

PROTOTYPE ROBOT FOR THE INSPECTION OF SEWER SYSTEMS

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Abstract

This paper reports on the development of a low-cost, easily portable automated vehicle for sewer pipeline inspection. Unlike the complex systems described in the open literature, this proposal overcomes the current engineering economic barrier. This allows for an efficient transition to full autonomy in critical environments.

The prototype has a laser sensor for obstacle detection and an optical encoder. The last records linear displacement and distance traveled in centimeters. Its gyroscope determines the device's orientation and position, and a viewing camera has been integrated. Besides, a hybrid wireless transmission system (Bluetooth and Radio Frequency) has been implemented to simultaneously send sensor telemetry and the camera's video signal to the operator. This is through a custom-developed teleoperation interface using NRF24L01 modules with amplification (PA+LNA). This ensures a stable reception of instructions for remotely controlling the robot's movement.

The information collected is stored in a database. The recorded parameters are position, orientation, distance traveled, and object detection. The camera allows real-time visualization through a graphical interface developed in Python. It provides a preliminary assessment of the pipeline's condition.

This solution eliminates the economic barrier to industrial automation, reducing workplace risks and optimizing diagnostic times in critical infrastructure.

Keywords: Encoder, Gyroscope, Teleoperation, Interface, Telemetry, Embedded system.

Introduction.

The advancement of robotics has redefined human intervention in critical tasks by replacing manual operations in hazardous environments with integrated systems capable of sensing, processing, and acting efficiently [1]. In wastewater infrastructure management, pipeline inspection represents a technical challenge due to the geometric complexity and restricted dimensions of the conduits [2]. The lack of preventive maintenance in these systems increases the risk of structural failures and occupational accidents, mainly attributed to vandalism (43%), poor management practices (15%), and corrosion (15%) [3].

The management of hydraulic infrastructure in Mexico is currently facing an obsolescence crisis. Although sewerage coverage reaches 93.8%, the physical condition of the networks is alarming because a large portion of the pipelines has exceeded its service life, particularly in areas with high geological complexity such as the Valley of Mexico. This deterioration causes subsidence and leakage, contaminating aquifers and jeopardizing urban safety.

Methodology

The methodology followed includes conceptual design, prototype instrumentation, control system design, instrumentation programming, control system programming, prototype construction, and results, as shown in Fig. 1.

