Low-Cost, Semi-Autonomous Pipe Inspection Rover for Guatemalan Hydroelectric Power Plants

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I. Abstract

Water inlet pipes are critical in hydroelectric plants, but prolonged use leads to wear, requiring thorough inspections to identify potential problems. To address this, a mobile, modular robot has been developed for manual or semi-autonomous pipe inspections. Equipped with LiDAR, RGB-D cameras, and IMU, the robot scans pipes for damage and accurately locates itself. Its modular design allows for easy assembly and entry through manholes.

II. Introduction

According to the Latin American Energy Organization (OLADE), hydroelectric plants produce 52.3% of Guatemala's total electrical generation [1]. Thus, ensuring the infrastructure's proper condition is crucial to maintaining the production and distribution of power. However, limitations to regular inspections arise due to extensive subterraneous pipe routes (about 2-4 km) and few access points. Additionally, human inspections on slippery, confined spaces are inefficient and risky. This work presents a modular, mobile robot capable of manual or semi-autonomous pipe inspections, adapting to diameter changes, slopes, and physical conditions. Manual mode involves joystick control for movement and turning, while semi-autonomous mode automates turning to keep the robot centered. The custom tracked rover equipped with multiple sensors scans pipes for localization, damage and deformation assessment, and stores relevant data for a findings report. The modular design facilitates assembly, transport, and entry through access holes. It comprises of control (computing, sensors) and locomotion/power modules (batteries, motors).

III. Methods

The robot is equipped with several sensors, including:

- 3D LiDAR with 16 laser light beams
- Three RGBD sensors with a structured light scanner
- Inertial Measurement Unit (IMU) with 6 DoF
- Two quadrature encoders for accurate movement estimation.

During the inspection process, the LiDAR sensor continually performs a 360-degree sweep, resulting in the acquisition of 16 concentric rings. These rings are instrumental in spatially reconstructing the circumference of the pipeline. This spatial data is subsequently employed to verify the degree of circularity deviation, or ovality, exhibited by the pipe [2]. Furthermore, the deployment of two lateral depth sensors facilitates the partial reconstruction of specific pipe segments, enabling visual scrutiny to detect any potential imperfection in addition to enabling visual inspection in the GUI deployed in Fig 4. Additionally, precise size measurements are conducted at each pipe joint connecting the diverse segments constituting the pipeline.

Fig 1. Side and front view of the inspection rover

The integration of data gleaned from the frontal depth sensor with that provided by the LiDAR, inertial measurement unit (IMU), and the pair of quadrature encoders serves a pivotal role. This amalgamation of data enables the precise localization and inclination of the robotic apparatus within the pipeline. Such localization is achieved through the application of sophisticated simultaneous localization and mapping (SLAM) techniques, as shown in Fig. 2.

Fig 2. Map produced by SLAM with the 3D LiDAR

IV. Results

The rover shown in Fig. 1 was designed, built, tested and deployed to conduct a successful inspection in the pipes of a hydroelectric power plant in Guatemala. The measurement tool for pipe joint spacing achieved results with less than 95% deviation from ground truth data, demonstrating high accuracy. Additionally, the analysis of LiDAR data yielded the percentage of ovality as illustrated in Fig 3. Finally, proper inclination estimation has been achieved with the 6 DoF IMU sensor, as illustrated in Fig 5.

