Torque Measurement

Motor Real-time Torque Measurement

ELECOMP Capstone Design Project 2025-2026

Sponsoring Company:

Zebra Technologies Corporation
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Johnston, RI 02909
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-sublimination thermal card printers, which produce images which are used for personal identification, access control, and financial transactions; RFID printers that encode data into passive RFID transponders; accessories and options for our printers, including vehicle mounts and battery chargers; stock and customized thermal labels, receipts, ribbons, plastic cards, and RFID tags for printers; and temperature-monitoring labels primarily used in vaccine distribution. It also provides various maintenance, technical support, repair, and managed and professional services; real-time location systems and services; and tags, sensors, exciters, middleware software, and application software; as well as physical inventory management solutions, and rugged tablets and enterprise-grade mobile computing products and accessories. In addition, the company offers barcode scanners, RFID readers, industrial machine vision cameras, and fixed industrial scanners, workforce management solutions, workflow execution and task management solutions, and prescriptive analytics solutions, as well as communications and collaboration solutions. It also provides cloud-based software subscriptions and robotics automation solutions. The company serves retail and e-commerce, manufacturing, transportation and logistics, healthcare, public sector, and other industries through direct sales and a network of channel partners. The company was founded in 1969 and is based in Lincolnshire, Illinois.

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Project Motivation:

This project builds on a previous Capstone which successfully developed a method to measure system torque during Zebra printer operation. This earlier effort addressed a critical gap by enabling the measurement of torque under real-world conditions, such as during the printing process, where factors like media adhesive properties and printhead sticking play significant roles.

This new project shifts focus to documenting motor speed/torque performance under controlled testing conditions. While the previous method provided insights into overall system torque, this project aims to isolate and evaluate the stepper motor's specific performance characteristics. This includes establishing precise relationships between motor speed, torque output, and operational parameters like voltage and current.

By documenting the motor's performance envelope, Zebra will gain a deeper understanding of how the stepper motors in their products respond to different load scenarios. This data will be instrumental in optimizing motor configurations, troubleshooting torque-related issues, and ensuring reliable operation across a wide range of customer media and environmental conditions. Ultimately, this project will complement the earlier torque measurement method by focusing on the stepper motor's individual contribution to system performance, thereby enabling a comprehensive approach to improving Zebra printer functionality.

Project Details:

Comprehensive Motor Performance Characterization:

- The project will document the relationship between motor speed and torque output under various operating conditions, such as different load scenarios, voltage levels, and current settings.
- This data will enable Zebra to define the performance envelope of their stepper motors, offering insights into their limits and optimal operating points.

Dedicated Motor Testing Setup:

- A specialized testing setup will be developed to isolate the stepper motor from the broader system and evaluate its torque and speed independently.
- The setup will use advanced torque transducers, magnetic particle brakes, and custom motor driver boards to precisely simulate and measure performance.

Enhanced Testing Capabilities:

- The testing system will allow engineers to simulate real-world operational loads while precisely controlling motor parameters.
- By focusing on motor performance, this project will complement the previous system torque measurement method, offering a more detailed understanding of the stepper motor's role in overall printer functionality.

Graphical and Analytical Outputs:

- The project will provide detailed graphical representations of motor speed/torque curves, enabling easy interpretation of the data.
- A graphical user interface (GUI) will allow for streamlined control of testing parameters and visualization of results.

Data for Optimization and Troubleshooting:

- The collected data will help Zebra optimize motor configurations and prevent torque-related issues like printer stalls and performance degradation due to third-party media.
- This information will also support rapid troubleshooting by identifying motor performance constraints under specific conditions.

