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RPAS And Lidar Technologies: An Alternative For Monitoring Power Line

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Abstract:
This study explores the use of Remotely Piloted Aircraft Systems (RPAS) equipped with Light Detection and Ranging (LiDAR) technology for monitoring high-voltage power lines. By integrating RPAS and LiDAR, the inspection process becomes more efficient, accurate, and safer compared to traditional methods. LiDAR's ability to capture detailed 3D data provides valuable insights into the condition of transmission line corridors, including vegetation encroachment and structural damage. The research highlights the potential of these technologies to reduce operational costs, improve data accuracy, and enhance the management of power grids, offering a sustainable solution for infrastructure monitoring in challenging environments.
Key Word*: RPAS, LiDAR, Power Line Monitoring, Geospatial Data, Infrastructure Inspection.*

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I. Introduction

The rapid advancement of technology has revolutionized the way critical infrastructure, such as power transmission lines, is monitored and maintained. Traditionally, inspecting high-voltage transmission lines has been a challenging task, requiring significant manpower and exposing workers to various safety risks. However, with the integration of Remotely Piloted Aircraft Systems (RPAS) and Light Detection and Ranging (LiDAR) technology, the process of monitoring power lines has become more efficient, accurate, and safer.

RPAS, commonly known as drones, are now equipped with advanced sensors like LiDAR, which allow for precise mapping and real-time data acquisition. This combination offers numerous advantages, including the ability to conduct aerial surveys at lower altitudes, providing high-resolution data that traditional aerial platforms cannot match. LiDAR technology enhances the monitoring capabilities by capturing detailed 3D representations of transmission line corridors, allowing for better identification of issues such as vegetation encroachment, structural damage, or faults that could impact the reliability of power systems.

This paper explores the applications of RPAS and LiDAR technologies in the monitoring of power lines, focusing on their ability to improve safety, reduce operational costs, and provide highly accurate geospatial data. By examining the advantages of these technologies, this study highlights their potential to transform how energy infrastructure is managed, particularly in challenging terrains and complex environments. With the growing need for more sustainable and efficient energy systems, RPAS and LiDAR technologies present a promising solution for the future of power line inspection and maintenance.

II. Literature Review

RPAS System

The terms "drone," "UAV" (Unmanned Aerial Vehicle), and "RPAS" (Remotely Piloted Aircraft System) are frequently used to describe remotely piloted equipment that operates in airspace without a human onboard [1][2]. While "drone" is a popular expression derived from the buzzing sound similar to that of a bee made by some of these devices during flight, "UAV" is considered obsolete by the International Civil Aviation Organization (ICAO) [1]. In contrast, "RPAS" is a technical term internationally standardized by ICAO to refer to remotely piloted aircraft systems primarily used in non-recreational contexts, as noted by [3]. Thus, these terms essentially describe the same category of equipment, varying in their popularity and technical specificity.

The RPAS consists of several subsystems, including a control station, an aircraft carrying a camera, a communication system between the control station and the aircraft, and other supporting equipment. The aircraft, referred to as an unmanned aerial vehicle (UAV), operates without an onboard crew and can be controlled remotely or autonomously via onboard computers. There are many different types of UAVs, and depending on the vehicle itself and its subsystems, they can be used for various missions [4]. Among the advantages provided by these systems are the ability to collect real-time data, rapid assessment and mapping of resources at user-defined spatial-temporal scales, no need for airports for takeoff, flexibility in data acquisition, and offering refined spatial resolution since they operate at lower flight altitudes than conventional aerial platforms [3].

In the context of applications such as aerial surveys and transmission line inspections, technological advancements make RPAS accessible solutions for observing power transmission systems at short distances [5],[6].. RPAS provide various types of data for precise inspections of power lines through multiple remote sensing technologies, such as optical cameras, LiDAR, infrared cameras, and ultraviolet cameras [5]. The RPAS systems (Figure 1) employed in this work were the LiAir50 and LiAir70, both equipped with the Matrice 600 UAV, GNSS, IMU, LIDAR, and an RGB camera. The main distinction between the systems lies in the LiDAR sensor used. These systems demonstrate their potential for geospatial data acquisition in works such as those by [7].