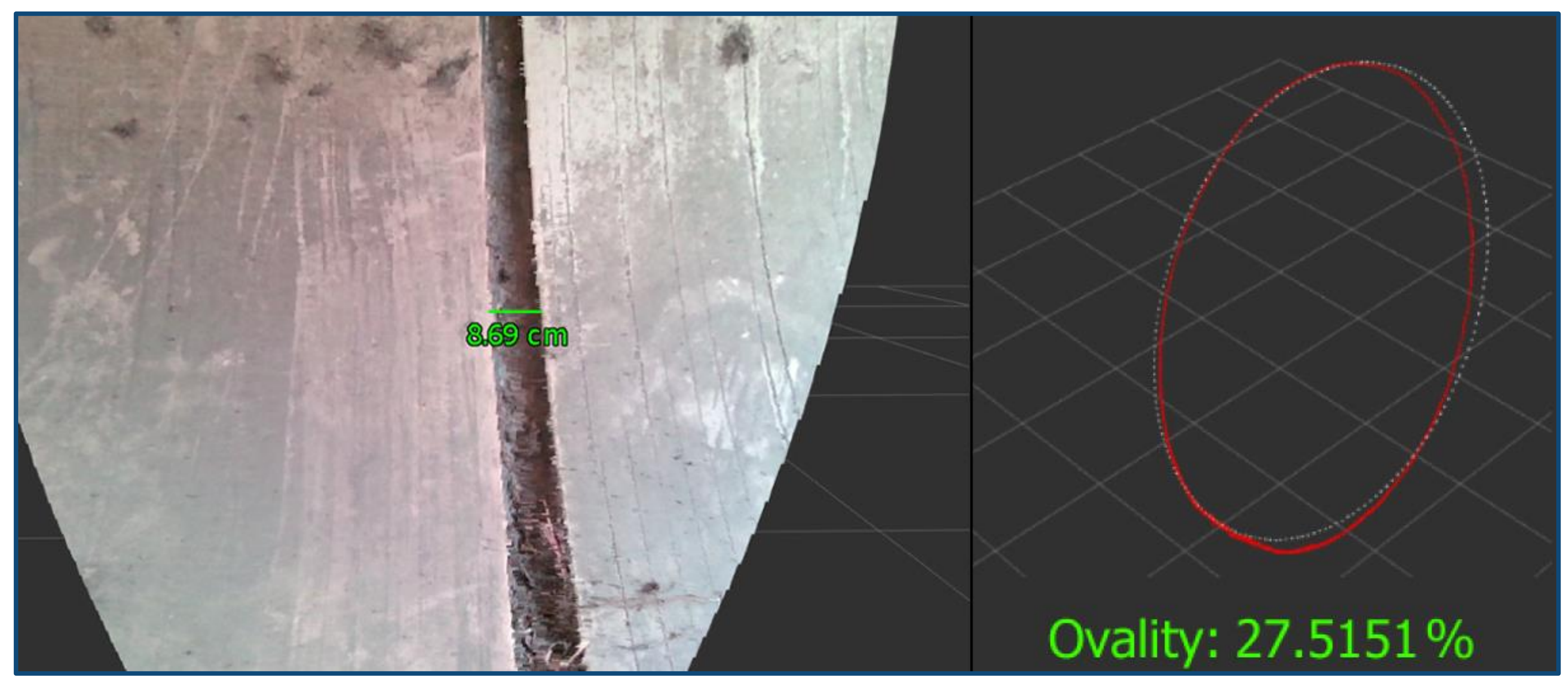

Fig 3. Test distance measurement of a pipe junction and ovality percentage obtained.

