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Precision Elevation Mapping Through Drone Integration

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Abstract: This research focuses on conducting an aerial survey of the playground at SVERI's College of Engineering, Pandharpur, using advanced drone-based mapping technology. Utilizing Ideaforge's Ryno drone equipped with an RGB payload, the survey captured 51 high-resolution aerial images, which were processed using 3Dsurvey software to generate key geospatial outputs, including reduced levels, contour maps, and a high-resolution orthophoto. The integration of drone data with advanced methodologies demonstrates the potential of unmanned aerial vehicles (UAVs) for high-accuracy mapping and geospatial analysis in academic and infrastructural projects. A critical component of this research is the generation of Digital Elevation Models (DEMs), where the resolution plays a pivotal role in fields like environmental monitoring, urban planning, and resource management. The research emphasizes that UAVs significantly enhance DEM resolution by combining very high-resolution (VHR) satellite imagery with low-altitude drone data, overcoming limitations of single-source data. Advanced super-resolution reconstruction algorithms further refine the DEMs by leveraging both internal and external data patterns, resulting in enhanced spatial detail and more accurate topographical representation. This hybrid approach not only improves the precision of DEMs but also contributes to better environmental context, essential for applications such as watershed management and climate modeling. By integrating these innovative techniques, this research opens new possibilities for the use of UAVs in generating detailed, high-quality DEMs, improving decision-making in areas where accurate topographic data is critical for infrastructure planning and environmental analysis.

Keywords — Digital Elevation Models (DEMs), Super-resolution algorithms, Drone-based 3D mapping, Data integration techniques, High-resolution satellite imagery.

I. INTRODUCTION

The landscape of topographical surveying has undergone a transformative shift, driven largely by advancements in technology and the increased accessibility of drone integration. Traditionally a labor-intensive and time-consuming process, elevation mapping is now more accurate and efficient, thanks to the precision capabilities of unmanned aerial vehicles (UAVs). Drones equipped with high-resolution cameras and LiDAR sensors can capture vast areas with a level of detail that far surpasses conventional methods. This change not only enhances the quality of the data collected but also facilitates real-time analysis, which is crucial for industries ranging from urban planning to environmental monitoring. By examining the implications of this technological evolution, the paper aims to illuminate the significant benefits that drone-assisted precision elevation mapping offers, ultimately contributing to more informed decision-making processes in various fields reliant on accurate geographical data. Different drone technologies significantly influence the accuracy of elevation mapping through various factors such as the type of UAV, the methods of data acquisition, and the processing techniques employed. For instance, UAVs like the DJI Phantom 3 have been shown to produce digital elevation models (DEMs) with varying accuracy based on the number and distribution of ground control points (GCPs) used during mapping, highlighting the importance of proper planning in data collection [1]. Additionally, the

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precision of relative elevations in DEMs can be maintained even without precise coordinate references, allowing for effective modeling in many geographical studies [2]. However, abrupt terrain changes and vegetation cover can adversely affect vertical accuracy, necessitating careful consideration of these factors during UAV operation [3]. Furthermore, advancements in radar-drone technology, including altitude control systems, can enhance the stability of elevation measurements, thereby improving the accuracy of soil water content estimations [4]. Overall, the choice of drone technology and its operational parameters are crucial for achieving high accuracy in elevation mapping.

A. Overview of Drone Technology in Mapping Applications

Emerging drone technology has revolutionized mapping applications across various fields, particularly in agriculture and geological studies. By utilizing lightweight, unmanned aerial vehicles equipped with advanced sensors, practitioners can swiftly generate high-resolution topographic data and detailed georeferenced maps. For instance, drones have made significant contributions to precision agriculture, enabling farmers to detect diseases, monitor crop health, and optimize yields through detailed pest detection and nutrient deficiency mapping [5] Similarly, in geological research, the transition from conventional airborne LiDAR systems to drone-based LiDAR technology facilitates the acquisition of precise Digital Terrain Models (DTMs), crucial for analyzing landscape changes and understanding fault dynamics [6] These capabilities not only enhance data accuracy but also minimize costs and operational constraints, thus paving the way for broader applications. As advancements continue, drone technology is poised to further transform mapping methodologies, solidifying its role as an indispensable tool in various disciplines.

