019).

Capturing, modeling, and mapping 3D information in a built-up environment is a big challenge. Several techniques and technologies are now in use. These include EDM, GPS, photogrammetric, and remote sensing applications.

The traditional surveying methods mainly use total stations or GNSS equipment to collect and measure the coordinates of the cadastral or house. However, the efficiency of this method is very low, and the mapping quality is difficult to control (Cina et al., 2016) and (Abidin et al., 2015).

In recent years, with the popularity of unmanned airborne vehicle (UAV) and the maturity of micro-airborne Light Detection and Ranging (LiDAR) surveying and mapping and data processing technology, many surveying and mapping workers have begun to use the UAV LiDAR technology to carry out rural cadastral surveying and mapping (Bao J, 2019) and (In et al., 2011).

Accurate geospatial data is crucial for various applications, such as urban planning, forestry, infrastructure management, and disaster response. Also, High-quality urban development is vital for regional and global sustainable development (Chen, 2021). LiDAR technology has emerged as an essential tool for acquiring precise and in-depth geographic information due to its ability to capture high-density point clouds of data (Benedek, 2021).

To assure the truthfulness of subsequent analyses and applications, it is essential to evaluate the accuracy of features obtained from LiDAR point clouds (Kim, 2020). This study intends to present an overview of the approach used for LiDAR point cloud data-based positional accuracy assessment of features.

LiDAR technology offers several advantages, while challenges

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exist in achieving optimal positional accuracy. Certain factors, such as vegetation cover, buildings, and terrain characteristics, can impact the accuracy of LiDAR measurements (Pramod, 2022). Additionally, the data preprocessing steps, such as selecting filters and removing outliers, can affect the accuracy of feature extraction and subsequent accuracy assessment.

Modelling and mapping 3-D buildings, which allows urban planners or GIS professionals to create 3-D smart city models, has increased interest among various research communities. With the increasing popularity and availability of LiDAR techniques, many studies have been conducted using an image-based approach, LiDAR techniques, or hybrid approaches. Despite the number of studies, it is still hard to create an accurate 3-D representation of a city across a wide area.

This research aims to provide the methodological framework and 3-D mapping accuracy by adopting terrestrial laser scanning to rapidly map a built-up area with point, line, and polygon features. Finally, it creates a 3-D map of the built-up area having planimetric and elevation accuracy analyses. Although there may exist various traditional methods, i.e., GNSS and Total Station, the overall operation efficiency of the survey using LiDAR surveying technology is improved and is more than the conventional method.

2. Study Area

Roorkee is a municipal corporation in the Haridwar district of the Uttarakhand state. Sir Proby Cautly founded Roorkee Municipal Corporation in the year 1868. Indian Institute of Technology (IIT) Roorkee campus, shown in Figure 1, has been chosen as a study area in the Haridwar district. IIT Roorkee, the oldest technical institute in Asia, was formerly known as the University of Roorkee (1949-2001) and Thomason College of Civil Engineering (1847-1949), established by Sir James Thomason in 1847.

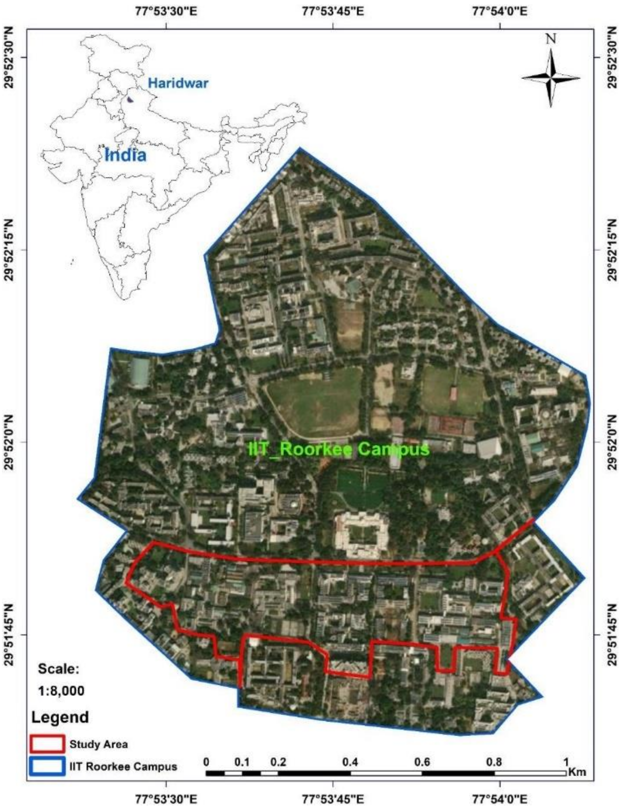

Figure 1 Location map of the study area (IIT Roorkee campus)

The center geographical coordinates of the IIT Roorkee campus are 77°35'45.24" E and 29°51'58.67" N. The total area of the campus is 358.5 acres (1.48 km^2) as per the 2011 census; the total population of Roorkee is 238422, where 35.17% population lives in urban. Roorkee has an average elevation of 268 m. The climatic condition of Roorkee is warm and temperate. Moreover, Roorkee is well connected to India's capital and other important cities of India by road and rail network. The terrain topography of Roorkee is plain. The city's average elevation is 268 meters or 879 feet from sea level.

