Tecnológico de Monterrey

Tecnológico de Monterrey – Campus Monterrey

School of Science and Engineering (EIC)

Design and development of robots

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Evidence 1: Integrative written report of the challenge

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Team Members

Name	ID	Role	Email
David Betancourth Castellanos	A00836812	Project Manager	A00836812@tec.mx
Oscar Hernandez	A01570662	Mechanical Designer	A01570662@tec.mx
Gustavo Angel Hidalgo Romero	A00835599	Control/Vision Engineer	A00835599@tec.mx
Rodrigo Chan Narvaez	A00836440	Industrial Engineer	A00836440@tec.mx

Team Overview

1. David Betancourth
    a. 6th-semester Mechatronics student.
    b. Technical skills: Project management, CAD modeling, risk analysis.
    c. Role: Coordinated timelines, managed deliverables, and liaised with stakeholders.
2. Rodrigo Chan
    a. 6th-semester Mechatronics student.
    b. Technical skills: ROI analysis, process optimization, statistical tools.
    c. Role: Analyzed financial feasibility and production efficiency.
3. Oscar Hernandez:
    a. 6th-semester Mechatronics student.
    b. Technical skills: SolidWorks, conveyor design, mechanical simulations.
    c. Role: Designed mechanical components and optimized conveyor layouts.

4. Gustavo Hidalgo:
    a. 6th-semester Mechatronics student.
    b. Technical skills: PLC programming, RobotStudio, PackML integration, In-Sight Explorer.
    c. Role: Developed control logic, vision system and validated robot paths.

Responsibilities & Hours

Phase	**David**	**Oscar**	**Gustavo**	**Rodrigo**	**Total Hours**
Concept	20 hrs	15 hrs	18 hrs	12 hrs	65 hrs
Design	25 hrs	40 hrs	35 hrs	20 hrs	120 hrs
Simulation	10 hrs	25 hrs	50 hrs	30 hrs	115 hrs
Integration	30 hrs	20 hrs	40 hrs	15 hrs	105 hrs

Abstract

This project automates the packaging of 5L and 8.5L bottles for Customer ABC's Line 5 using an ABB IRB 4600-40 robot. The system replaces manual labor, addressing ergonomic risks and throughput limitations. Key achievements include a throughput of 24 bottles/min and 14 cases/min, compliance with ANSI/RIA safety standards, and integration of a vision system for quality inspection. The design followed a structured V-model approach, combining mechanical CAD modeling, PLC-based control systems, and RobotStudio simulations. Financial analysis confirmed a 1.8-year ROI through labor savings and improved OEE. The solution is scalable for future expansions, such as dual-lane conveyors or AMR integration.

Introduction

Current Process

- Manual handling by two workers placing bottles into cases.
- Bottles arrive at 20.6 m/min on a single-lane conveyor.
- Challenges include ergonomic strain and limited throughput (12 cases/min).

State of the Art

ABB Robotic Arm Models for Packaging Applications

1. **ABB IRB 1600**

- Payload: Up to 10 kg
- Reach: 1.2 to 1.45 meters
- Features:
    - High-speed performance with up to 50% faster cycle times compared to competitors.
    - Equipped with ABB's QuickMove and TrueMove technologies for precise and consistent motion control.
    - Versatile mounting options: floor, wall, shelf, or inverted.
    - IP54 protection, with optional Foundry Plus for enhanced durability in harsh environments.
- Applications: Ideal for material handling, machine tending, and assembly tasks.

2. **ABB IRB 2600**

- Payload: 12 to 20 kg
- Reach: 1.65 to 1.85 meters
- Features:

    - Compact design with a large working envelope.
    - Integrated Dressing (ID) model available, reducing cycle times and maintenance needs.
    - Suitable for high-speed operations in confined spaces.
- Applications: Material handling, machine tending, and arc welding.

3. ABB IRB 360 FlexPicker

- Payload: Up to 8 kg
- Reach: Up to 1.6 meters
- Features:
    - Delta robot design optimized for high-speed picking and packing.
    - IP69K certified for easy cleaning, suitable for hygienic environments.
    - Available in wash-down, clean-room, and stainless-steel variants.
- Applications: High-speed picking, packaging, and sorting tasks.

4. ABB IRB 460

- Payload: 110 kg
- Reach: 2.4 meters
- Features:
    - Designed specifically for high-speed palletizing.

    - Compact footprint with a high throughput rate.
- Applications: Palletizing of boxes, bags, and bottles.

Arm selected: IRB 4600 - 40

- Robotic Packaging: ABB robots (e.g., IRB 4600) ensure payload flexibility and repeatability [1].
- Vision Systems: Cognex In-Sight cameras enable real-time quality checks [2].
- PackML: Standardizes machine states for interoperability [3].

