Predictive Inspection of Vegetation Encroachment on Power Lines using Line-Crawling Robot and Multimodal Sensor

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***Abstract*—This paper presents an approach for the predictive inspection of high-voltage transmission lines utilizing a multimodal sensor mounted on an autonomous robot capable of navigating the transmission cables and overcoming obstacles. The primary aim is to assess the proximity of vegetation to the power lines and to predict potential electrical faults, such as arcing and current leaks, which could lead to outages or safety hazards. This intelligent, sensor-driven method enhances early fault detection, contributing to improved maintenance strategies and increased reliability of the power transmission infrastructure.**

Keywords-robot; inspection; predictive; vegetation.

I. INTRODUCTION

Inspection of high-voltage power lines is critical in ensuring reliable and safe electricity transmission between the generation and great centers. Systematic inspections are vital to identify potential faults, assess infrastructure integrity, and implement repairs to mitigate disruptions and enhance the longevity of the power grid system [1].

Corrective maintenance is very costly because it occurs after a failure, and the time required for maintenance is directly related to the time without a power supply to large centers. Preventive maintenance is used as a periodic tool to guarantee the longevity of transmission lines, but it leads to frequent unnecessary equipment replacement, resulting in unnecessary costs [2]. The ideal solution is to use predictive maintenance, which occurs through a correct inspection diagnosis and leads to changes or corrections that are truly necessary for the continuity of electrical energy transmission.

Predictive inspection of high-voltage power lines without the assistance of robotic technology presents considerable challenges due to the inaccessible and hazardous environments in which these lines are situated and because it is necessary for a rigorous diagnostic. Human inspection requires significant resource allocation, including deploying helicopters or other specialized equipment, which can be costly and time-consuming. These inspections are prone to human error and may not consistently identify all defects [3].

Vegetation encroachment is a critical issue for power transmission lines because of the growth of trees and other vegetation into the clearance zones around high-voltage lines, which can pose significant risks to the reliability and safety of power distribution networks. When vegetation contacts power lines or equipment, it can lead to interruptions and electrical faults, including short circuits and grounding faults that may result in power outages. An electric arc must be created with an arc fuge, which can lead to burning vegetation and nearby areas [4].

The remainder of this paper is structured as follows. Section 2 presents the proposed multimodal inspection approach, detailing the sensing technologies and data acquisition strategies adopted for high-voltage transmission line monitoring. Section 3 focuses on predictive inspection of vegetation encroachment, describing the analytical methods and algorithms applied to assess proximity risks and enable early fault detection. Finally, Section 4 concludes the paper by summarizing the main contributions and outlining directions for future work.

II. MULTIMODAL INSPECTION

Multimodal inspection of power lines involves integrating various sensing and data acquisition techniques to comprehensively monitor the transmission infrastructure's health and safety [5]. The MultiSpectrum sensor aims to enable the detection of a wide range of issues, such as damages, vegetation encroachment, thermal anomalies, and corrosion, combining technologies such as visual imaging, infrared thermography, multispectral sensors, and depth sensors, as shown in Figure 1. The synergy of multiple inspection modalities provided by this sensor produces a more detailed and more accurate assessment than any single method could achieve alone, allowing early fault detection.

The *Power Transmission Lines Inspection Robot* (PTLIR) is line-crawling robot that moves on transmission line cables, overcoming obstacles, such as spacers, insulators, and conductor path variations. The topology aims to ensure efficient cable adhesion and perform evasive maneuvers without external intervention. The robot disengages its wheels from the cable, surpasses the obstacle, and reestablishes contact and traction to continue moving, offering a practical approach for future autonomous inspection systems. As Figure 2 illustrates, this robot moves the MultiSpectrum robot above the power lines.

From a technical point of view, the robot has six degrees of freedom distributed among its main mechanisms: two degrees

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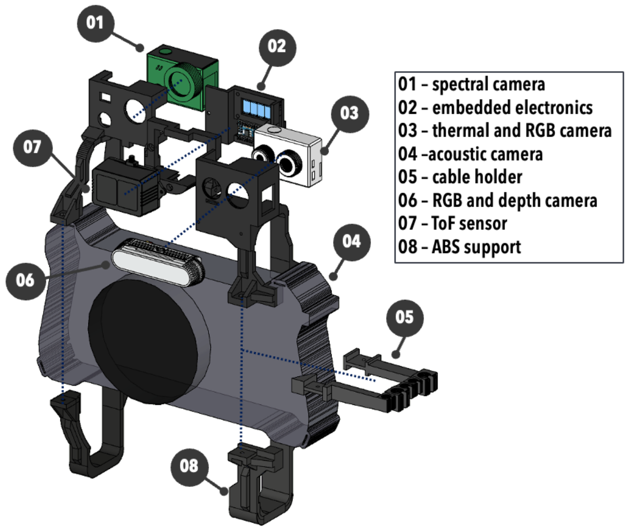

Figure 1. Multimodal inspection sensor [3].

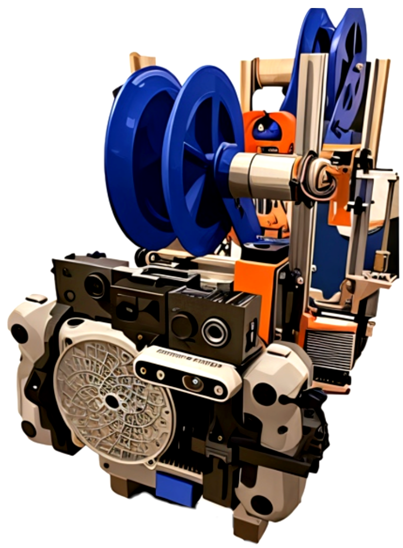

Figure 2. RPTLIR robot with MultiSpectrum inspection sensor.

for the traction wheels, which separate laterally to release the cable; two degrees in the lifting mechanisms, which move the wheels vertically to bypass obstacles; one degree of freedom in the wheelbase opening and closing system, adjusting the robot's width as needed; and an additional degree corresponding to the closure of the claw that secures the robot to the cable during operations. This combination of movements enables the system to perform complex bypass maneuvers with precision while maintaining its mechanical fixation and alignment along the line.