3. Data Used

Data used for this study are as follows:

- A terrestrial Laser Scanner (TLS) with an accuracy of +-0.0001 (instrumental accuracy) has been used to acquire the study area's LiDAR point cloud data.
- Establishing Ground control points is necessary to start the survey with a Terrestrial laser scanner; therefore, RTK-GPS and checkerboards have been used. The accuracy of the GCPs survey was found to increase asymptotically with more GCPs (Gindraux, 2017). Further. Table 1 shows the latitude, longitude, and elevation of each GCP acquired before the scans.

Table 1 Acquired Coordinates of Ground Control Points (GCPs)

S. No.	**GCPs**	**Latitude**	**Longitude**	**Elevation (m)**
1	GCP1	3307134.6198	780073.6586	221.0125
2	GCP2	3307129.9839	780070.5256	221.2599
3	GCP3	3307132.7404	780076.4080	220.6451

4. METHODOLOGY

Figure 2 shows the overall methodology adopted for this study.

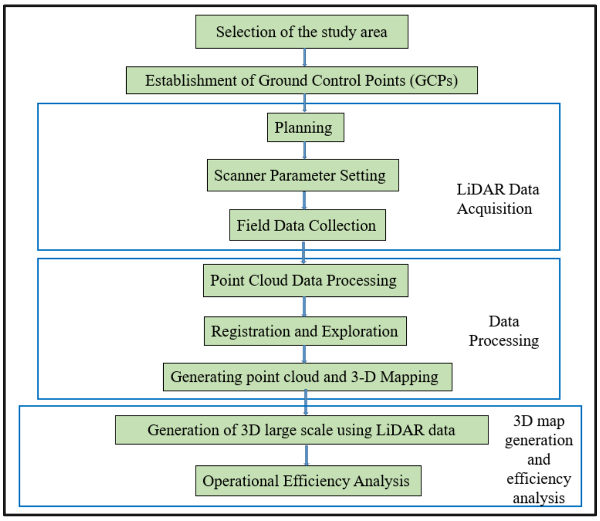

Figure 2 Overall Methodology

4.1 Selection of the study area:

The first step is to select the study area for mapping.

4.2 Establishment of Ground Control Points (GCPs):

Ground Controls Points must be established before the field observation is to be taken. Table 2 shows the GCPs acquired before the scanning using TLS.

4.3 LiDAR Data Acquisition

4.3.1 Planning: Before the TLS collects data in the field, weather conditions must be checked and various scanner settings must be done.

4.3.2 Scanner Parameter Setting: Under Profile setting, the selected profile is set to outdoor 20 m, and resolution and quality are set to 1/4, i.e., 43.7 MPts and 4x. All four sensors, i.e., Altimeter, GPS, Inclinometer, and Compass, can carry out the field observation. In the advanced color setting, the internal camera setting is set to even weighted metering, which determines the camera's exposure setting regarding the light information coming from the entire scene and averages without giving weight to a particular area.

4.3.3 Field Data Collection: LiDAR data collection is the primary data collection method, which can obtain information on most of the features in the study area. The TLS scanner is initially kept in a position, and the scanner scans the site at 360. While browsing the place, the white spheres are kept at an appropriate distance from the scanner. Once the scan has been completed, the scanner is shifted to the next position within a proper space so the sphere which were moved forward may be visible to the scanner. This process is performed for the whole of the study area.

After the LiDAR data collection is completed, the collected original data must be exported to the computer and backed up in time to prevent data destruction or loss. Figure 4 shows the raw data of a scene obtained at NIR band by the scanner.

Figure 3 Raw data of a scene obtained at NIR band by the scanner

4.4. Data Processing

4.4.1 Point Cloud Data Processing: Point cloud data preprocessing is to transform the original laser-measured point cloud data collected by LiDAR equipment into laser point cloud data with 3-dimensional coordinate information in the WGS84 coordinate system.

4.4.2 Registration and Exploration: After processing the scans geoferencing has been done with the help of the GCP's acquired before the collection of the data. And an analysis has been done on this obtained data.

4.4.3 Generating point cloud and 3-D Mapping: After obtaining the three-dimensional point cloud data file in .Las format through preprocessing, 3-D mapping has been done.

4.5 Operational Efficiency Analysis

To evaluate the operational efficiency of LiDAR surveying and mapping a built-up area, use the staff and time invested in this method (GNSS + total station), the workload and efficiency are compared, and the comparison results are shown in Table 2.