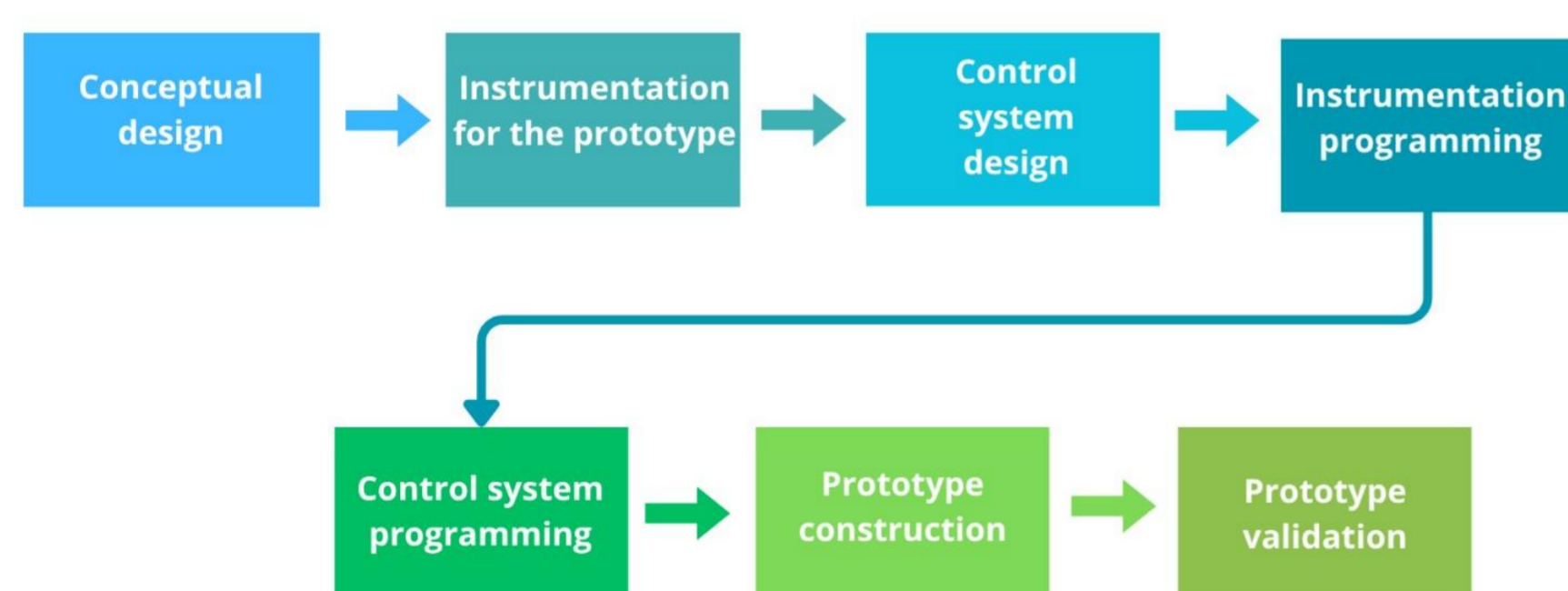


Figure 1. Methodology

Figure 2 shows the functional architecture diagram of the inspection robot.

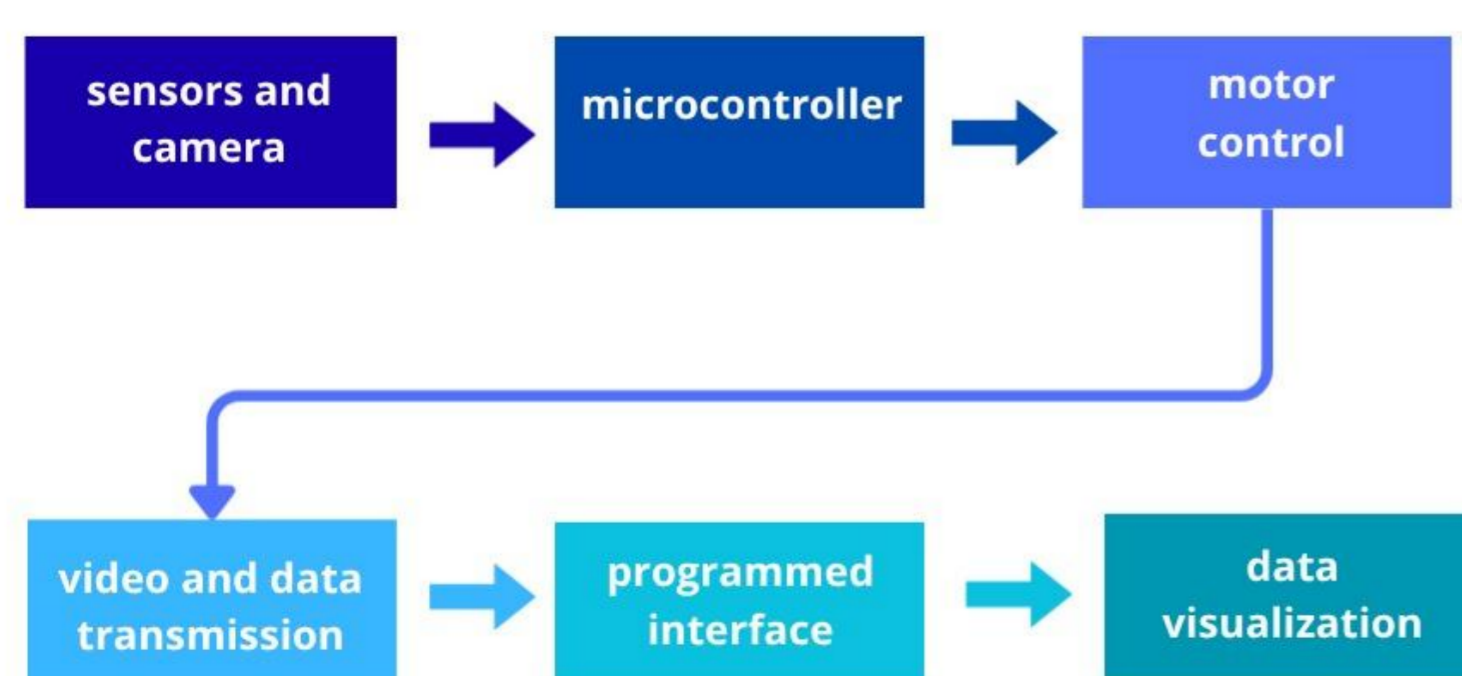


Figure 2. Process of robot operation

Figure 3 illustrates the electrical schematic of the system based on the Arduino platform. This illustration shows the integration of the sensor network with the power stage controlled by the H-Bridge.