Figure 1 - RPA MATRICE 600 with LiDAR
Source: GVI (2023).

LiDAR Sensor

According to [8], the term "LiDAR scanner" refers to a technology for collecting three-dimensional data that employs a scanning system with LiDAR rays. This system follows the principle of measuring angles and distances to achieve positioning in three dimensions, similar to how a total station operates. The total station is an electronic instrument that emerged in the 1990s and is widely used for measuring angles and distances. It allows internal data storage which facilitates fieldwork and provides greater sophistication than a theodolite [9]. Therefore, the distinction lies in the number of points captured and the speed of data acquisition.

The LiDAR scanner system comprises three essential components: a LiDAR measurement unit, an optomechanical scanning system, and a supporting measurement recording unit [10]. These systems can be categorized as static or dynamic; typical examples of static systems include terrestrial ones that are commonly mounted on tripods for detailed surveys over short distances. In contrast, traditional mobile systems like airborne systems are installed on aircraft such as planes or helicopters and are used to cover extensive areas. Mobile LiDAR scanning systems (MLS) or Mobile Terrestrial LiDAR Scanning (MTLS) are classified as dynamic systems commonly installed on vehicles but can also be adapted for use on boats and trains as highlighted by [11]. This mobile technology entered the market in the early 2000s with the aim of conducting high-precision terrestrial surveys that surpass aerial survey limitations. One of the primary advantages of mobile LiDAR systems is their ability to collect substantially more data points compared to aerial surveys, making them valuable tools for applications requiring high resolution and detail.

Operation

The basic objective of a LiDAR scanner is to measure three-dimensional coordinates of points on a surface. To do this, LiDAR pulses are emitted by the system and directed using a scanning mirror to hit various points on object surfaces. These objects reflect the incident pulse back towards the system. Thus, the distance between the sensor and the object is determined through the time interval between emission and reflection (return) of the pulse [12]. To measure distance accurately requires precise timing between emission and reception of the pulse.

The distance can be measured using Equation 1:

$$R = \frac{1}{2} \times c \times dt$$

where:
R = distance (range);
c = speed of light;
dt = time interval between emission and registration of reflected pulse.

Currently, LiDAR sensors can be either pulsed or continuous wave types and typically have a rotating head capable of collecting points in all directions (360 degrees). Through vehicle movement combined with sensor scanning allows for effective profiling over broad areas [13].

LiDAR sensors also provide an intensity value indicating how much energy is reflected from surface elements back towards the sensor. This value is crucial for distinguishing objects within point clouds; depending on the sensor characteristics may yield different results.

Raw LAS Cloud

Typical 3D sensors use line-of-sight measurement principles to capture point clouds—3D points on surfaces like cars or houses. To store two-dimensional data in three-dimensional space often uses sparse data formats represented as coordinate lists. In this format, each point's coordinates are stored as floating-point numbers along with additional information such as RGB colors or intensity values [14].

When representing point clouds where each point has three spatial coordinates (x, y, z), organizing this information into lists requires considerable storage space because all coordinates are expressed as floating-point numbers requiring high precision for detailed capture.

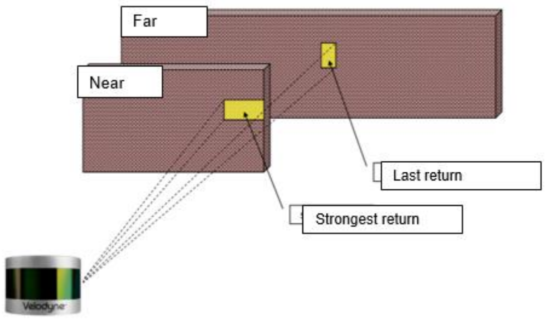
The intensity of points in a LiDAR point cloud measures how much energy is reflected by target objects towards the LiDAR sensor. This information is generally recorded numerically as an indicator of signal return strength. In some applications, intensity helps infer characteristics about objects like light reflectivity or vegetation density.

