Validation and functional testing protocol of the robot DuqueXII [score: 94/100]

Abstract—**This document outlines the validation and functional testing protocol designed for the DuqueXII robot. The protocol ensures that all the robot's systems and subsystems work correctly through a series of tests in a controlled environment.**

Index Terms—**Validation, functional testing, static robot, risk prevention, evaluation score, childhood safety.**

Contents

I. Introduction

This document presents the testing process carried out on DuqueXII, a robot developed to prevent domestic accidents during early childhood. The evaluations focused on functionality, accuracy and response times under controlled laboratory conditions. The tests covered areas such as power consumption, sensor accuracy, mechanical movement and neural network performance. The findings highlight the system's effectiveness in meeting objectives and identify areas for potential improvement in future versions.

II. Description of the robot

The DuqueXII is a stationary robot designed to prevent domestic accidents in early childhood. It features a 360-degree rotational mechanism and head movements controlled by servomotors, tested for precision and smooth operation. It integrates a high-resolution camera for real-time object detection, environmental sensors to monitor temperature, noise, air quality, and proximity and RGB LEDs as visual indicators. The robot includes a power management system with backup batteries, tested to ensure continuous operation during power outages. It operates in three modes: sleep, active, and backup, all validated to guarantee reliable performance.

DuqueXII uses ROS2 for communication between subsystems and a web interface for real-time monitoring. Each component and system was rigorously tested to ensure effectiveness in detecting risks and delivering early alerts.

A. Environmental conditions

The tests for the robot were carried out in the ML-042 laboratory at the University of Los Andes under controlled conditions. Scenarios with variable lighting (low, medium, high), ambient noise (silence to ≥ 50 dB), and temperatures ranging from 18°C to 25°C were simulated. These conditions were chosen to replicate typical domestic environments and validate the robot's performance in realistic scenarios.

B. Ethical scope of the tests

All tests were conducted exclusively by the creator of the robot, as ethical committee approval to involve children in the trials has not yet been obtained. To ensure the validity of the results and demonstrate that each functionality of the robot operates correctly, videos were documented to support each test, providing evidence of the proper functioning of the integrated systems.

III. Objectives

- Validate the functionality of the robot's hardware, sensors and software under controlled conditions.
- Assess the precision, response time and reliability of environmental sensors and the image analysis system.
- Test the robot's ability to detect hazards and issue alerts through visual, auditory and web-based notifications.
- Verify the efficiency of the power management system during transitions between main power and backup batteries.

IV. Test categories

A. Power stage

The energy management system of DuqueXII was evaluated to ensure functionality during power outages. Tests determined that the backup battery provides an average runtime of 8 minutes, while full recharge takes approximately 2.15 hours. These results meet expectations, considering electrical losses and variable computational load. Additional technical details are available in the annex *Electronic schematics* [4], file *Energy and battery budget*.

B. Movements (Pan and Til)

The DuqueXII robot features precise horizontal and head movements for effective monitoring. The 360-degree horizontal rotation, powered by MG996R servomotors, was tested and confirmed to operate smoothly and accurately. Similarly, the head's forward, backward, and lateral motions, controlled by MG90S servomotors, were validated for responsiveness and alignment with expected ranges. These tests confirm the robot's ability to track objects and monitor its surroundings effectively. For more details, refer to the annex *Consultorio IMEC* [4], *Case C51 final report* and *Mechanical drawings*.

C. Camera characterization (Zoom and Focus)

The Arducam 12MP PTZ camera used in DuqueXII allows adjusting zoom (range 210-2100) and focus (range 0-1830) to optimize the detection of dangerous objects. An experimental characterization was performed to relate these parameters, approximated with a 4th-degree polynomial (Figure 1):