Table 2 The comparison of technical efficiency between traditional measurement and TLS LiDAR

Work Content	**Traditional method (GNSS+ Total Station)**	**LiDAR Measurement**	**Efficiency Ratio of LiDAR v/s Traditional Method**
Field survey	10 days	2 days	Approx. 12 times
Man-power required	6 people	2 people	Approx. 2 times
Compre-hensive per feature collection efficiency	6-7 features per day	12-13 features/ day	Approx. 4-5 times

5. RESULT AND DISCUSSION

Figure 4 shows the 3D point cloud obtained after the processing of the LiDAR data. With the uniformity of the LiDAR observable features (i.e., straight walls) in the alleyway, the scan fails to generate an accurate odometry estimate. Without loop closure, the trajectory estimates degrade with drift, and the GPS-only and GPS-with-LiDAR positions deviate from the true path. The application of loop closure allows the LIDAR to constrain its motion at the start and end of the trajectory, leading to a more accurate trajectory estimate in the alleyway (Chen, 2019).

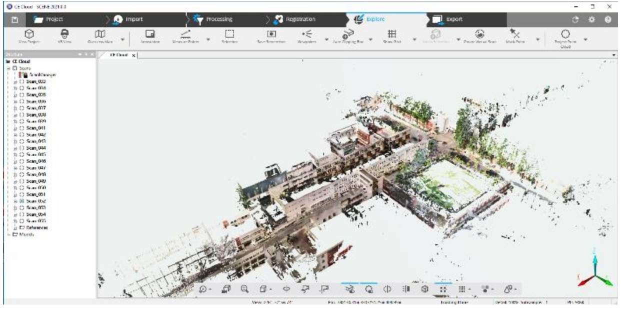

Figure 4 3D point cloud

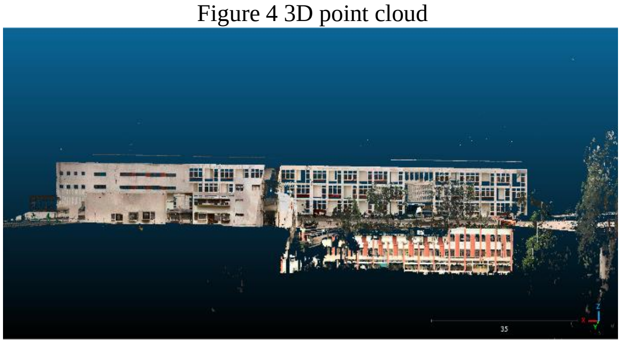

Figure 5 3D map using LiDAR point cloud

Finally, figure 5 shows the generation of the large scale 3D map of the area using Terrestrial Laser Scanner LiDAR point cloud. Table 2 shows the comparison of the technical efficicency between the traditional method and the TLS LiDAR which also shows that the modern technique of 3D mapping for large scale maps has an improved overall operation efficiency by more than 4-5 times. This improved efficiency will be very much helpful and required in the development of the 3D smart cities.

Thus, the use methods helps to improve the accuracy of the survey by reducing the survey costs.

6. CONCLUSION

This paper highlights the importance of 3D geospatial data for infrastructure analysis and various applications. It discusses the limitations of traditional methods and introduces terrestrial laser scanning (TLS) as an efficient technique for capturing dense point clouds. The article presents a methodological framework and discusses 3D mapping of a built-up area using TLS LiDAR data, emphasizing its potential for urban and rural planning in a 3D GIS environment and disaster mitigation.

LiDAR measurement technology has the advantage of high efficiency and high accuracy for modern survey. Although TLS has its inbuilt GPS, which gives automatic georeferencing from the scans, RTK-GPS has been used for georeferencing surveys, improving the accuracy of 2-3 mm.

This paper has also outlined a methodology for generating a 3D realistic urban environment, through LiDAR data, within a commercial GIS followed by georeferencing. The focus then moved on to creating the 3D model of the area. This model is then analyzed and finally leads to the creation of a 3D point cloud for large-scale maps.

Through this work, several benefits were provided through LiDAR data: an improved accuracy was obtained with less time effort as compared to the traditional methods. In addition, the use of LiDAR for 3D mapping reduced cost of survey and the time to carry out the survey. This experiment can provide practical and theoretical references for the application of the LiDAR scanning technology in the related field.

Although this procedure proved very successful, future work will focus on increasing automation and reducing the workflow steps involved in the current process. In this regard, more advanced tools can be used for 3D mapping along with LiDAR. All the features may be more clearly defined compared to the traditional methods. Finally, the creation of a 3D map will be investigated, to allow for more accurate (x, y) and z values.

Futhermore, future work may focus on comparing the planimetric and height accuracy of the features with the help of a few other geospatial tools.

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