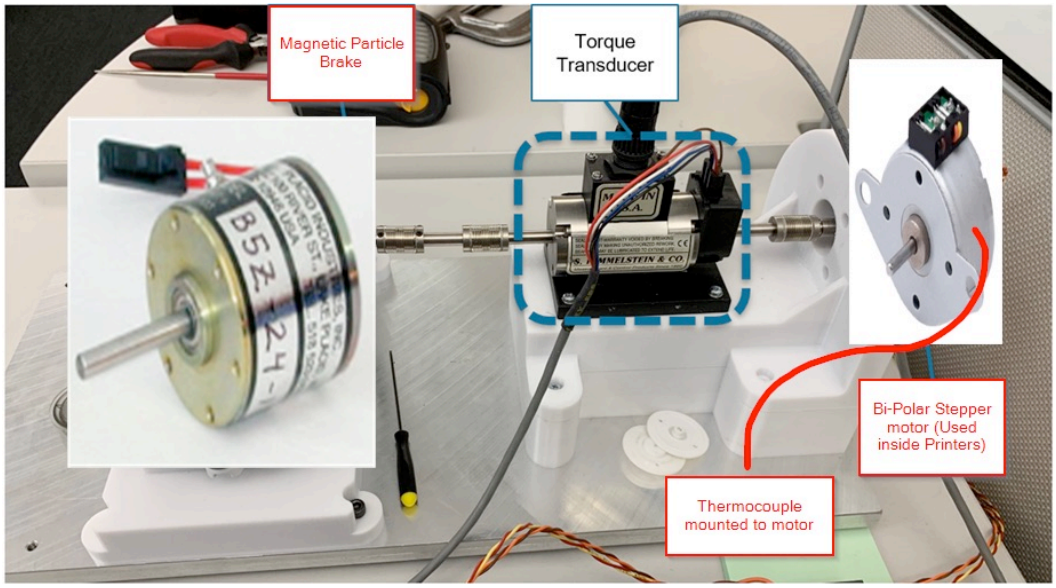
Alignment with Broader Goals:

- By focusing on the motor speed/torque performance, this project will ensure Zebra has a complete and robust understanding of torque dynamics in their printers.
- It will bridge the gap between system-level torque measurements from the previous Capstone and motor-level performance data, creating a comprehensive testing framework.

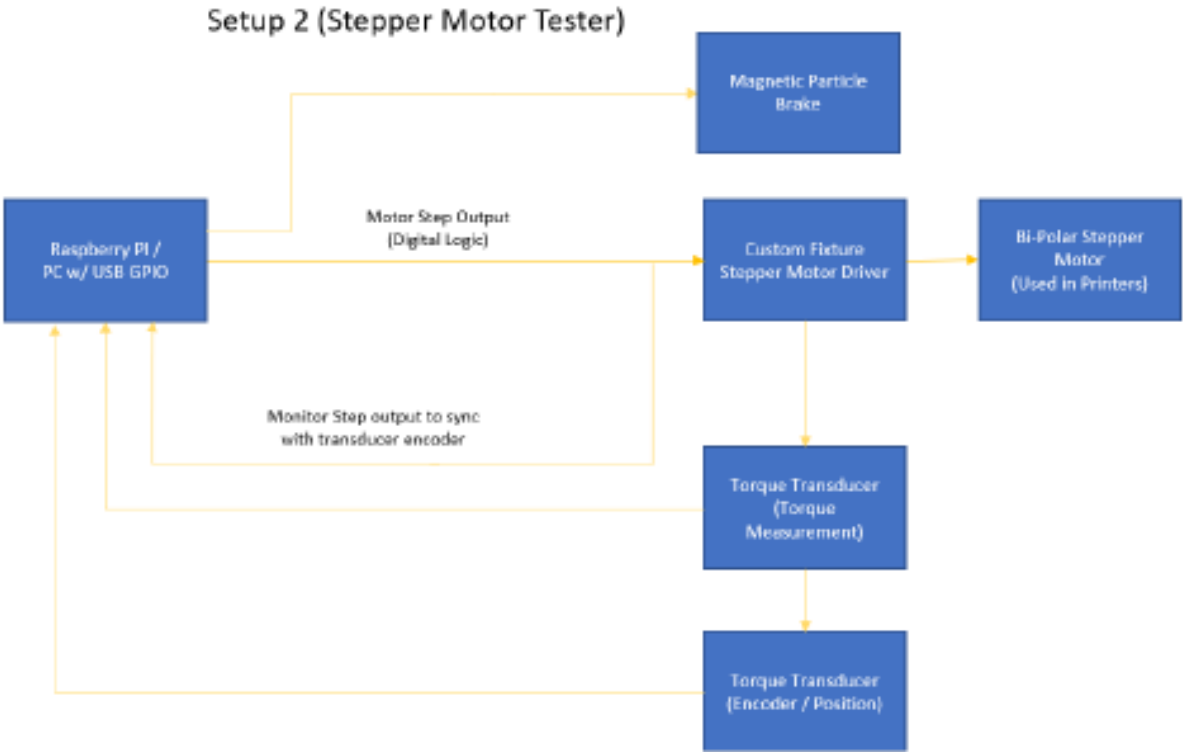
Through these outcomes, the project will empower Zebra Technologies to refine their stepper motor designs, adapt to diverse customer requirements, and maintain their leadership in mobile printing technology. This focused approach on motor performance will serve as a critical complement to the earlier torque measurement method, ensuring a holistic understanding of the system's operational behavior.