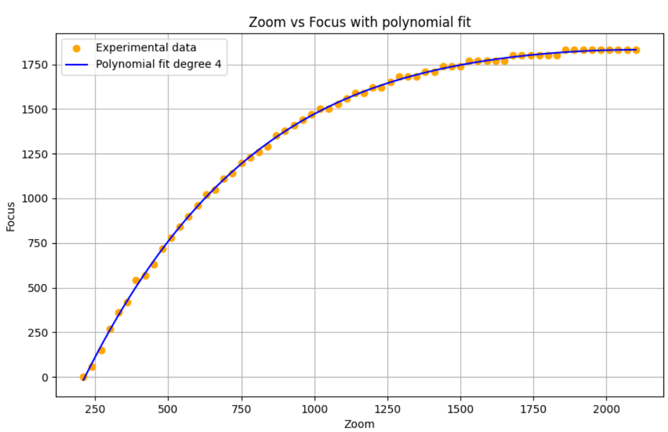

Fig. 1: Camera characterization.

$$f(x) = -1.225 \times 10^{-10}x^4 + 9.413 \times 10^{-7}x^3 - 0.002935x^2 + 4.41x - 821.8 \quad (1)$$

This ensures precise focusing after zooming, enhancing the accuracy of visual monitoring, as shown in Equation (1).

D. Sensors

The robot's sensors were thoroughly tested to validate their functionality and performance. Each sensor has a specific scoring function designed to calculate the performance score for each test. A total of 10 tests were conducted for every sensor and the average score from these tests represents the overall functionality score for each sensor. For each functionality, a detailed score table is provided, showcasing the results of all tests performed. For more information, refer to the annex *Testing protocol* [4], where the testing conditions and scoring functions are specified. Below is the final score for each functionality and its corresponding graph with the score for each test.

1) *IR flame detection sensor:* 96% (Figure 2)
2) *Environmental noise sensor:* 93% (Figure 3)
3) *Obstacle detection sensor:* 99% (Figure 4)
4) *Open door and window detection:* (Figure 5) 97%
5) *Temperature sensor:* 94% (Figure 6)
6) *Thermal camera sensor:* 99% (Figure 7)
7) *Air quiality sensor:* 98% (Figure 8)
8) *Ambient light sensor:* 99% (Figure 9)
9) *IMU earthquake sensor:* 99% (Figure 10)
10) *Dangerous object detection: Outlet:* 62% (Figure 11)
11) *Dangerous object detection: Coin:* 72% (Figure 12)
12) *Dangerous object det.: Glass marbles:* 62% (Figure 13)
13) *Dangerous object detection: Knife:* 65% (Figure 14)
14) *Dangerous object detection: Pill:* 56% (Figure 15)
15) *Dangerous object detection: Scissor:* 69% (Figure 16)

E. Web page and notifications

The DuqueXII robot's web interface, built with Flask [3], serves as a central platform for monitoring and control. It features real-time video streaming, allowing users to view the environment through the robot's camera, even in low-light conditions with infrared support. The interface displays sensor data, including noise levels, air quality, temperature and proximity alerts, while providing real-time notifications with visual and auditory warnings. It adapts its design based on the situation, using a green background for normal mode and red for alerts (see Figures 17 and 21).

Users can control the robot directly through the interface, managing its movements (pan and tilt), activating or deactivating the robot and silencing alarms. Designed for both desktop and mobile devices, the interface ensures a responsive and seamless experience. Demonstrations of its functionality can be found in the annex *Support videos* [4]. The web interface of the DuqueXII robot performed efficiently during testing, with rapid updates and minimal refresh times. Flask proved well-optimized, ensuring seamless data exchange and responsive manual controls. These results confirm the interface's reliability as a key component of the robot's system.

F. YDLidar X4

The YDLidar X4 was utilized to detect open windows or doors by scanning specific data ranges rather than the full 360-degree field of view. Due to mechanical design constraints, the robot focuses on two angular ranges: 45° to 160° and 190° to 315°, which correspond to its accessible vision areas. Although the robot cannot capture the entire environment simultaneously, it compensates by using its horizontal rotation (pan) capability to scan the entire surroundings when necessary. As shown in the Figure 18, the data ranges are represented in blue and red, indicating the monitored areas. The robot maps the environment's silhouette and identifies significant changes in distance values as indicative of open doors or windows. This functionality assumes the robot remains stationary in its pan axis during analysis, avoiding false positives that could occur when rotating.

The YDLidar X4 performed effectively during testing, reliably identifying changes in the environment's structure. Demonstrations of its functionality can be found in the annex *Support videos* [4], under the files *Detection of open doors and windows 1* and *Detection of open doors and windows 2*.

