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Lidar Point Clouds to Precision Forestry

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Abstract: Light Detection and Ranging (LiDAR), is a remote sensing technology that uses laser light to measure distances and create detailed three-dimensional (3D) models of the Earth's surface. This paper highlights the application and uses of lidar point clouds in precision forestry. The study has been carried out by reviewing several literatures. The study also indicates the uses and application of Lidar technology in national and international contexts. The study reveals that LiDAR technology has witnessed widespread adoption across diverse countries, showcasing its versatility and utility in various domains. The study of possible application of LiDAR on archaeology in three archaeological sites of Ireland. Similarly, the study indicates that there are potential emerging areas where advanced LiDAR-based GIS applications can be successfully implemented such as 3D landscape modeling, aquatic applications, and environmental monitoring. In comparison to the international context, LiDAR technology is a novel technology in Nepal till now. The Survey Department of Nepal has started preparing the High-Resolution DTM and orthophoto of about 20,000 square kilometers of Nepal using LiDAR technology. While the majority of projects in Nepal currently center around biomass estimation, this paper discusses the diverse applications of LiDAR beyond this specific context. Finally, the study highlights the transformative potential of LiDAR technology to enhance the accuracy of forestry practices, which is evident in multi-dimensional applications around the world. While developed countries are using LiDAR in various industries, Nepal is still in the early stages of the technology.

Keywords: LiDAR, Precision Forestry, Nepal

1. Introduction

Light Detection and Ranging (LiDAR), is a remote sensing technology that uses laser light to measure distances and create detailed three-dimensional (3D) models of the Earth's surface. In contrast to other passive remote sensing methods such as satellite imagery and Unmanned Aerial Vehicle (UAV) drones, LiDAR is an active sensing system that emits laser pulses and calculates the time it takes for the light to return[1]. This provides highly accurate and precise measurements of terrain and features, enabling detailed geographic mapping and 3D modeling. While satellite imagery provides greater coverage and UAV drones provide flexibility in low-altitude data acquisition, LiDAR stands out for its ability to penetrate vegetation, high spatial resolution, and independence from daylight or climate, making it valuable for applications such as forestry, urban planning, and infrastructure development[2].

LiDAR is increasingly important in various fields due to its unique capabilities and applications. A key feature is its ability to provide highly accurate and detailed topographic information, making it of great value for landscape modeling and mapping[3]. This accuracy is crucial for urban planning, infrastructure development, and environmental monitoring. In forestry, LiDAR's ability to penetrate through vegetation allows for detailed assessments of forest structure and biomass, aiding in sustainable forest management and conservation efforts. Additionally, LiDAR plays a vital role in disaster management by accurate flood modeling and seismic risk assessment, including monitoring changes in coastal areas. In an autonomous vehicle, LiDAR is an important sensor for navigation, obstacle detection, and obstacle avoidance. Its applications extend to archaeological studies, where it helps uncover hidden features on the Earth's surface. Overall, LiDAR's versatility and accuracy make it an indispensable tool for a wide range of scientific, environmental, and technological applications, contributing significantly to improved decision-making and resource management.

The objective of this paper is to discuss and explore the diverse potential applications of LiDAR technology in the field of forestry, encompassing various aspects and possibilities for utilizing LiDAR for improved forest management and analysis.

2. Materials and Methods

The study was conducted after reviewing research articles in the field of LiDAR technology and precision forestry. Research materials such as journal articles, conference papers, books and documents containing research/project reports were used for the purpose of this study and are cited in the reference section.

3. Lidar Applications Across Fields and Borders

This section explores the applications of LiDAR on both national and international scales, encompassing areas such as precise terrain mapping, forestry management, and global environmental monitoring.

3.1. Application of Lidar in an International Context

LiDAR technology has witnessed widespread adoption across diverse countries, showcasing its versatility and utility in various domains. The study of possible application of LiDAR on archaeologyin three archaeological sites of Ireland: Newtown Jerpoint abandoned medieval settlement, Dún Ailinne prehistoric hillfort and the Hill of Tara archaeological complex has shown that the subtle features of archaeological monuments can now be recorded within similar accuracies to ground-based survey techniques but with a much greater level of resolution and definition. Also, the resulted Digital Terrain Model (DTM) and Digital Surface Model (DSM) from the LiDAR data enables the identification of new features and more detailed records of those already recognized rapidly and cost-effectively[4]. There has also been a study regarding the application of LiDAR on autonomous vehicles for object detection and classification[5]. Since, the world is moving towards self-driving mode, countries like Denmark, Germany, and Finland have already started self-riding buses and metro trains as means of transportation [6]. Similarly, LiDAR has already been used for disaster management.

