LINE SCANNER

Low-Cost Integrated Line Scanner for Real-Time Barcode Grading and Intelligent Calibration

ELECOMP Capstone Design Project 2026-2027

Sponsoring Company:

Zebra Technologies Corporation
1301 Atwood Avenue, Suite 106N
Johnston, RI 02919
http://www.zebra.com

Company Overview:

Zebra Technologies Corporation and its subsidiaries provide enterprise asset intelligence solutions in the automatic identification and data capture solutions industry worldwide. The company designs, manufactures, and sells printers, which produce labels, wristbands, tickets, receipts, and plastic cards; dye-sublimation thermal card printers for personal identification; RFID printers; and a wide range of accessories, software, and services. Zebra serves retail and e-commerce, manufacturing, transportation and logistics, healthcare, and public sector industries through direct sales and a network of channel partners. Founded in 1969, Zebra is headquartered in Lincolnshire, Illinois.

Technical Director(s):

Morgan Malone
Manager, Engineering
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Project Motivation:

In high-volume industrial printing, undetected print defects can cause severe supply chain disruptions. Currently, verifying print quality and grading barcodes requires external, bulky, and prohibitively expensive verification equipment. A core motivation of this project is to develop a strictly low-cost, internal line scanner solution that fits directly inside a Zebra tabletop thermal printer. Because of its compact form factor, a line scanner can be placed immediately adjacent to the printhead. By capturing the image as it is printed, the system will dynamically and accurately grade barcodes (to ANSI/ISO standards) and enable "intelligent calibration" to automatically adjust to changes in media parameters without user intervention.

Anticipated Best Outcome:

The anticipated best outcome is a fully functional, highly cost-optimized line scanner PCBA and firmware prototype integrated into a Zebra tabletop printer. The prototype must successfully demonstrate real-time image capture using a custom, uniform illumination system. Crucially, the system must process the scan data on-the-fly to perform accurate, standardized barcode grading and execute automated media calibration routines, all while adhering to a strict low-cost bill of materials (BOM).

Project Details:

Overall system concept:

The high-level system concept for this project is to provide a low-cost, internal line scanner solution capable of fitting inside a tabletop printer for real-time print verification. This project requires blending optical-electrical component selection, custom PCBA design, and advanced embedded firmware to achieve high-end grading performance on a low-cost hardware budget. All mechanical design, housing, mounting, and structural integration will be provided by Zebra Technologies engineering staff as needed to support the student team.

Key Tasks & Deliverables:

Focus Area	Technical Deliverables & Tasks
Low-Cost Component Selection	Research and select an appropriate, highly cost-effective Contact Image Sensor (CIS) or linear sensor array, along with suitable LEDs that meet the speed and resolution requirements for accurate grading.

Illumination Electronics Design	Design and validate a custom LED illumination circuit. The lighting must be perfectly uniform across the entire width of the print line to prevent shadows or glare, which is an absolute requirement for accurate barcode grading and defect detection.
Electronics & PCB Development	Develop the required electronic interfaces (custom PCBA) to power the line scanner and illumination system, and handle the high-speed data transfer between the scanner and the printer's main processing board.
Firmware & Algorithm Integration	Develop the embedded C/C++ firmware required to initialize the scanner, control the illumination strobing, and acquire raw image data in sync with the printer's stepper motors. Implement algorithms capable of accurately grading barcodes (evaluating symbol contrast, edge determination, modulation, etc.) in real-time.
Intelligent Calibration Logic	Develop initial logic to process the line scan data to detect media edges and gaps, allowing the printer to self-calibrate to new media types autonomously.

Composition of Team:

2 Electrical Engineers & 1 Computer Engineer

Skills Required:

The project demands a robust combination of hardware design, optoelectronics, and low-level firmware expertise.

Electrical Engineering Skills Required:

- Value Engineering and Hardware Design: Experience in designing custom circuit boards, sensor interfaces, and power regulation with a strict focus on cost-optimization and BOM management.
- Optoelectronics and Illumination: Understanding of LED circuitry, light diffusion, and sensor optics to design a uniform lighting environment electrically.

Computer Engineering Skills Required:

- Embedded Firmware Development: Proficiency in C/C++ for microcontrollers, handling high-speed peripheral interfaces (e.g., SPI, MIPI, or parallel data lines), and hardware synchronization.
- Algorithm Development (Barcode Grading): Strong signal/image processing skills to translate raw sensor data into strict grading metrics and automated edge-detection.

AI Usage:

The AI Use Policy for this project is defined in Appendix A at the end of this proposal. Technical Directors have completed the checklist in Appendix A to indicate which AI uses are permitted on this project. Any item left unchecked is not allowed.

Anticipated Best Outcome's Impact on Company's Business, and Economic Impact

Developing a low-cost, internal barcode grader is a massive competitive advantage. It democratizes print verification, allowing Zebra to offer high-end, zero-defect compliance printing at a fraction of the cost of current external verifiers. This directly reduces the total cost of ownership for customers. Furthermore, intelligent self-calibration drastically reduces media waste and setup time, improving the ROI for end-users and solidifying Zebra's tabletop printers as the most advanced and user-friendly on the market.

Broader Implications of the Best Outcome on the Company's Industry:

- Accessible Compliance: By drastically lowering the cost barrier, accurate barcode grading can become a standard feature rather than a premium add-on, averting costly chargebacks across the entire supply chain.
- Autonomous Printing Systems: Intelligent calibration represents a major step toward "plug-and-play" industrial printers that require zero manual tuning, setting a new industry standard for ease of use.
- Advanced Analytics: Real-time print data opens the door for predictive maintenance, allowing the printer to flag a failing printhead element before the human eye can even detect the print degradation.

Appendix A: AI Use Policy – Low-Cost Integrated Line Scanner for Real-Time Barcode Grading and Intelligent Calibration

Allowed

- Students may use AI tools for
  - ☒ brainstorming support
  - ☒ concept development
  - ☒ literature and publicly available documentation review
  - ☒ software development
  - ☒ debugging
  - ☒ data analysis
  - ☒ test development
  - ☒ non-proprietary paragraph editing
  - ☒ non-proprietary single-slide formatting
  - ☒ preparation of project deliverables
  - ☐ note taking or transcription of meetings
  - ☐ Others: _____

Not Allowed

- Using AI in violation of university policies, applicable laws, or course-specific rules identified by capstone instruction team and project-specific rules identified by the technical directors.
- Entering proprietary, confidential, personally identifiable, security-sensitive, or otherwise restricted information into an AI system without authorization.
- Submitting AI-assisted work without understanding, reviewing, verifying, and appropriately disclosing its use.
- Submitting entire documents or presentations to an AI system for editing or formatting.
- Any unchecked items from the allowed list above.

Requirements

- If any use is allowed, AI tools may only be used to enhance, but not replace, students' technical reasoning, engineering judgment, and understanding. Students must be able to explain, justify, and defend all submitted designs, code, analyses, test results, documentation, and conclusions.
- During the first two weeks of the project, the student team shall work with the Technical Directors to: identify any proprietary or confidential information that may be

involved in the project; determine what information may or may not be shared with AI systems; identify the AI tools, models, accounts, and configurations approved for project use; and document any project-specific restrictions or approval requirements.

- Students shall transparently document the uses of AI using the URI CYPHER AI Usage Marking guidelines (https://web.uri.edu/cypher/ai-marking/). A workshop is planned for September to familiarize students with these guidelines.
- Students retain full professional responsibility for all design decisions, analyses, implementations, testing, documentation, presentations, and final deliverables, regardless of whether AI tools contributed to the work.