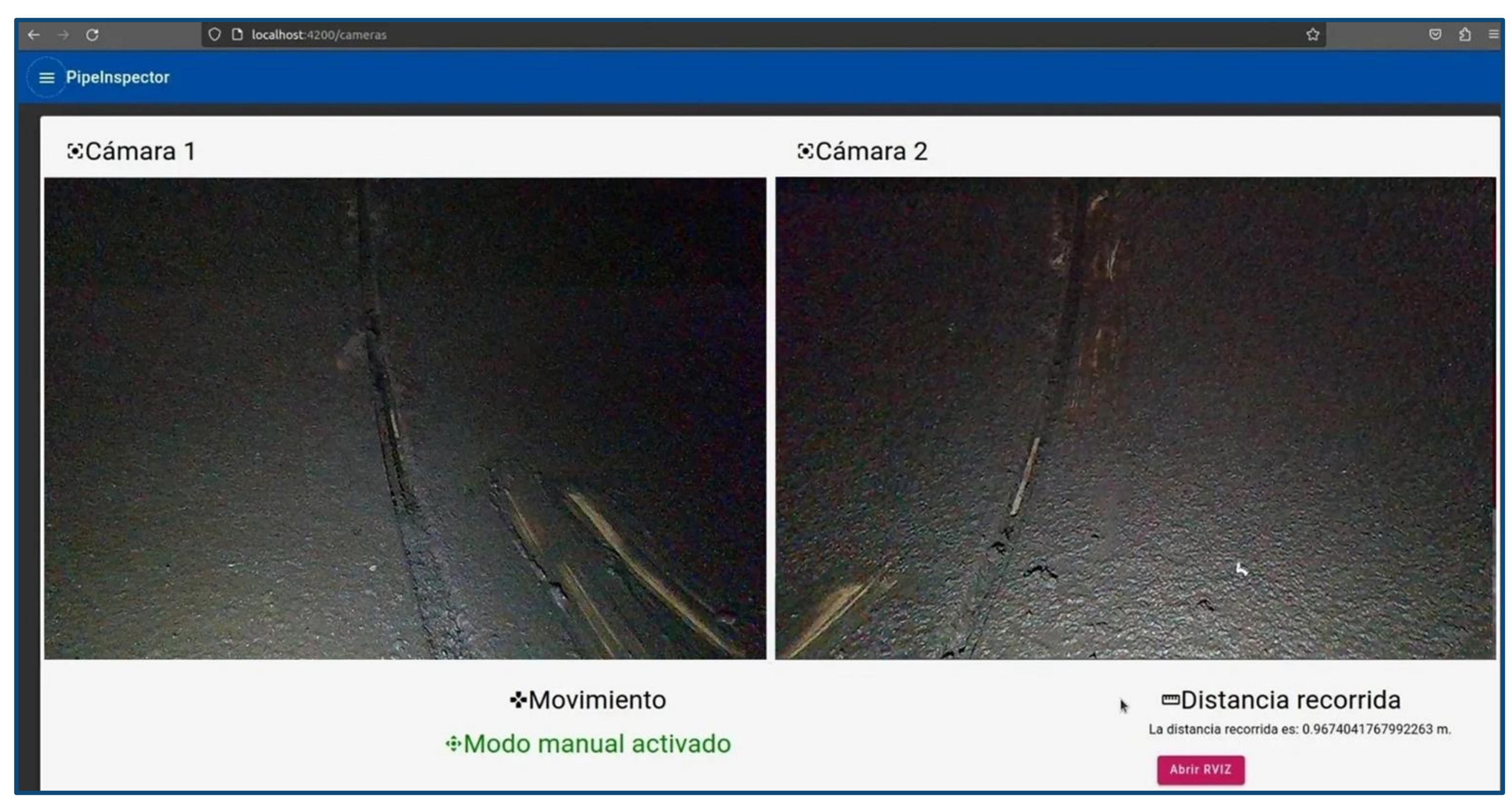

Fig 4. Graphical user interface of the rover.

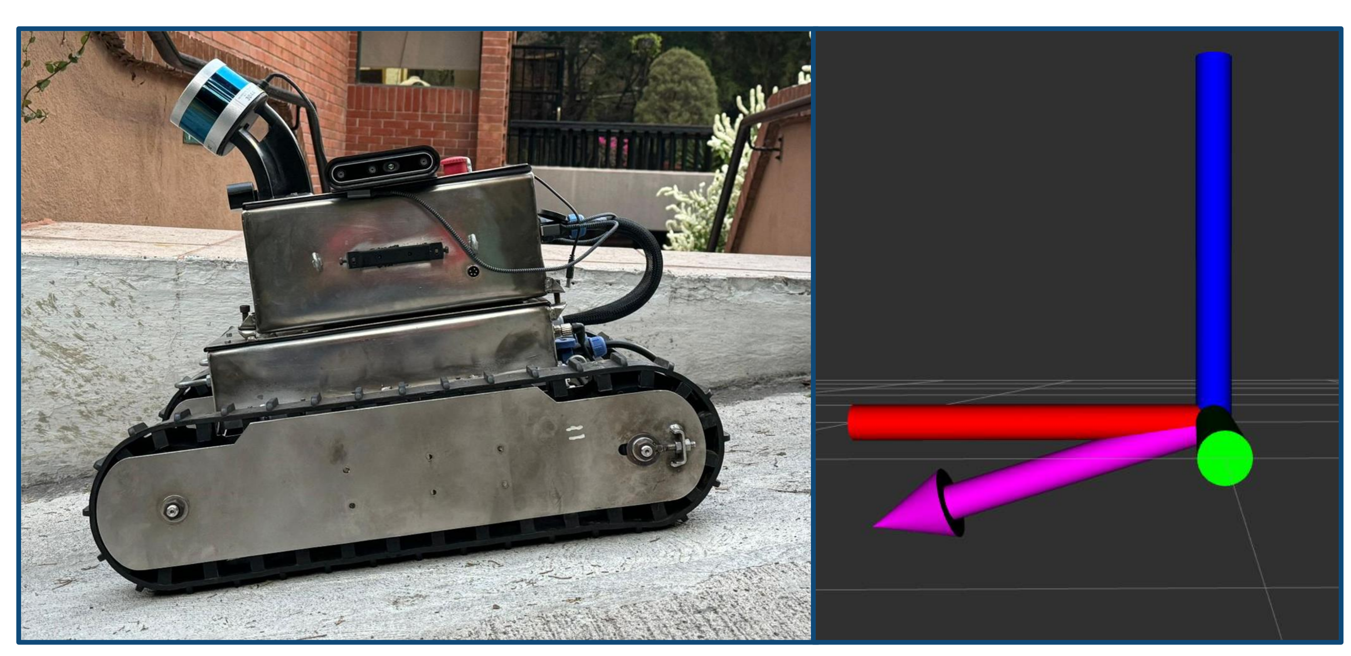

Fig 5. Inclination measurements performed using IMU data.

V. Conclusions

- Regular infrastructure inspections are indispensable for electricity reliability.
- Human inspections are slow, inefficient and risky.
- A mechanical device is more reliable, and prevents workers exposure.
- Expert analysis and interpretation are still needed to plan, execute and evaluate reparations.
- Relevant measurements and information are now easily obtainable remotely.

VI. References

[1] T. Castillo, F. Garcia, L. Mosquera, T. Rivadeneira, K. Segura, and M. Yujato, "Panorama Energético de América Latina y el Caribe."
[2] Q. X. J. X. J. W. Cheng Yi, Dening Lu, "Tunnel deformation inspection via global spatial axis extraction from 3d raw point cloud," 2020.