V. Integrated systems

A. Serial communication (TX, RX)

The serial communication between the Arduino Nano 33 BLE Sense and the Jetson Nano was implemented successfully, ensuring seamless and conflict-free data exchange. Using two ROS2 nodes ControlArduinoNode to send data and DataArduinoNode to receive data reliable communication system was established. A control mechanism using the control_serial_access topic prevented conflicts by temporarily locking serial access for one node while the other operated. This ensured smooth data transmission and reception without delays or errors.

The system performed efficiently during testing, with no issues in synchronization, data loss or communication delays. The implementation details can be reviewed in the annex *Codes* [4], specifically in the files *data_arduino.py* and *control_arduino.py* which document the functionality and structure of the communication system. Demonstrations of its performance are also available in the annex *Support videos* [4], showcasing its reliability and integration.

B. ROS (Robot Operating System)

The DuqueXII robot uses ROS2 [1] with Python [2] to manage communication among its eight nodes, ensuring seamless coordination between all systems and subsystems. This modular setup prevents interference between inputs and outputs, enabling efficient and reliable operation. ROS2's architecture allows independent yet collaborative functionality for components such as sensors, actuators, and the web interface (see Figure 20). Testing confirmed excellent performance, with no delays or miscommunications, demonstrating the system's reliability. Detailed configurations and implementations can be found in the annex *Codes* [4], while the annex *Support videos* show cases the integration in action.

VI. Results

The testing protocol for the Duque XII robot achieved an average score of 94/100 , calculated as the mean of the scores obtained for each functionality (see Figure 19). This rigorous protocol ensures that the robot effectively fulfills its primary goal: issuing alerts efficiently to prevent domestic accidents in early childhood.

The functionality with the lowest score was the detection of dangerous objects, due to limitations in the detection model. It was identified that the model requires training with a more realistic dataset and further exploration of optimal training parameters to improve confidence in object detection in real-world scenarios. Despite this challenge, the protocol proved to be comprehensive and robust, evaluating the robot under diverse conditions and justifying each criterion, ensuring its efficiency and reliability in detecting and alerting about potential risks.

VII. Added features

The DuqueXII robot incorporates additional features, such as speakers for audio alerts, a microphone for voice commands, RGB LEDs to display emotional states, and gesture and voice control capabilities. While these features are not directly tied to the robot's primary objective of preventing domestic accidents, they offer a significant advantage by enhancing user interaction and providing greater comfort to caregivers. These additions, designed to make monitoring more convenient, reflect the prototype's broader goal of supporting caregivers in their tasks. Although these features are not fully integrated into the robot's operational framework and were not subject to rigorous testing, their functionality is demonstrated in the annex *Support videos*, particularly under emotional states and control by gestures and web page.

References

[1] Open Robotics, "ROS 2 Documentation" [Online]. Available: https://docs.ros.org/en/rolling/

[2] Python Software Foundation, "Python 3 Documentation" [Online]. Available: https://docs.python.org/3/

[3] Flask, "Flask Documentation" [Online]. Available: https://flask.palletsprojects.com/

[4] Trochez Leffer "DuqueXII Robot Repository" [Online]. Available: https://github.com/LefferTrochez/DuqueXII-Robot.git

Figures

This section includes all figures from the Duque XII robot's testing protocol, illustrating key functionalities, performance metrics and results obtained during the evaluations.

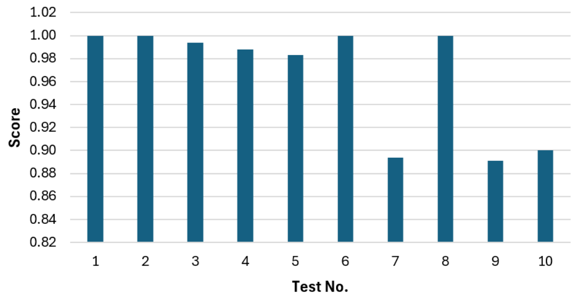

Fig. 2: IR flame results.

