Inspection Robot for Confined Spaces – Requirements Specification

Made by: Moataz SEGHYAR

1. Introduction

1.1 Purpose

This document outlines the functional and non-functional requirements for a tracked inspection robot designed to operate in confined spaces within industrial environments. The robot will perform autonomous and remote inspections, monitor environmental conditions, and support modular expansion for enhanced functionality.

1.2 Scope

The inspection robot will:
- Utilize tracks, LiDAR, and a depth camera for navigation.
- Collect and transmit environmental data, including temperature, humidity, and gas concentrations, using industrial-grade sensors.
- Support both manual remote control and autonomous operation modes.
- Feature a modular expansion bay for the integration of additional sensors or tools.
- Operate effectively in harsh environments and provide real-time data transmission.

2. Overall Description

2.1 System Perspective

The robot system comprises the following components:
- Tracked Propulsion System: Powered by two DC motors for mobility.
- Processing Unit: A Jetson Nano for processing LiDAR and depth camera data.
- Microcontroller: An STM32 for low-level motor control and sensor management.

- Power System: A battery system capable of sustaining at least 2 hours of continuous operation.
- Environmental Sensors: Industrial-grade sensors for monitoring temperature, humidity, and gas levels.

2.2 Assumptions and Constraints

- Dimensions: The robot shall not exceed 40 cm (width) x 60 cm (length) x 20 cm (height).
- Power System: The robot will operate on a 24V power supply.
- Weight: The total weight shall not exceed 20 kg.
- Modularity: The modular expansion port will support plug-and-play integration of additional components.
- Environmental Resistance: The robot will be IP65-rated for protection against dust and moisture.

3. Specific Requirements

3.1 Functional Requirements (FRs)

ID	Requirement
FR-01	The robot shall utilize a tracked propulsion system powered by two DC motors.
FR-02	The robot shall navigate autonomously using LiDAR and depth camera data.
FR-03	The robot shall support manual remote control via a wireless interface.
FR-04	The robot shall collect and transmit temperature, humidity, and gas sensor data.
FR-05	The robot shall support wireless communication for real-time data transmission.
FR-06	The robot shall include a modular expansion bay for additional components.
FR-07	The robot shall provide an emergency stop function for safety.

3.2 Non-Functional Requirements (NFRs)

ID	Requirement
NFR-01	The robot shall achieve a maximum speed of at least 0.5 m/s.
NFR-02	The robot shall operate continuously for a minimum of 2 hours on battery power.
NFR-03	The robot shall be IP65-rated for dust and moisture resistance.
NFR-04	The robot shall function in ambient temperatures between -20°C and 100°C.
NFR-05	The robot's communication latency shall not exceed 500 ms.
NFR-06	The battery system shall support a minimum of 500 charge cycles.
NFR-07	The modular expansion bay shall enable easy integration of additional sensors or tools.
NFR-08	The robot shall weigh less than 20 kg for ease of transportation.

Appendix

component Selection Calculation

Force Calculation

The total force required includes:

1. Gravitational force: mg
2. Acceleration force: ma
3. Frictional force: $\mu \cdot mg$

So, the total force is:

$$F = (m \cdot g) + (m \cdot a) + (\mu \cdot m \cdot g)$$

Using:

- $m = 20\ kg$
- $g = 9.81\ m/s^2$
- $a = 0.5\ m/s^2$
- $\mu = 0.5$

We can now calculate the total force.

The total force required, including the frictional force, is **304.3 N**.

Torque Calculation

Now, we calculate the torque required:

$$T = F \times r$$

With $r = 0.075\ m,$ the torque becomes:

$$T = 304.3 \times 0.075 = 22.82\ Nm$$

For two motors, the torque per motor would be:

$$T_{\text{motor}} = \frac{22.82}{2} = 11.41\ \text{Nm per motor}$$

Power Calculation

Now, let's calculate the power required per motor, using the angular velocity from 100 RPM:

$$\omega = 2\pi \times \frac{\mathrm{RPM}}{60}$$

Then, the power per motor is:

$$P_{\mathrm{motor}} = T_{\mathrm{motor}} \times \omega$$

$$\omega = 2\pi \times \frac{100}{60} = 10.47\,\mathrm{rad/s}$$

So the power required per motor:

$$P_{\mathrm{motor}} = 11.41 \times 10.47 = 119.03\,\mathrm{W\ per\ motor}$$

For two motors:

$$P_{\mathrm{motors\ total}} = 119.03 \times 2 = 238.06\,\mathrm{W}$$

Total Power Consumption

Now, let's account for the power consumed by other electronics:

- **Jetson Nano + STM32**: 15 W
- **Sensors + Lidar + Camera**: 15 W

Total power consumption = 238.06 + 15 + 15 = 268.06 W

Battery Sizing

For **2 hours** of operation:

$$E = P_{\mathrm{total}} \times t = 268.06 \times 2 = 536.12\,\mathrm{Wh}$$

Battery capacity needed:

$$C = \frac{E}{V} = \frac{536.12}{24} = 22.33\,\mathrm{Ah}$$

Design will be inspired by: Dr. Robot Jaguar Lite Tracked Robot