Applications of LiDAR Sensors in RPAS

The data obtained from LiDAR sensors mounted on RPAS can be georeferenced in various coordinate systems and have a wide range of applications, including entertainment and precise mapping for terrestrial surveys, road, rail, and hydrographic projects. In Brazil, LiDAR technology is becoming increasingly relevant, particularly in precision agriculture, where technological advancements optimize processes and resources while minimizing environmental impacts. The use of LiDAR in road projects has also grown due to many systems being equipped with both LiDAR sensors and digital cameras, allowing for the acquisition of necessary topographic, planimetric, and altimetric information for road development.

Additionally, LiDAR technology shows significant potential in the context of wind energy projects in Brazil. Given the country's favorable geographical and climatic conditions for wind generation, LiDAR can provide precise assessments of wind potential in specific regions, aiding in the selection of suitable sites for wind farm installations. Furthermore, the use of LiDAR in the wind energy sector enhances plant design and park operations by improving understanding of local wind patterns, ultimately maximizing energy generation efficiency. This approach also helps reduce costs associated with feasibility analysis and energy production monitoring, making projects more sustainable and economically viable.

VLP-16 LiDAR Sensor



The Velodyne VLP-16 (Figure **2**) sensor utilizes Time-of-Flight (ToF) methodology, which involves emitting infrared light pulses to determine depth information. When the light pulse encounters an obstacle, some of the energy is reflected back to the sensor's receiver. By analyzing the time taken for the pulse to return and its signal strength, the sensor can accurately calculate both distance and return intensity. This technology allows for the capture of highly detailed and accurate three-dimensional point clouds, facilitating a precise reconstruction of the environment where the sensor operates. The VLP-16 sensor achieves high spatial and temporal resolution, making it suitable for various applications, from urban mapping to topographic surveys.

In addition to its depth measurement capabilities, the VLP-16 sensor provides a wide dynamic range, enabling it to capture both nearby and distant objects with high accuracy. As illustrated in Figur2, it offers three types of returns: strongest return, last return, and dual return, which occur when the emitted light beam hits multiple objects within its field of view. This functionality enhances its applicability across different scenarios, such as urban area mapping and rugged terrain surveys. Overall, the Velodyne LiDAR sensor stands out for its ability to deliver precise geospatial data while effectively distinguishing between different objects based on their reflective properties.

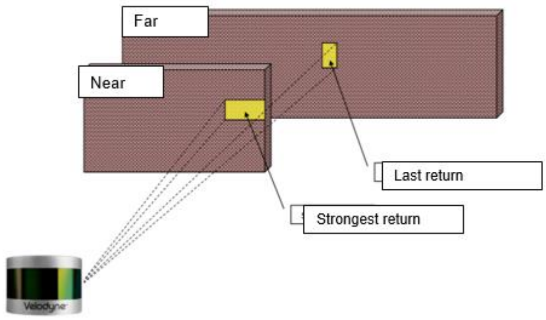


Figure 2 - Types of Returns from the Velodyne VLP-16 [26].
Sensor LiDAR Livox AVIA

The AVIA LIVOX (

Figure 3) sensor is an advanced option compared to the VLP-16, despite both being notable LiDAR sensors. While the functional characteristics found in the VLP-16 are also present in the AVIA LIVOX, the main distinctions lie in performance and design. The AVIA LIVOX stands out for its remarkably high spatial and temporal resolution, enabling meticulous and precise environmental detail capture, whereas the VLP-16 offers a robust alternative with a proven track record of consistent performance. Additionally, the physical characteristics of these sensors differ significantly; the AVIA LIVOX is designed to be compact and lightweight, weighing only 500 grams, making it ideally adaptable for integration into various RPAS platforms, while the VLP-16 is slightly larger and heavier.

Both devices are proficient in determining different signal return modes, such as strongest return, last return, and dual return; however, nuances in their signal return technology can vary between models, directly influencing data interpretation and application contexts. The differences in design and functionality enhance the applicability of the AVIA LIVOX across diverse scenarios, such as urban mapping and rugged terrain surveys. Overall, while both sensors deliver precise geospatial data, the AVIA LIVOX's advanced features may provide advantages in specific applications where high-resolution data capture is critical.