Drones offer several key advantages for precision elevation mapping, primarily through their ability to generate high-accuracy Digital Elevation Models (DEMs) efficiently. The integration of advanced technologies such as GNSS and IMU systems allows drones to produce detailed topographic maps without the need for extensive ground control points (GCPs), significantly reducing time and costs associated with traditional surveying methods [8]. Studies have shown that drones equipped with PPK-GNSS can achieve elevation accuracy comparable to traditional methods, with height differences as minimal as 1 cm [7]. Furthermore, UAVs can operate in challenging terrains, making them ideal for mapping areas that are difficult to access [9]. The use of LiDAR technology in drones enhances the precision of topographic data, with Root Mean Square Errors (RMSE) reported as low as 3.6 cm [10] Overall, drones provide a versatile, cost-effective, and efficient solution for precision elevation mapping across various applications.

II. The Role of Drones in Elevation Mapping

Advancements in drone technology have significantly enhanced the precision of elevation mapping, providing detailed insights into topographical variations. Drones equipped with high-resolution cameras and sensors can capture elevation data with unprecedented accuracy, allowing for the creation of intricate 3D topographical models. These models are invaluable in applications ranging from agriculture to urban planning, where specific terrain features must be mapped for effective resource management. For instance, in the agricultural sector, the use of drones contributes to precision agriculture by enabling farmers to assess land characteristics, thereby facilitating optimal crop management decisions [12]. Moreover, integrating drone-derived data with Geographic Information Systems (GIS) allows for sophisticated spatial analysis, thereby enhancing the understanding of elevation-related factors in various contexts. Ultimately, the role of drones in elevation mapping not only improves efficiency and accuracy but also empowers stakeholders to make informed decisions based on comprehensive topographical information.

A. Advantages of Using Drones for High-Resolution Topographic Data

The integration of drones in high-resolution topographic data collection offers a transformative approach to terrain mapping, particularly in challenging environments. Traditional methods often struggle with efficiency and detail, whereas drones provide a unique combination of rapid data acquisition and exceptional spatial resolution. Notably, the application of aerial imaging can cover extensive areas rapidly, enabling precise delineation of various surface features, such as vegetation types and surface conditions, which is crucial for environmental monitoring and land management [16] Furthermore, recent advancements in drone technology, such as Real-Time Kinematic (RTK) positioning, have significantly enhanced measurement accuracy. A study highlighting the use of UAVs for gravel road profiling in Sweden found minimal discrepancies between drone-derived data and traditional methods, underlining drones' capability to yield highly precise measurements despite operational altitude [18]. Ultimately, the adoption of drones for topographic data brings unparalleled efficiency, accuracy, and adaptability to the field of precision elevation mapping.

III. Techniques and Technologies in Drone-Based Mapping

Advancements in drone-based mapping leverage various techniques and technologies that significantly enhance the precision of elevation data. One promising method involves the integration of high-resolution aerial imagery to create detailed orthomosaics, which are essential for analyzing

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complex terrains. The deployment of sophisticated machine learning algorithms allows for effective classification of habitat types based on drone imagery, as demonstrated in the systematic approach to shallow water habitat analysis [17] Moreover, innovations such as optimized trajectory planning, illustrated by the multi-strategy improvement Jaya algorithm, mitigate challenges associated with obstacle avoidance and elevate mapping accuracy in meteorological contexts [15]. These technologies not only streamline data collection but also expand the potential for effective environmental monitoring and resource management. Consequently, the evolution of drone-based techniques provides a powerful toolkit for achieving precision elevation mapping with applications across diverse fields, from ecology to urban planning.

A.Integration of LiDAR and Photogrammetry for Enhanced Accuracy

The combination of LiDAR (Light Detection and Ranging) and photogrammetry offers a transformative approach to mapping that enhances overall accuracy and detail. Each technology brings unique strengths to the table: while LiDAR excels in delivering precise elevation data through its laser-based measurements, photogrammetry provides rich color and texture information derived from overlapping photographs. By integrating these methods, practitioners can overcome the limitations inherent in each standalone system. For instance, photogrammetry can introduce discrepancies in densely vegetated areas due to occlusions, a challenge effectively mitigated by the unencumbered line-of-sight capabilities of LiDAR technology. Moreover, the fusion of these datasets through advanced algorithms allows for the creation of highly detailed and accurate 3D models, which can be invaluable in applications ranging from topographic surveys to infrastructure analysis. This synergy not only improves spatial resolution but also fortifies the reliability of the resultant data, making decisions derived from this integrated approach significantly more sound [19].

IV. Methodology

This section elaborates on the steps and tools employed in the survey mapping of SVERI's College of Engineering playground using UAV technology. Each stage of the methodology is broken down into key components: equipment selection, flight planning, data acquisition, and data processing.

