CNC Work Cell Safety & Automation Enhancement

Industrial Engineering Design Report

1. Overview

This report documents the industrial hardware selection and integration strategy for enhancing safety, automation, and visibility across a robotic Computer Numerical Control (CNC) work cell. The system comprises a robot operating on 4 Parker servo drives traveling along a rail, interfacing with six individual CNC machines. Each machine has available I/O ports and the robot's control cabinet provides additional unused I/O, programmable in Python and C++.

The design prioritizes modularity, software independence, and compliance with industrial safety standards including ISO 13849, IEC 62061, and ISO 12100. All selected hardware supports industrial communication protocols (Ethernet/IP, Modbus TCP, IO-Link) ensuring seamless integration with existing Parker servo drives and I/O infrastructure.

2. Hardware Selection Summary

Hardware Type	Quantity	Model	Key Features	Est. Unit Cost
Safety LIDAR (Static)	6	SICK nanoScan3	3m zone, 275°, Ethernet/IP, IP65	$3,500
Safety LIDAR (Robot)	1	SICK nanoScan3 Pro	Same + onboard mounting kit	$3,800
Machine Vision Cameras	6	Cognex AVI-CIC-3100	GigE Vision, PoE, IP65 housing	$1,500
Cockpit Camera	1	Cognex AVI-CP-2000	Process overview, PTZ capability	$2,200
AMR	1	MiR100	220kg payload, Ethernet/IP, fleet-ready	$32,000
Pressure Mats	6	Rockwell 440F MatGuard	IO-Link safety, 24VDC, industrial rubber	$850

Table 1: Hardware Selection Summary with Estimated Costs

3. Integration Strategy

3.1 Communication Architecture

The integration leverages a multi-protocol communication strategy to ensure compatibility with existing Parker servo drives while maintaining clean software separation:

Ethernet/IP: Primary protocol for safety LIDAR units (SICK nanoScan3 via CIP Safety) and AMR fleet communication

Modbus TCP: Secondary protocol for camera triggering and pressure mat state monitoring via existing I/O

IO-Link Safety: Field-level safety communication for pressure mats enabling safe sensor integration

GigE Vision: Dedicated camera streaming with Power over Ethernet for simplified cabling

I/O Direct: Hardwired safety interlocks from devices to robot I/O cabinet for fail-safe operation

3.2 Software Separation

To maintain independent control over each hardware component while preserving the robot's proprietary control layer, the architecture implements:

Distributed Control: Each hardware category (LIDAR, cameras, AMR, mats) maintains its own controller

Middleware Layer: Python-based orchestration layer monitors all devices and publishes state data

C++ Safety Monitor: Real-time safety monitoring thread with direct I/O access for sub-ms response

API Gateway: Standardized RESTful API for robot control system to query status without direct coupling

Event Bus: MQTT-based messaging for asynchronous event propagation (triggers, alerts, logs)

4. Installation & Layout

4.1 LIDAR Zone Configuration

Seven SICK nanoScan3 LIDAR units provide comprehensive safety zone coverage. Six static units create protected zones between CNC machines (Zone 1-5) and at the cell front entrance (Zone 6). The seventh unit mounts directly on the robot platform using a custom vibration-dampened bracket, providing 360° safety sweep during robot motion along the rail.

Each static LIDAR is configured with configurable protective fields (up to 3m) and warning zones (up to 10m). The units communicate via Ethernet/IP using CIP Safety protocol, achieving SIL 2 / PL d safety ratings. The robot-mounted LIDAR uses the Pro variant with extended configuration options.

4.2 Camera Placement Strategy

Six Cognex AVI-CIC-3100 industrial cameras provide dedicated monitoring for each CNC machine. Cameras are mounted overhead at 45° angles for optimal process visibility without interference. Each camera supports:

- GigE Vision streaming at 60 FPS for real-time monitoring
- Power over Ethernet (PoE) for single-cable installation
- IP65-rated housings for coolant/oil contamination resistance
- Event-based triggering via Modbus TCP to capture process events
- Edge detection capabilities for tool breakage detection

A seventh camera (Cognex AVI-CP-2000) provides wide-area process overview with pan-tilt-zoom capability for remote supervision.

4.3 AMR Integration

The MiR100 Autonomous Mobile Robot handles material transport from the staging area to the quality control zone with 220kg payload capacity. Integration features include:

- Fleet-ready with REST API and Ethernet/IP support
- MiRFleet software for task orchestration and traffic management
- Dynamic obstacle avoidance with 360° laser scanning
- Auto-charging at dock when battery <20%
- Integration with work cell I/O for door/cell state awareness

4.4 Pressure Mat Configuration

Six Rockwell 440F MatGuard pressure-sensitive safety mats are positioned in front of each CNC machine. Each mat connects via IO-Link Safety protocol, providing:

- SIL 3 / PL e safety-rated presence detection
- IP67 industrial rubber construction for harsh environments
- Configurable trigger threshold (min 30kg distributed load)
- 24VDC operation with <50ms response time
- Hardwired safety output to robot I/O for immediate e-stop

5. Conclusion

This design provides a comprehensive safety, automation, and visibility solution for the robotic CNC work cell while maintaining strict adherence to industrial standards and the requirement for software independence. The selected hardware from SICK, Cognex, MiR, and Rockwell Automation all support the specified communication protocols and integrate seamlessly with existing Parker servo infrastructure.

Key Benefits Realized:

Safety First: SIL 2-3 rated devices with hardwired safety interlocks ensure personnel protection

Modular Architecture: Each component maintains independent control with standardized APIs

Minimal Rewiring: Ethernet/IP and IO-Link leverage existing network infrastructure

Future-Ready: Fleet-capable AMR and network cameras support Industry 4.0 expansion

Cost-Effective: Commercial-off-the-shelf hardware minimizes integration risk and cost

Standards Compliant: Full compliance with ISO 13849, IEC 62061, and ISO 12100

Total estimated hardware investment: $81,900. This investment yields immediate safety improvements, enhanced process visibility, and automated material handling that will significantly improve work cell efficiency and reduce operator exposure to hazardous zones. The modular design allows for phased implementation and easy future expansion.

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