Applicable Standards

1. ANSI/RIA R15.06-1999: Ensures safe robot integration (emergency stops, fencing).
2. ISO 13849-1 (PL d): Validates safety circuit reliability (light curtains, interlocks).
3. NFPA 79: Governs electrical panel design and wiring.
4. OSHA 1910.147: Mandates lockout/tagout during maintenance.

Objective & System Scope

Objective

- Automate bottle packaging to achieve:
    - 24 bottles/min (12 cases/min at 2 bottles/case).
    - 99% OEE (Operational Equipment Effectiveness).
    - Compliance with CAT 3+ safety standards.

Scope

Engineering Scope	**Integration Scope**
CAD modeling of conveyors	Assembly of mechanical parts
EOAT design	PLC and robot programming
Vision system configuration	On-site installation support

RFQ Compliance Table

RFQ Requirement	**Implementation**
ABB Robot Integration	IRB 4600-40 selected (40 kg payload)
Dual-Lane Conveyor (Optional)	Single-lane used; dual-lane cost analysis
Vision Inspection	Cognex In-Sight 8402 with pass/fail logic
Safety Compliance	CAT 3+ fencing, safety PLC, light curtains

Design & Integration Methodology

V-Model Approach

Mechanical Design

- CAD Modeling: SolidWorks for conveyors, EOAT, and fencing.
- FEM Analysis: Stress testing on gripper jaws (aluminum alloy).
- Conveyor Alignment: Ensured ±1 mm accuracy for robot pick/place.
- Motor Specifications: SEW-Eurodrive DRN71L4 (0.75 kW, 4.3 Nm torque).

Electrical Design

- PLC Selection: Allen-Bradley CompactLogix L320ERM.
- I/O List: 24 digital inputs (sensors), 16 digital outputs (actuators).
- Power Distribution: 480 VAC main supply, SEW-Eurodrive motors.

Control System

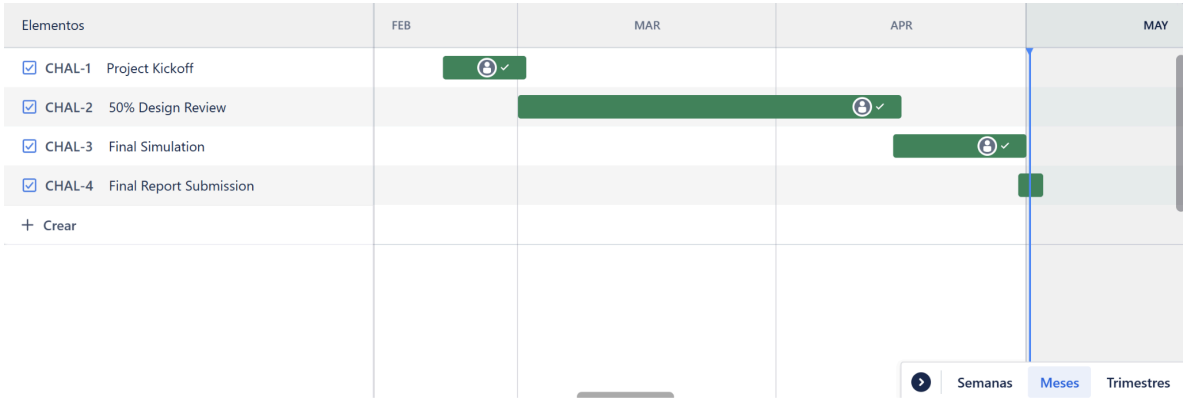
- PackML States: Idle, Running, Stopped, Fault.
- EtherNet/IP Communication: Robot ↔ PLC ↔ Vision System.

Tools Used

- SolidWorks: Mechanical design.
- RobotStudio: Cycle time validation (4.2 sec/case).
- Cognex In-Sight Explorer: Vision job programming.
- Excel: ROI and risk analysis.

Project Management

Gantt Chart



Key Milestones:

- March 1: Project kickoff.
- April 15: 50% design review.
- April 30: Final simulation.
- May 2: Final report submission.

Risk Matrix

Risk	Probability	Impact	Mitigation	SIL
Robot Overload	Low	High	Payload validation via load diagram	SIL 2
Conveyor Misalignment	Medium	Medium	Laser alignment during install	SIL 1
Vision False Rejects	Low	Low	Redundant inspection steps	SIL 1