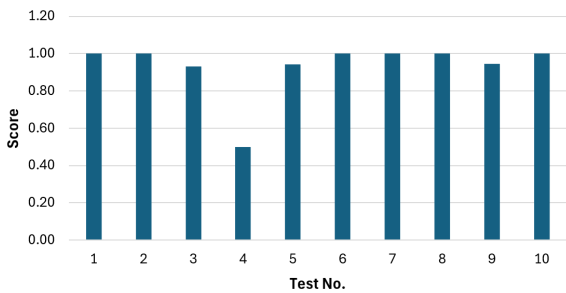

Fig. 3: Enviromental noise results.

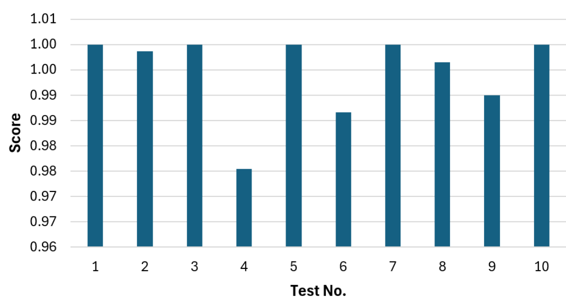

Fig. 4: Obstacle detection results.

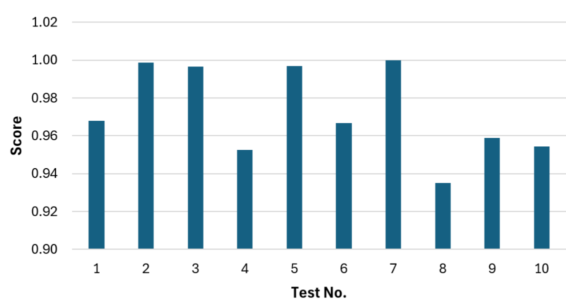

Fig. 5: Open door and window results.

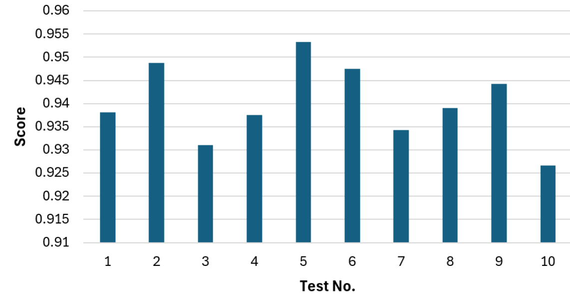

Fig. 6: Temperature results.

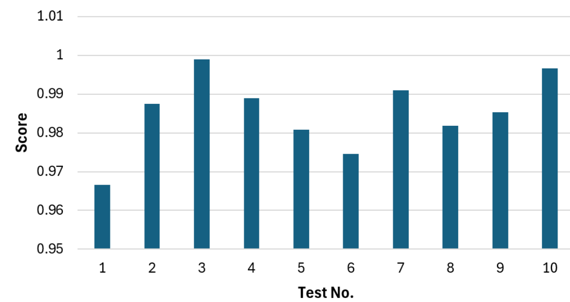

Fig. 7: Body temperature results.

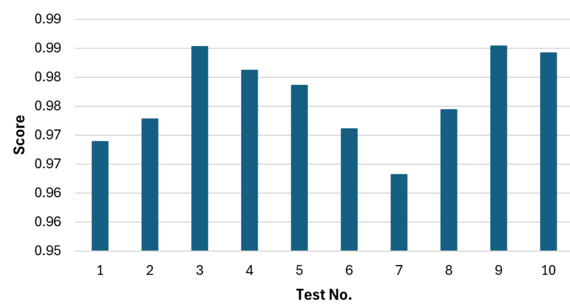

Fig. 8: Air quiality results.

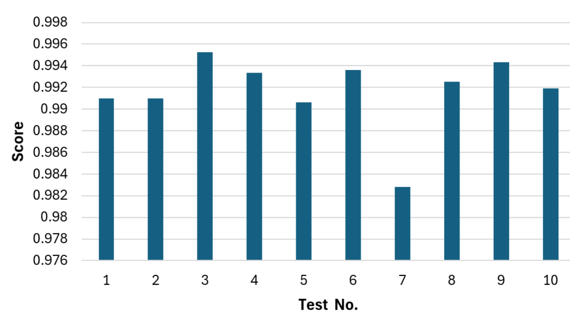

Fig. 9: Ambient light results.