The MultiSpectrum sensor generates a composite inspection map in which each layer represents a specific integrity analysis. The map is spatially and temporally referenced, allowing the status of electrical power elements to be determined at specific times. Predicting future behavior and potential failure progression is possible by correlating different inspection maps for the same elements, as shown in Figure 3.

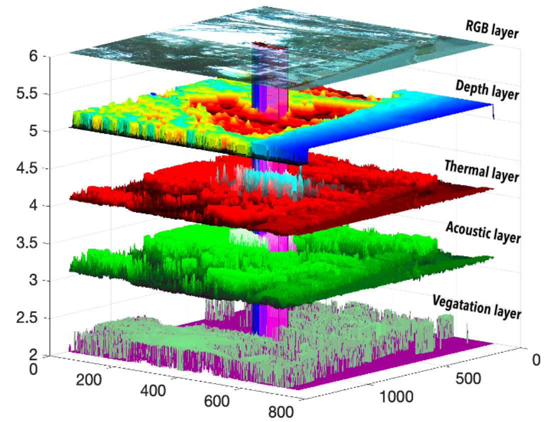

Figure 3. Multilayer Inspection Map.

III. Predictive Inspection of Vegetation Encroachment

Invasive vegetation inspection is carried out using a multispectral camera that is a module of a MultiSpectrum sensor and captures detailed spectral data across multiple wavelengths, assessing vegetation health. By analyzing specific spectral bands — particularly those associated with chlorophyll absorption and reflectance, such as the red, green, and near-infrared regions — the camera can detect subtle variations in plant vitality that are not visible to the naked eye. This capability enables precise assessment of plant health, stress levels, and potential issues such as disease or inadequate water supply. This information is directly related to the distance of vegetation from the power lines and the current fugue that causes the electric arc, as illustrated in Figure 4.

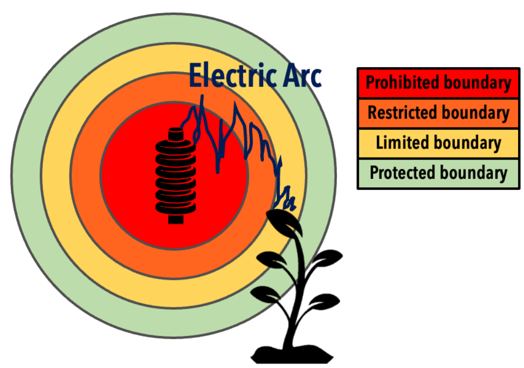

Figure 4. Electric arc occurrence on Vegetation Encroachment.

The multispectral image is segmented using k-means clustering in the Lab color space. The process begins by loading the image and converting it from sRGB to improved perceptual uniformity. The 'a*' and 'b*' channels, which carry color information, are then extracted. The pixel data is reshaped into a two-dimensional matrix and clustered into three groups using k-means, with multiple iterations to enhance the clustering accuracy. The resulting cluster labels are reshaped back into the original image dimensions, producing a labeled image and separate segmented images for each cluster, where only the pixels belonging to a specific cluster are visible. This method effectively groups the image based on color similarities, enabling a detailed analysis of different regions. The segmented results are subsequently mapped onto the RPB classified layer of the inspection map to identify the regions of the transmission line elements and to generate three-dimensional security boundaries for a comprehensive assessment of the infrastructure, as shown in Figure 5.

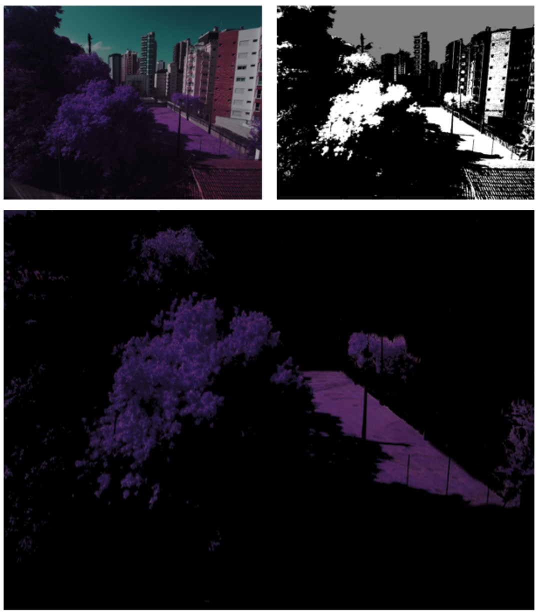

Figure 5. Multispectral imagem processing.

IV. Conclusion and Future Work

This paper discussed the use of multimodal sensors on autonomous robots for predictive inspection of high-voltage transmission lines, enabling accurate assessment of vegetation proximity and early detection of electrical faults. Future work should focus on refining sensor integration for real-time data processing, expanding autonomous navigation capabilities in diverse environmental conditions, and developing advanced algorithms for predictive analytics to improve fault prediction accuracy and inspection automation further.

Additional experiments with more detailed data processing results are currently being developed. These include the presentation of larger datasets, numerical matrices, and complete examples of image and sensor data processing workflows. As the research progresses, these results will provide a more comprehensive view of the methodology and its performance under different operational conditions, contributing to the robustness and scalability of the proposed approach.

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