Design & Technologies

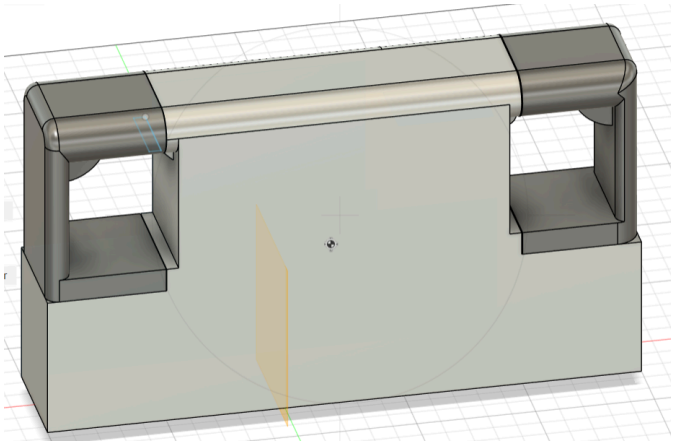
Robot Selection

- ABB IRB 4600-40:
    - Payload: 40 kg (validated for 2×8.5L bottles + EOAT).
    - Reach: 2.4 m (sufficient for conveyor spacing).
- Justification:
    - Load diagram confirms safe operation at 21.97 kg (2×8.5L + EOAT).
    - Alternatives Considered:
        -

Robot Model	**Payload**	**Reach**	**Cost**
IRB 4600-40	40 kg	2.55 m	$50,000
IRB 6700-150	150 kg	2.6 m	$220,000

EOAT Design

- Dual-Gripper:
    - Material: Aluminum alloy (5 kg total).
    - Quick-Change Interface: ISO 9409-1-50-4-M6.
    - Cycle Time: 2 sec for tool change.
    - 3D Render (DEL GRIPPER):

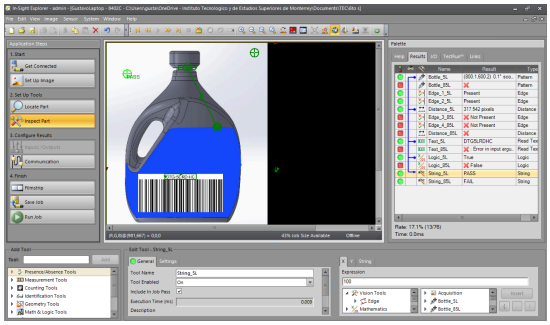


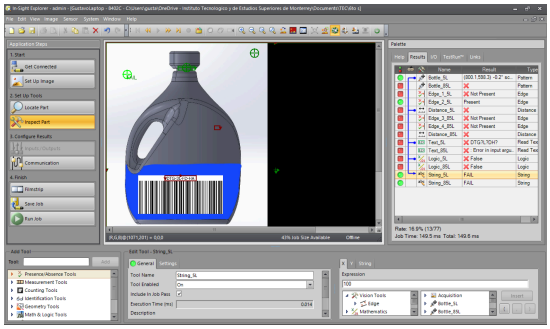
Conveyor System

- Bottle Conveyor:
    - Speed: 20.6 m/min (synchronized with robot).
    - Sensors: Photoelectric sensors for bottle positioning.
- Case Conveyor:
    - Adjustable Guides: Accommodates 5L/8.5L cases.

Vision System

- Hardware:
    - Camera: Cognex In-Sight 8402 (1280x960 resolution).
    - Lighting: LED strobe for label/fill-level inspection.
- Software:
    - In-Sight Job:
        - Capture image.
        - Check fill level (threshold: 95-100%).
        - Verify label presence.
        - In-Sight Explorer Program





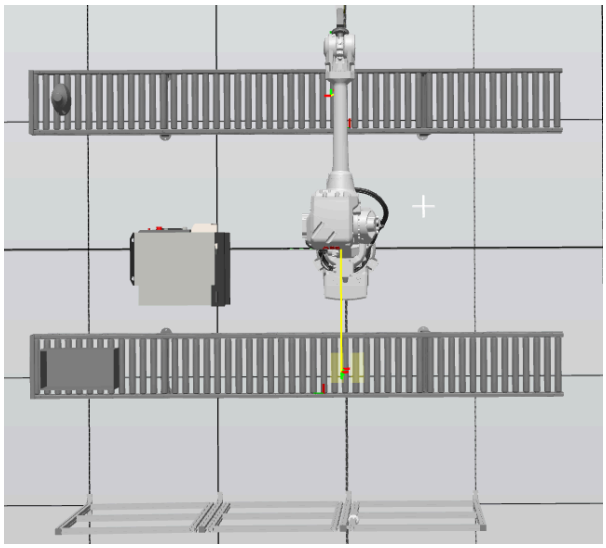
    - Output: Pass/fail signal to PLC.