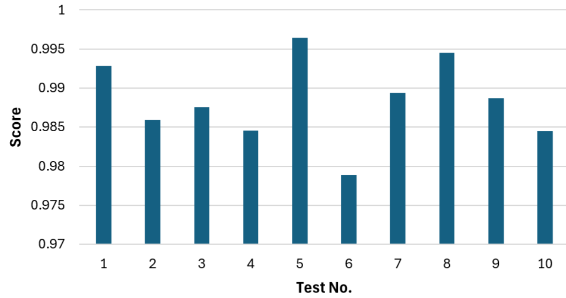

Fig. 10: Earthquake results.

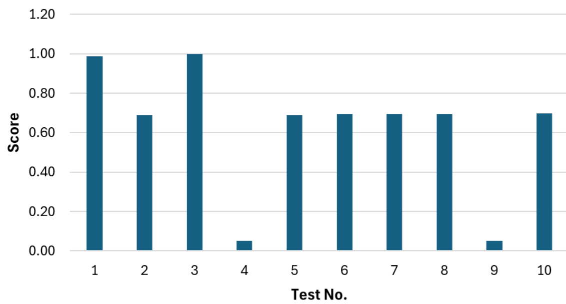

Fig. 11: Outlet detection results.

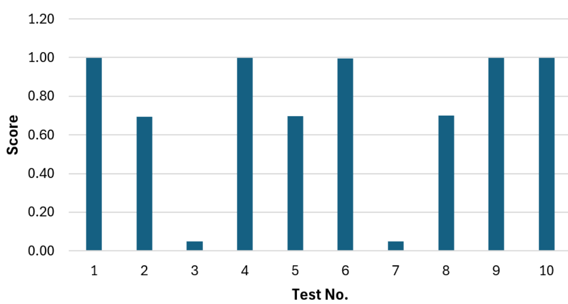

Fig. 12: Coin detection results.

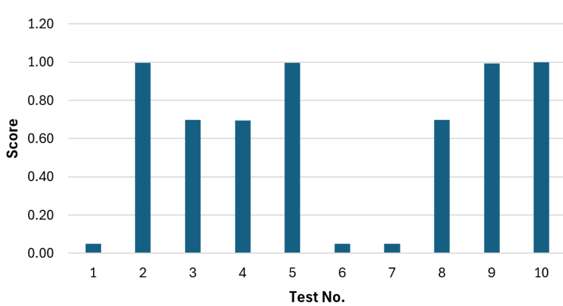

Fig. 13: Glass marbles detection results.

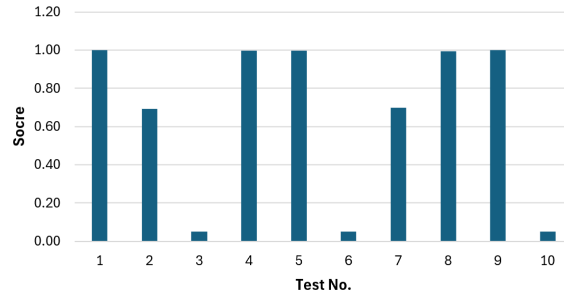

Fig. 14: Knife detection results.

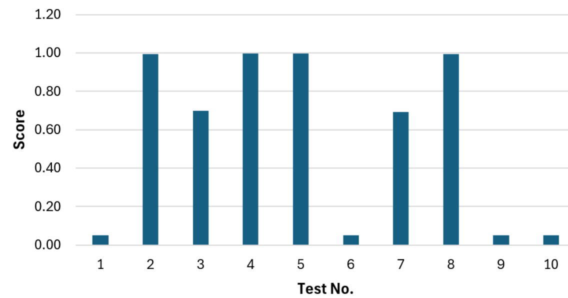

Fig. 15: Pill detection results.

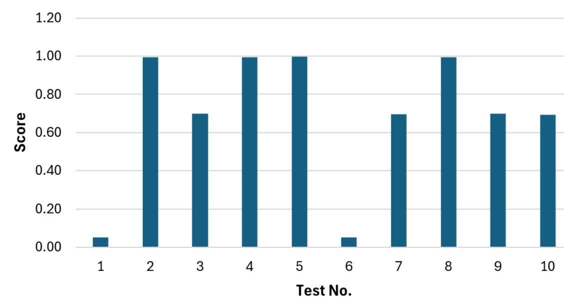

Fig. 16: Scissor detection results.