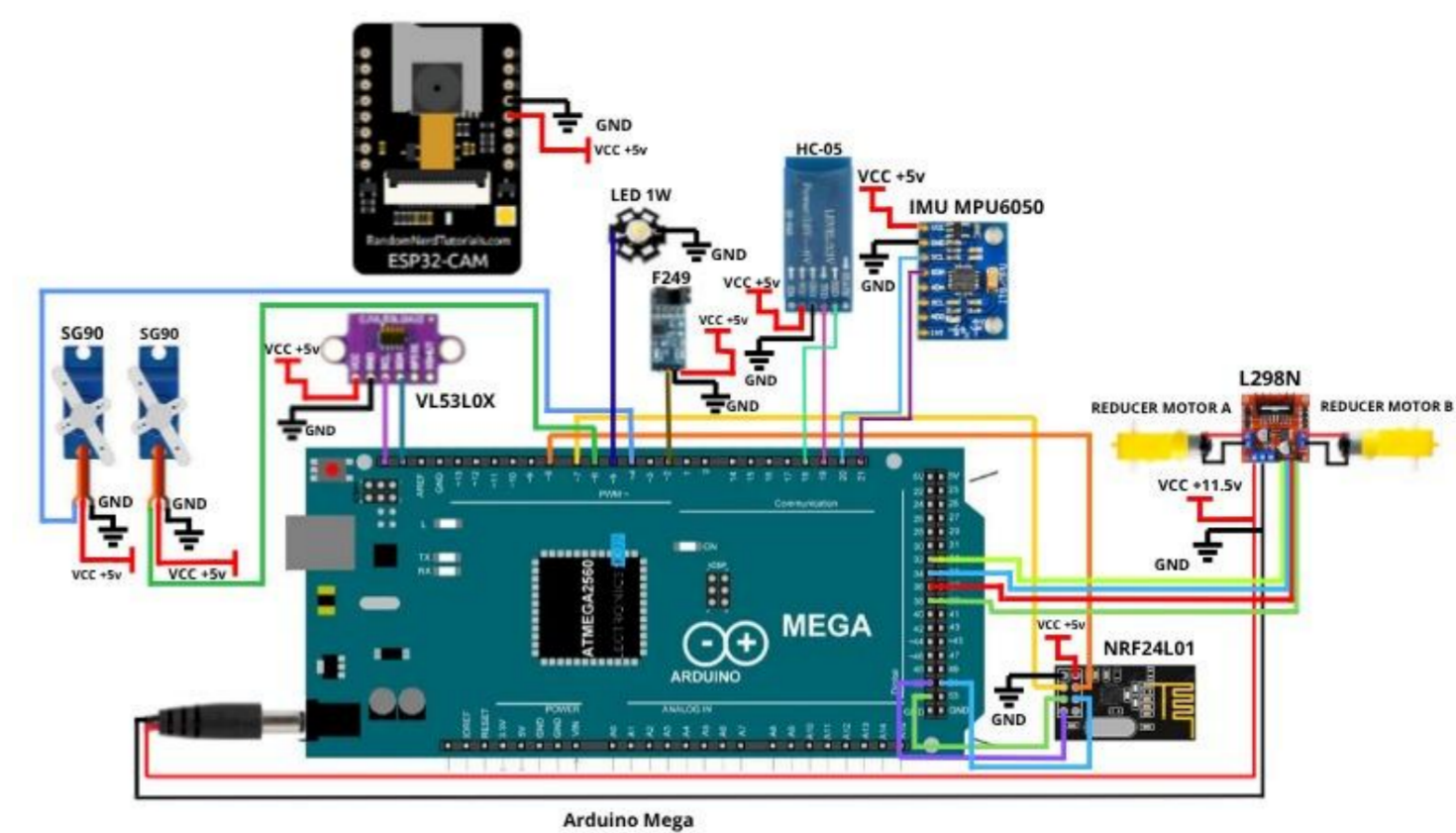


Figure 3. Electrical schematic based on the Arduino Mega

Results

The orientation analysis performed using the GY-521 sensor shows that the Yaw angle exhibits significant dynamic variations, including a sustained right turn of up to 170°, while the Pitch remains stable between -25° and 5°, confirming that the robot moves on a regular surface with slight inclinations caused by inertia. Regarding linear displacement, the encoder system recorded a cumulative distance of 61 meters over a period of 100 seconds, with stationary intervals or “plateaus” identified for conducting visual inspections or image processing without movement.

Furthermore, the validation of the obstacle detection sensor against a reference distance of 20 cm demonstrated high reliability and accuracy, obtaining an average measurement of 20.33 cm and a percentage error of only 1.65% after 99 measurements. To supervise the entire system in real time, a user interface was developed in Visual Studio Code using Python, enabling visualization of the video stream from an ESP32-CAM, telemetry monitoring, laser sensor readings from the VL53L0X, multimedia file capture, and centralized database management. Finally, the implementation of a smoothing algorithm is highlighted, as it optimizes the raw orientation signal by eliminating fluctuations and phase shifts, achieving a cleaner, more continuous, and more accurate representation of the vehicle's actual trajectory in Fig. 4.