1 Equipment Selection

For the survey, Ideaforge’s Ryno drone was chosen due to its versatility and proven performance in aerial mapping tasks. This drone is equipped with an RGB payload, which consists of a high-resolution camera capable of capturing detailed images in the red, green, and blue (RGB) color spectrum. RGB payloads are particularly suitable for mapping and photogrammetry applications as they produce high-quality visual imagery that can be used for terrain modeling and topographic studies.

Key features of the Ryno drone that made it suitable for this task include:

- **Stability and Maneuverability:** The drone’s robust design ensures stable flight, which is critical for acquiring high-quality images without motion blur.
- **High-Resolution Camera:** The RGB camera provides detailed imagery required for generating accurate orthophotos and elevation models.
- **Autonomous Flight Capabilities:** The drone can be programmed for autonomous flight using pre-defined waypoints, ensuring systematic coverage of the survey area.

2 Flight Planning

Before data collection, the survey area (the playground) was carefully defined. The following steps were taken during the planning phase:

- **Defining the Survey Boundaries:** The boundaries of the playground were established using GPS coordinates to create a flight path for the drone.
- **Setting the Flight Parameters:** Parameters such as altitude, flight speed, and image overlap were determined to ensure optimal data collection. Typically, an altitude of around 50 to 100 meters is selected for small-to-medium-sized areas to balance image resolution and coverage.
- **Image Overlap:** Both frontal and lateral overlap between images was set to around 70–80%. This is essential for accurate photogrammetry, as overlapping images enable the software to stitch them together into a continuous map.
- **Ground Sampling Distance (GSD):** The GSD, which represents the distance between pixel centers on the ground, was optimized to ensure high spatial resolution of the output maps.

The flight mission was pre-programmed into the drone’s flight control system to ensure systematic coverage of the entire playground area.

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Fig 1: Flight Planning

3 Data Acquisition

The Ryno drone, equipped with the RGB camera, was deployed to perform the survey under suitable weather conditions to avoid any interference from wind or excessive sunlight, which could impact image quality.

During the flight:

- A total of **51 aerial images** were captured, covering the entire playground. The images were taken at regular intervals to ensure complete coverage with significant overlap between successive images.
- The drone's autonomous flight mode ensured precise adherence to the pre-defined flight path, enabling consistent data acquisition across the survey area.
- All images were geotagged, meaning that each photo was associated with the exact GPS coordinates of the location where it was captured. This is crucial for generating accurate orthophotos and geospatial models later in the process.

Fig 2: Data Acquisition

4 Data Processing

Once the aerial images were captured, the data was processed using **3Dsurvey software**, a specialized tool for converting aerial photogrammetry data into actionable outputs.

The following steps were involved in the data processing:

4.1 Image Alignment:

The first step in the software involved aligning the captured images. The software automatically identifies common features in overlapping images to create a continuous 3D representation of the terrain. This process is known as photogrammetric stitching, where the geotagged images are combined into a unified dataset.

4.2 Point Cloud Generation:

From the aligned images, a dense point cloud was generated. This point cloud contains millions of data points representing the surface of the surveyed area. Each point has a 3D coordinate (x, y, z) and color information from the RGB images. The point cloud serves as the foundation for creating accurate 3D models of the terrain.

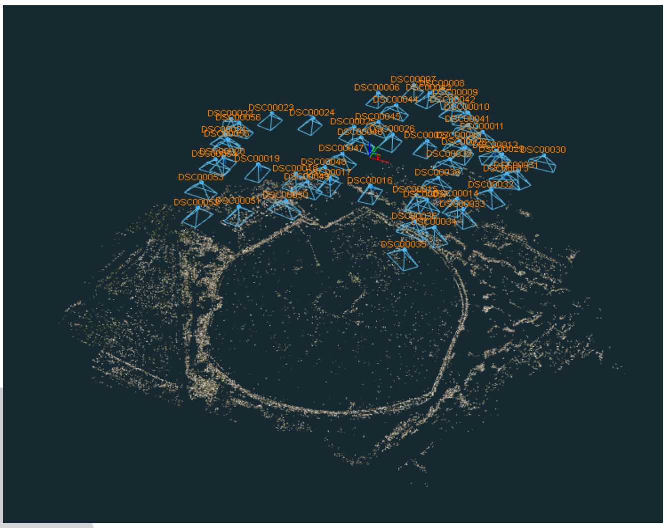

Fig 3: Point Cloud Generation

4.3 Digital Elevation Model (DEM) and Reduced Levels:

Using the point cloud data, the software generated a Digital Elevation Model (DEM), which represents the terrain's elevation. From this DEM, the reduced levels of the playground were extracted. Reduced levels indicate the elevation of specific points relative to a common reference, which is essential for understanding topographical variations across the site.