Fig. 17: Web page landscape format (computer).

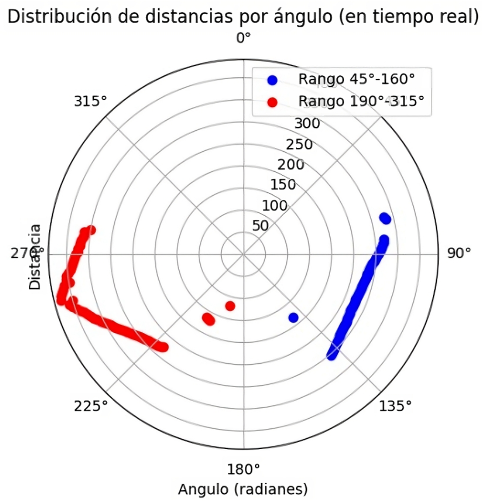

Fig. 18: YDLidar X4 graph.

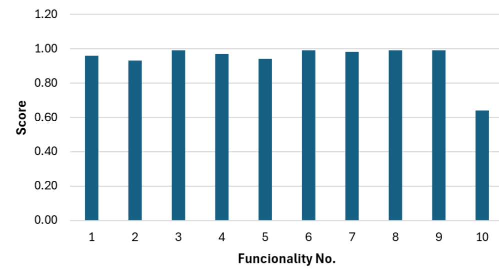

Fig. 19: Final results.

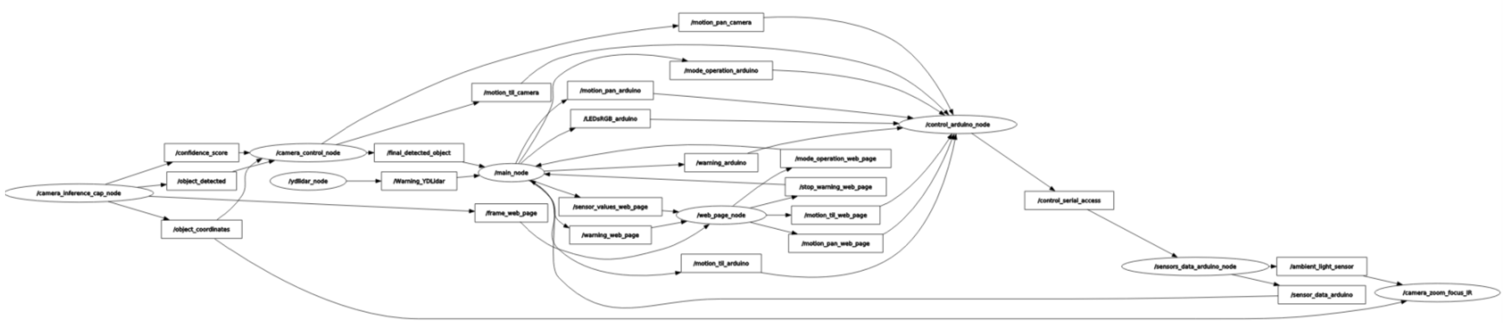

Fig. 20: ROS2 graph.

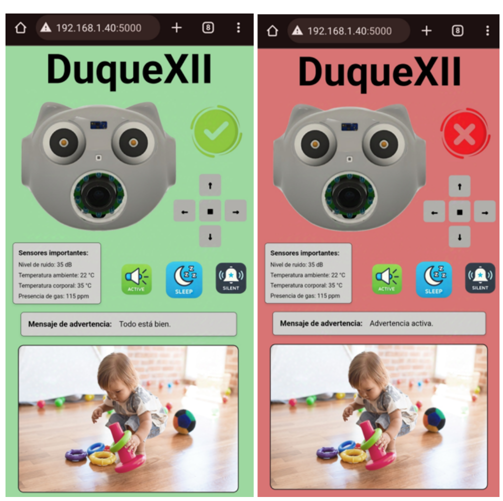

Fig. 21: Web page vertical format (smartphone).