The drone with an infrared camera fused with a LiDAR sensor has been used to identify the victims during disasters in India [7]. Also, there has been a study regarding the identification of inclined buildings from aerial LiDAR data for disaster management[8]. The study has shown that the LiDAR system can offer high-density and high-resolution DEM data to improve the flood model input, thus resulting in a higher accuracy of flood modeling results, especially in small-scale flood modeling studies[9]. Even, a study has been conducted regarding the application of LiDAR in cattle grazing areas in Hungary which has concluded that the application of LiDAR in animal husbandry provides an opportunity to observe animal behavior and its changes, and also suitable to examine the welfare of cattle along with the temporal and spatial changes of the pasture (e.g. soil, vegetation, grazing ability, etc.)[10]. Several researchers have already worked on the application of LiDAR in precision agriculture. There have already been several uses of LiDAR on environment conservation sectors. The study of airborne LiDAR on river environments: The River Coquet, Northumberland, UKhas concluded that LiDAR shows considerable potential for accurate mapping of gravel-bed river environments[11]. The study regarding using LiDAR technology in forestry activities has shown that there is a great potential for efficiently performing many forestry activities using LiDAR remote sensing technology[12]. The paper has also suggested that there are potential emerging areas where advanced LiDAR-based GIS applications can be successfully implemented such as 3D landscape modeling, aquatic applications, and environmental monitoring. Even LiDAR has been used to generate 3D city models of city of Logroñoto, Spain and advanced towards a smart city[13]. A study has also been carried out regarding the application of LiDAR data on urban planning and generating 3D urban models[14].The literature review indicates that LiDAR technology has been applied in various sectors globally.

3.2. Application of Lidar in the National Context

Comparison to the international context, LiDAR technology is a novel technology in Nepal till now. The Survey Department of Nepal has started preparing the High-Resolution DTM and orthophoto of about 20,000 square kilometers of Nepal using LiDAR technology[15]. The Survey Department is conducting a LiDAR survey in the western Terai regions of Nepal from Chitwan to Kanchanpur district. LiDAR has also been used to calculate the forest carbon that is estimate the biomass in the Terai Arc Landscape (TAL) ranging from the lowlands of Terai region up to the southern slopes of the Himalayas in Churia hills [16]. Similarly, there has been project regarding the comparison of cost and accuracy between LiDAR and Field based data acquisition in monitoring aboveground forest biomass. There has also been a research regarding biomass estimation using LiDAR in subtropical forest of chitwan district, Nepal [17]. Furthermore, a study has been carried out regarding the vertical profile of aerosols in the Himalayas revealed by LiDAR, which plays a crucial role in climate change[18].The literature review highlights a significant trend wherein the majority of projects utilizing LiDAR technology are primarily centered around biomass estimation, particularly within the specific context of Nepal.

4. Lidar and Precision Forestry

While the majority of projects in Nepal currently center around biomass estimation, this review discusses the diverse applications of LiDAR beyond this specific context. The paper explores how LiDAR can be utilized for various purposes in precision forestry, offering insights into its potential for forest inventory, tree species identification, terrain modeling, and ecological assessments.

Traditional forest inventory methods have faced challenges in providing accurate and complete information for effective decision-making. However, the advent of LiDAR technology has allowed greater flexibility in the field, enabling more detailed three-dimensional characterization of forest habitats and providing a wealth of information critical for informed decision-making across various aspects of forestry management[19]. LiDAR technology promises to extract various data from forested landscapes, providing unparalleled insights into ecosystem structure and dynamic characteristics. The precision and accuracy of point clouds from LiDAR make it extremely valuable for various purposes in the forestry sector. Additionally, the possible use of LiDAR in different forestry applications is discussed below:

4.1. Forest Inventory and Mapping

LiDAR technology has changed how we map and catalog forests. It is a powerful tool that collects exact three dimensional data on forests. In the forest inventory, LiDAR helps find key details like tree height, canopy structure, species spread, and the density of the forest. LiDAR works by sending laser pulses and calculating their return time. This process creates a detailed point cloud, showing the forest's vertical structure. This data gives forest managers the specific information they need for sustainable resource management[20].

4.2. Digital Elevation Model and Terrain Mapping

The LiDAR data is essential for creating detailed DEMs, providing precise elevation information across the forest landscape. These detailed representations aid in identifying terrain inclines, discerning water drainage patterns, and characterizing the topography, all of which are vital for optimizing forestry operations, such as roadway development, harvest management, and water flow control. Notably, the capability of LiDAR to capture even the smallest terrain features makes it an invaluable asset in promoting efficient and sustainable forestry practices. By incorporating LiDAR-generated terrain information, precision forestry can greatly enhance its operational planning, thereby minimizing environmental impact and improving overall forest management strategies[21].