Figure 3 - Sensor LiDAR LIVOX AVIA [27]

Transmission Lines (Section 2.2.1)

The transport of energy generated in power plants to transformer stations, as well as the interconnection with other transmission systems, is carried out through transmission lines, which operate at high voltage, allowing energy to be transported over long distances [16]. According to [17], transmission lines are the most effective way to deliver electricity from its generation source to end users, making them a critical part of the power system.

Energy transmission lines interconnect various power generation facilities and distributors in the bulk electricity transmission system [5]. According to [16], in Brazil, transmission lines operate at voltage levels equal to or greater than 230 kV. Aerial transmission lines generally consist of bare conductor cables supported by structures or towers and insulated by isolators [16]. In summary, an aerial transmission line is composed of the elements schematically presented in Figure 4. A typical overhead power line system in the electrical grid consists of thousands of components, including conductors, ground wires, insulators, clamps, splices, spacers, and dampers [5].

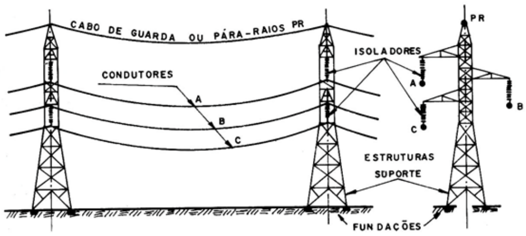


Figure 4 - Basic Components of an Aerial Transmission Line – [17]

The management and inspection of transmission line corridors, including objects within their easement zones, play an extremely important role in risk management for power lines. This task is a challenging part of routine monitoring in an electric utility company [17]. Accurate monitoring using robust solutions for these power transmission networks enables the reengineering of transmission lines by estimating the altimetric variation in the cable catenary curve and identifying potential intrusions (such as vegetation growth damaging transmission lines or illegal constructions in non-buildable zones). [5],[19].

High electromagnetic field levels can harm humans, animals, or objects near transmission lines, making it necessary to inspect easement zones along the lines to minimize the impact of these fields (SILVA et al., 2016). Transmission line components can be destroyed or damaged by natural disasters such as windstorms, lightning, and fires, as well as anthropogenic activities such as pollutant leaks. These incidents result in infrastructure failures, including overheating, erosion, collapses, fires, or arc faults [5]. For these reasons, transmission lines are of extremely high priority for utility companies [18].

According to [19], traditional inspection methods for transmission lines are inefficient, indicating the need for more efficient and automated approaches to maintain grid safety and improve the reliability of power supply. Traditional methods typically rely on professional personnel using laser rangefinders, optical theodolites, total stations, thermographic devices, and related equipment to perform inspections [21]. These methods have disadvantages such as safety risks and low efficiency, failing to meet the needs of energy system management or the requirements for grid development and institutional reform [21], [22].

LiDAR technology, mounted on RPAS, is recommended for low-altitude aerial surveys or the acquisition of 3D data at short distances. With the rapid development of these systems, some inspection sensors can be integrated into these aircraft to enhance their environmental perception capabilities in energy transmission [22]. Notable advantages include their small size, low cost, and excellent mobility. By embedding active remote sensing technology based on laser beams, it is possible to detect fine structures, such as overhead transmission lines, public lighting wires, and fences. This technique for inspecting power line corridors offers a fast way to obtain high-precision 3D geospatial information, represented by dense point clouds. [21] [23] [24]

Transmission Line Components

The electrical performance of transmission lines is largely determined by their physical characteristics and the topology of the interconnected system. These factors define their operational parameters under normal conditions and their behavior during adverse situations, such as energy flow limitations along the lines [17].

Conductor cables are the primary elements responsible for transporting energy through electric and magnetic fields. According to [17], these cables must exhibit high durability, excellent conductivity, low cost, strong mechanical resistance, lightweight properties, and high resistance to oxidation and corrosion caused by chemical pollutants.