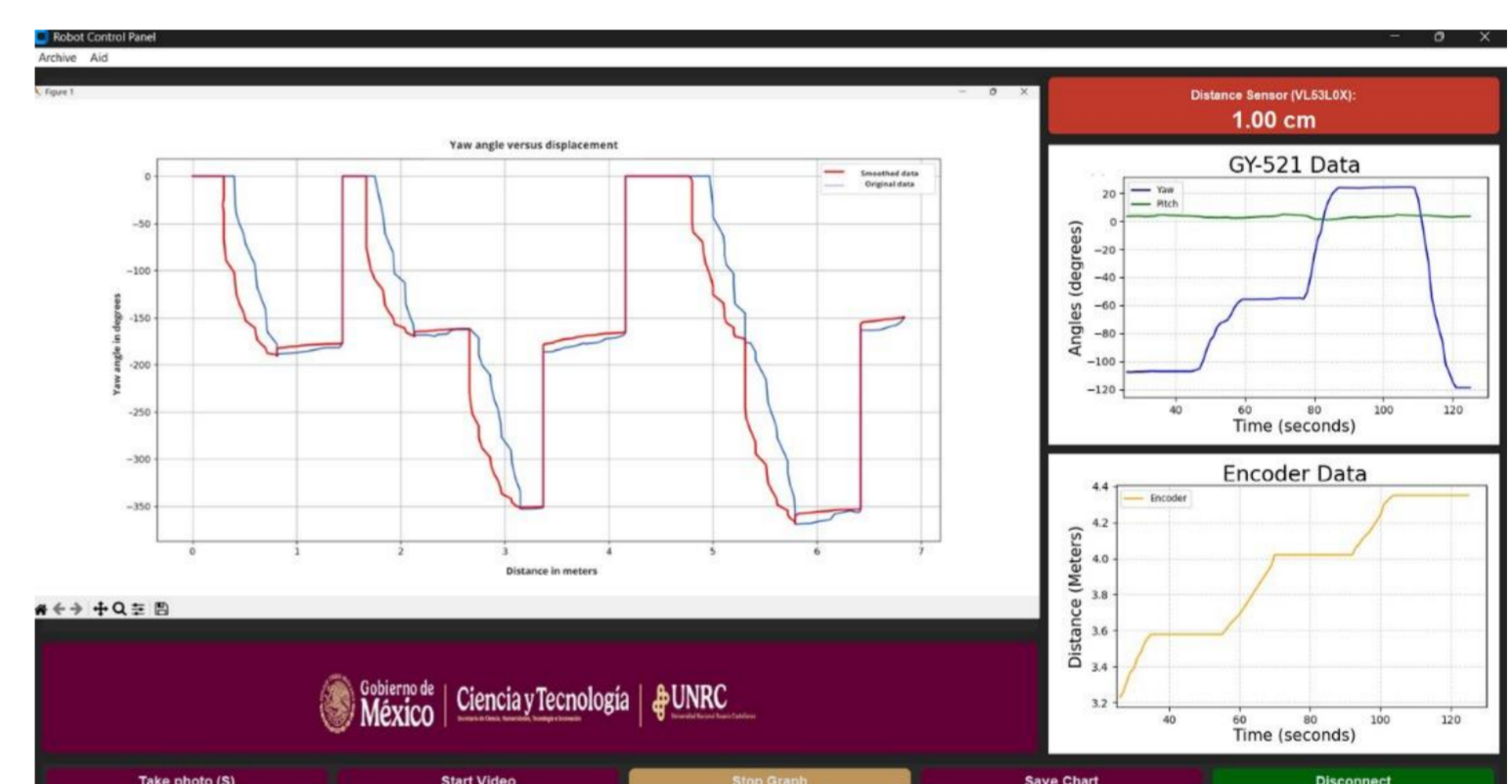


Figure 4. Graphical User Interface.

Conclusion

The experimental results validate the effectiveness of the designed robotic system, demonstrating that the integration of the Arduino Mega with the ESP32-CAM ensures stable telemetry and robust real-time supervision without loss of spatial-temporal reference. The kinematic analysis confirmed the system's accuracy, where the implementation of a smoothing algorithm in the Yaw signal was crucial for mitigating sensor noise and minimizing accumulated error over trajectories of up to 61 meters. Likewise, the correspondence between the controlled stopping phases and the odometry records validates the prototype's capability to perform precise visual inspections. Finally, the development of an interface in Python with centralized database management consolidates a scalable and low-cost ecosystem that meets the autonomy and fidelity standards required for preventive monitoring in hard-to-access environments.

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