4.3. Tree Health Assessment

LiDAR technology serves as a valuable tool in tree health assessment by providing detailed and non-invasive insights into the structural characteristics of forest canopies. In tree health assessment, this information proves crucial for identifying stressed or diseased trees. Changes in canopy height, density, and overall structure detected through LiDAR analysis can indicate potential health issues. Additionally, LiDAR facilitates the mapping of subtle variations in the canopy, revealing early signs of stress that may not be visible through other means[22]. This technology allows foresters and ecologists to target specific areas for closer inspection, enabling proactive management strategies such as pest control or disease mitigation. By providing a holistic view of the forest canopy, LiDAR contributes to a more comprehensive understanding of tree health and aids in the development of timely and effective interventions for maintaining the overall well-being of forest ecosystems.

4.4. Canopy Structure and Biomass Estimation

LiDAR is a cutting-edge technology that uses laser pulses to map out a detailed, three-dimensional image of the forest canopy. By measuring the time it takes for the signals to bounce back, this technology is able to capture even the most intricate structures of the canopy. It provides valuable data on tree height, crown dimensions, and vertical distribution of vegetation, making it an invaluable tool for accurately estimating biomass[23]. With its ability to precisely calculate volume and density, LiDAR is making significant contributions to our understanding of canopy dynamics and its impact on carbon cycling. Its high resolution and non-invasive approach make it a powerful tool for promoting informed and sustainable forest management practices.

4.5. Wildfire Risk Assessment

LiDAR helps identify factors that influence wildfire risk. These factors include vegetation density, topography, and proximity to vulnerable assets. LiDAR enables the accurate mapping of fuel loads and the assessment of potential fire behavior, allowing land managers to identify high-risk areas and implement targeted interventions. Additionally, LiDAR assists in creating fuel models, which represent the flammability of different vegetation types[24]. This information aids in simulating fire spread scenarios and developing evacuation plans. By incorporating LiDAR data into wildfire risk assessments, authorities can prioritize resources, implement proactive measures, and enhance overall preparedness for mitigating the impact of wildfires on both ecosystems and communities.

4.6. Biodiversity Monitoring

With LiDAR, various vegetation strata and habitat types can be effortlessly identified. Moreover, this innovative tool enables the mapping and quantification of habitat complexity, a key element in comprehending species diversity and distribution[25]. Not only that, but it also streamlines monitoring for ecological changes, providing valuable information for conservation efforts. By pinpointing critical habitats and areas of ecological significance, LiDAR plays a vital role in supporting conservation initiatives in a non-intrusive and efficient manner [26].

4.7. Forest Change Detection

LiDAR technology is proving invaluable in assessing forest change by providing detailed insights into long-term changes in the landscape. With its ability to transmit laser pulses and capture reflections, LiDAR provides high-resolution 3D point-cloud data that facilitates accurate monitoring of the forest environment.This data can be used to detect changes in tree height, canopy structure and overall vegetation distribution. By conducting repeated LiDAR surveys at different time intervals, foresters and researchers can compare datasets and identify areas of change[27]. Whether LiDAR is used for logging and detecting forest changes due to nature, human activities, or environmental concerns, it helps to assess the impact of natural phenomena such as land use change, or wildfire and allows informed forest management decisions to be made about strategies for change.

5. Results and Discussion

In developed countries that are technologically advanced, LiDAR technology has gained significant recognition and is being utilized across diverse fields such as forestry, urban planning, archaeological survey, autonomous vehicles, digital smart cities, disaster management, agriculture, landscape modeling, and environmental monitoring.However, in the context of Nepal, LiDAR is a novel and emerging technology that has not been used across various sectors, particularly when compared to international practices. Currently, its use is mainly observed in topographic mapping and forestry, specifically limited to biomass estimation. Despite its vast potential, there is a notable gap in the adoption of LiDAR technology in Nepal, especially within forestry. While the focus remains on biomass estimation, it is crucial to recognize LiDAR's broader applications in precision forestry, including forest inventory, tree species identification, tree health assessment, wildfire risk assessment, terrain modeling, and ecological assessments.Furthermore, acknowledging and embracing these diverse applications of LiDAR in precision forestry can significantly enhance our capacity for sustainable forest management and conservation efforts in the unique environmental context of Nepal.

6. Conclusion

In conclusion, this paper highlights the transformative potential of LiDAR technology to enhance the accuracy of forestry practices, which is evident in multi-dimensional applications around the world. While developed countries are using LiDAR in various industries, Nepal is still in the early stages of the technology.The study highlights the urgent need to expand the use of LiDAR for Nepal, especially in the area of precision forestry. Recognizing and incorporating these diverse applications can pave the way for more informed and sustainable forest management practices, aligning Nepal with international standards and fostering environmental resilience.Overall, these insights into the potential of LiDAR in precision forestry serve as a call for Nepal to widely adopt and incorporate this technology, facilitating enhanced decision-making and resource management in the country's unique environmental landscape.

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