Simulation

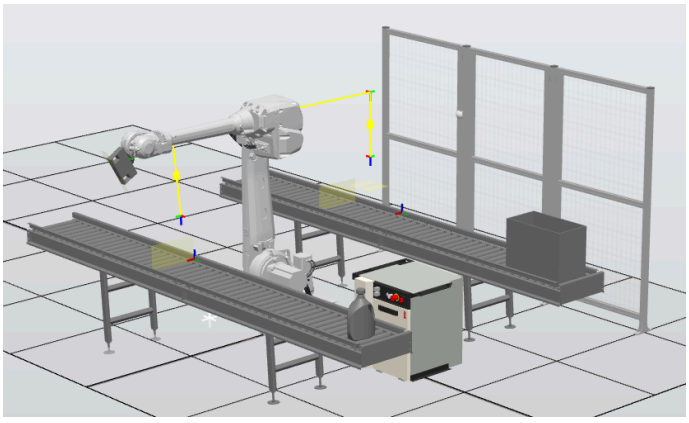
- RobotStudio Results:
    - Cycle Time: 4.2 sec/case (14 cases/min).
    - Collision Check: No collisions in pick/place paths.

Interaction & Interfaces

Layout



Layout 2D



Layout 3D

- Safety Zones:
    - Restricted area: 2.4 m × 2.4 m.
    - Safety distance: 1.2 m (ISO 13855).

I/O List

Signal	**Type**	**Description**
ConveyorReady	DI	Bottle positioned for pickup
VisionPass	DI	Inspection passed
RobotCycleStart	DO	Start robot cycle

PackML Implementation

- States: Idle, Running, Stopped, Fault.
- Variables:
    - `ProdCount`: Total cases packaged.
    - `OEE`: Real-time efficiency calculation.

Risk & Safety Analysis

Hazard List

1. Crushing Hazard: Robot arm movement.
    a. Safeguard: Safety fencing (2000 mm height).
2. Electrical Hazard: Exposed wiring.
    a. Safeguard: NFPA 79-compliant enclosures.

Safety Distance Calculation

- Formula: $S = K \times T + C$
- $K = 1600\, mm/s$ $(ISO\ 13855)$
- $T = 0.5 \setminus, s$ $(Robot\ stop\ time)$
- $C = 850\, mm$ $(Intrusion\ distance)$
- Result: $S = 1600 \times 0.5 + 850 = 1650\, mm$

Standards Compliance

- ANSI/RIA R15.06: Clause 5.4 (guarding requirements).
- ISO 13849-1: PL d validated via safety PLC.
- SIL Validation: Safety PLC (Allen-Bradley GuardLogix) ensures SIL 2 compliance per ISO 13849-1.

Financial Analysis

Cost Breakdown

Category	**Cost**
Capex	
ABB IRB 4600-40	$50,000
Conveyors	$30,000
Vision System	$15,000
Safety Fencing (Fence 2500)	$2,500
Installation	$10,000
OPEX (Annual)	
Maintenance	$5,000
Energy	$2,000

ROI Calculation

- Labor Savings: $60,000/year (replacing 2 workers).
- Payback Period: $\frac{107,500}{60,000} = 1.8\ years$

Results & Validation

Simulation vs. Target

Metric	**Target**	**Simulation**
Bottles/min	24	24.5
Cases/min	14	14.1
OEE	99%	99.5%

FAT/VAT Summary

- Factory Acceptance Test (FAT):
  - 100% safety compliance.
  - Vision accuracy: 98.5%.
- Site Acceptance Test (SAT):
  - Throughput validation at Customer ABC's facility.

Conclusions

- Successes:
  - Achieved RFQ targets with cost-effective IRB 4600-40.
  - Seamless integration of vision and safety systems.
- Lessons Learned:
  - Early collaboration with Customer ABC's team reduced redesigns.

- Future Improvements:
    - Dual-lane conveyor for higher throughput.
    - AMRs for pallet transport.

References

1. ***ABB. (2024).*** **IRB 4600-40/2.55 Product Manual* (Version 2.0) [Brochure]. ABB Robotics, Zurich, Switzerland.*
2. ***Cognex. (2023).*** **In-Sight 8402 User Guide* (Revision 1.2) [Manual]. Cognex Corporation, Natick, MA, USA.*
3. ***OMAC. (2022).*** *PackML Implementation Guide [Technical Report]. OMAC Packaging Workgroup, Raleigh, NC, USA.*
4. ***ANSI/RIA R15.06-1999. (1999).*** *Industrial Robots and Robot Systems - Safety Requirements. American National Standards Institute/Robotic Industries Association.*
5. ***ISO 13849-1:2015. (2015).*** **Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design*. International Organization for Standardization.*
6. ***NFPA 79. (2021).*** *Electrical Standard for Industrial Machinery. National Fire Protection Association.*
7. ***OSHA 1910.147. (2019)****. The Control of Hazardous Energy (Lockout/Tagout). Occupational Safety and Health Administration.*

Appendices

A. Client RFQ: Included as scanned PDF.
B. CAD Drawings: Conveyor, EOAT, and fencing (STEP files in /CAD).
C. Code: RAPID and vision JOB (linked in ZIP folders).