Insulating structures play a vital role in electrically isolating the supporting structures from the ground. They must also withstand vertical and horizontal forces caused by weather conditions, requiring robust resistance. Common types of insulators used in transmission lines include pin, post, and suspension insulators,

as shown in Figure 5.

Figure 5 - Types of Pins, Post, and Suspension Insulators [17]

Ensuring that these components meet stringent standards is essential for maintaining efficient energy transfer and enabling transmission lines to withstand environmental challenges.

Transmission line structures serve specific purposes based on the loads they are required to support. Suspension structures are designed to handle vertical loads, such as wind and the weight of cables and insulators. Anchoring structures, which are divided into terminal types for large deflections and intermediate types for moderate deflections, are used at the beginning and end of the lines as well as in their midpoints to balance longitudinal tensions. Phase transposition structures ensure the magnetic balance of the line, while branch structures allow line tapping to feed distribution branches without requiring sectionalizing yards [25].

Support structures, such as towers, bear the weight of cables and insulators. The arrangement and spacing of conductors in transmission lines, whether triangular, horizontal, or vertical, significantly influence the configuration of these structures. Additionally, the dimensions and forms of insulation are determined by the nominal voltage and anticipated overvoltages. Other key factors, such as conductor sag, safety clearance, and the mechanical function of the structures, also vary depending on the type of load the transmission lines must handle.

The choice between self-supporting structures (rigid, flexible, mixed, or semi-rigid) and guyed structures depends on the specific requirements of each case. Materials used for structural components—such as metal, wood, or concrete—play a crucial role in determining the strength and durability of the transmission lines. Furthermore, the number of circuits and other practical considerations also impact the design and operation of these lines.

The architecture of support structures is shaped by the goals and predefined requirements based on the line's capacity. Common types of structures include the ones shown in Figure 6, where this study focuses on delta and pyramid-shaped towers, labeled as Type 1 and Type 2. These structures are inherently complex for measurement using traditional methods like orthophotos due to their intricate geometry and the presence of various obstructions, such as surrounding vegetation or environmental features. As a result, using point clouds derived from LiDAR technology provides a more accurate and reliable strategy for measuring and analyzing these elements. The high density and precision of LiDAR point clouds allow for the detailed capture of complex shapes and structures, overcoming the limitations posed by traditional imaging techniques, and ensuring higher accuracy in the assessment of power line components.

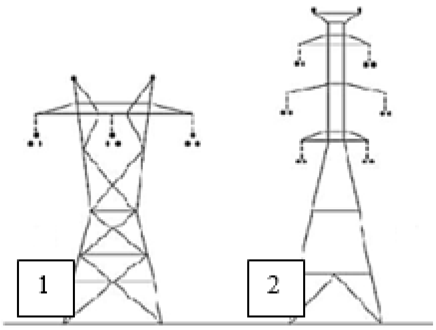


Figure 6 – Types of Tower Structures [17]

Data Capture for Transmission Lines

This section outlines the process for acquiring data, from planning to generating the final products, as illustrated in Figure 7. This flowchart presents the stages involved in both data acquisition and data validation, ensuring that the collected information meets the required standards for accuracy and quality. The process includes defining flight parameters, collecting point cloud data, and strategically placing control points for reference. Additionally, it highlights the validation steps, where raw data is compared with ground-truth measurements to confirm its integrity and alignment with predefined criteria, ultimately ensuring reliable results for further analysis and application.