Fig 4 Digital Elevation Model (DEM)

4.4 Contour Map Generation:

Based on the DEM, a **contour map** was created. Contours are lines connecting points of equal elevation, and they provide a visual representation of terrain slopes and gradients. The contour interval was set to an appropriate

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value to provide a clear understanding of the elevation changes across the playground.

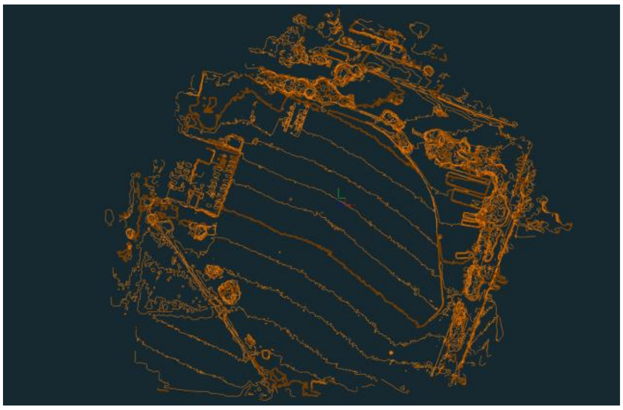

Fig 5: Contour Map

4.5 Orthophoto Creation:

A high-resolution orthophoto was generated by correcting distortions in the raw aerial images caused by terrain variations and camera tilt. The orthophoto is a geometrically corrected image that represents the playground's surface with true scale and without perspective distortions. It can be used as a base map for further site analysis and planning.

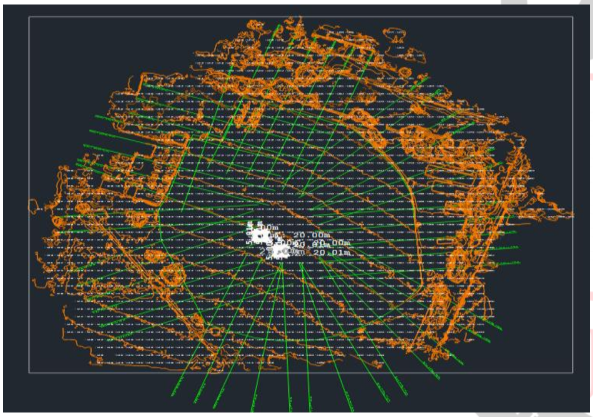

Fig 6: Orthophoto Creation

V. Results

The aerial survey of SVERI's College of Engineering playground using Ideaforge's Ryno drone generated several important geospatial outputs. A total of 51 high-resolution images were captured using the drone's RGB payload, which were processed using 3Dsurvey software to produce the following results:

Reduced Levels: Accurate elevation data for the playground was extracted, providing a detailed understanding of the terrain's high and low points. This data is crucial for engineering tasks such as grading, site planning, and construction.

Contour Maps: The processed data resulted in a contour map that visually represents the terrain's variations, with contour lines indicating changes in elevation. This is useful for designing effective drainage systems and understanding the slope patterns of the site.

Orthophoto: A high-resolution, true-to-scale orthophoto was produced, providing a detailed and geometrically corrected aerial image of the playground. This map can be used for accurate measurements and further analysis, such as facility planning and environmental assessments.

Digital Elevation Model (DEM): A 3D terrain model was generated, offering a comprehensive view of the site's topography. This is particularly valuable for civil engineering projects, enabling analysis of slope, elevation, and surface features in greater detail.

VI. Conclusion

This research demonstrated the effectiveness of UAV technology for fast and accurate geospatial data collection. The use of Ideaforge's Ryno drone, equipped with an RGB payload, significantly reduced the time and labor required compared to traditional land surveying methods. The survey outputs, including reduced levels, contour maps, and orthophotos, provided precise and actionable data for future development of the playground.

The contour map and reduced levels are particularly useful for planning site modifications, designing drainage systems, and evaluating slope stability. The orthophoto offers a high-resolution, distortion-free aerial image that can be utilized for infrastructure planning and facility management. Additionally, the DEM provides a detailed 3D view of the terrain, aiding in site analysis for construction or landscaping projects.

While the processing of large datasets required significant computational resources, the study confirmed that UAV-based surveys offer a cost-effective and reliable alternative to traditional surveying methods. The accuracy of the results, when cross-checked with ground control points (GCPs), showed that UAVs can achieve high precision in both elevation data and spatial mapping. This study underscores the potential for UAV technology in civil engineering and infrastructure planning, offering significant benefits in terms of time, cost, and data quality.

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