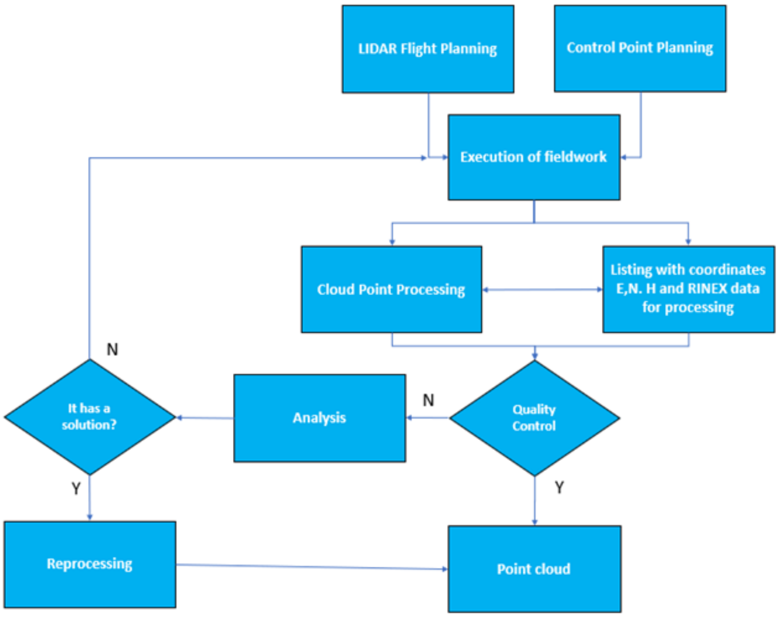


Figure 7 - Flowchart of Planning, Point Cloud Capture, and Control Point Collection Processes

The process of generating products to be used as inputs for the neural network involved several steps, as shown in the flowchart. Initially, flight planning parameters for LiDAR data acquisition were defined, including:

- Flight altitude: Maintained at approximately 100 meters to ensure resolution and coverage.
- Lateral overlap: Configured at 30% to provide comprehensive terrain coverage and minimize gaps.
- Longitudinal overlap: Set at 80% to ensure adequate point density and data quality.
- Flight speed: Adjusted to 10 meters per second for optimal data sampling without compromising quality.

These parameters align with best practices, as discussed by De Oliveira et al. (2017), who emphasize the uncertainties in reliably specifying RPA and sensor combinations for collecting useful data, particularly for high-voltage transmission lines. Proper selection of flight parameters and control point distribution was essential to capture cables and towers effectively.

Control points were strategically placed in unobstructed areas with minimal signal interference to avoid issues like signal multipath errors and ensure their visibility in the point cloud. Each step of the process underwent thorough evaluations to prevent costly field data recollection. If any established criteria were unmet, the workflow reverted to the corresponding step in the process, as indicated in the flowchart.

After completing the flight and control point collection, data integrity was assessed. A raw point cloud was generated and compared with field-collected control points. For this study, a maximum allowable discrepancy of 0.15 meters was established, based on the LiDAR equipment's nominal accuracy of 0.08 meters and a flight altitude of 100 meters. If results failed to meet the acceptance criteria, sensor misalignment parameters were recalculated.

III. Conclusion

The integration of RPAS and LiDAR technologies represents a transformative approach to monitoring power lines, offering precision, efficiency, and scalability for the energy sector. The use of RPAS systems, equipped with advanced LiDAR sensors such as the LiAir50 and LiAir70, has proven effective in capturing high-resolution geospatial data essential for inspecting and maintaining transmission lines. These systems allow for detailed mapping of key structural components, such as cables, towers, and insulators, while enabling accurate assessment of environmental risks, including vegetation encroachment and infrastructure degradation.

LiDAR's ability to generate dense and precise 3D point clouds makes it an invaluable tool for addressing the challenges posed by complex terrains, as demonstrated in datasets with varying altimetric conditions. Moreover, advancements in sensor technology, such as the Livox AVIA and Velodyne VLP-16, have further enhanced data acquisition capabilities, enabling effective monitoring in both urban and rural settings.

The automation and data processing capabilities provided by RPAS and LiDAR are particularly significant in the context of high-voltage transmission lines. These technologies not only reduce operational risks and costs compared to traditional methods but also improve data accuracy and reliability. The structured workflows for flight planning, data collection, and quality control ensure that the results meet stringent standards, supporting informed decision-making in the design, operation, and maintenance of power grids.

In conclusion, the adoption of RPAS and LiDAR technologies offers a robust alternative for monitoring power lines, aligning with the growing need for sustainable and efficient energy solutions. As these technologies continue to evolve, their potential applications in the energy sector are expected to expand, driving innovation and improving the resilience of critical infrastructure systems.

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