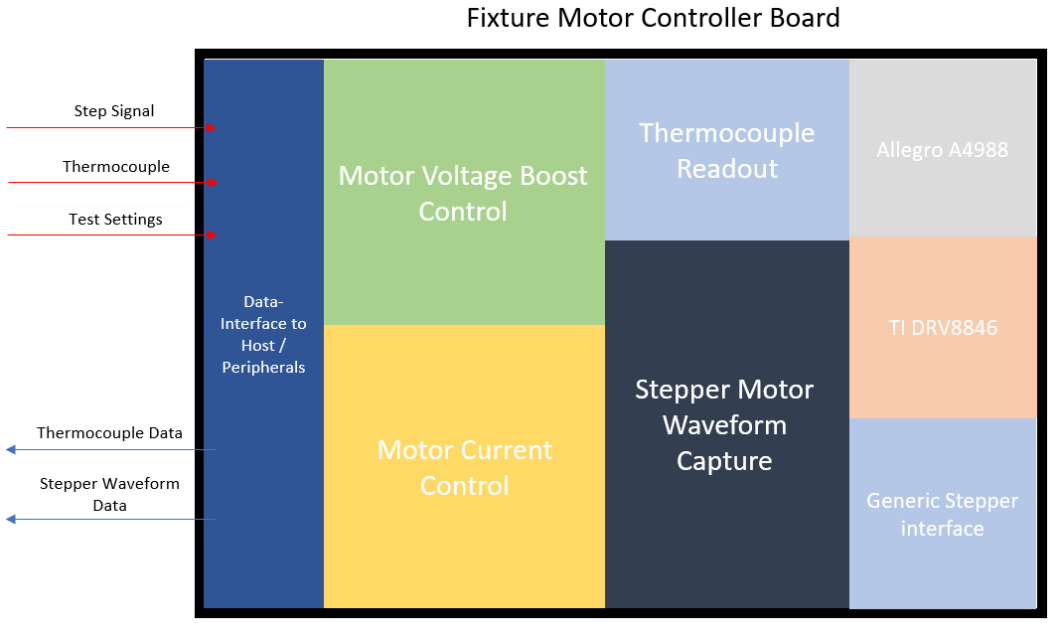
The proposed project aims to develop a dedicated fixture setup to test the torque output of a stepper motor. This setup will specifically cater to the requirements of testing the small bipolar stepper motors used in Zebra's printers. The configuration will integrate advanced components and software controls to ensure precise measurements and streamlined operation.

This setup will mount a small bipolar stepper motor that is used inside of Zebra printers and a magnetic particle brake on each side of the transducer. The stepper motor will be driven, and a load will be applied with the particle brake.



For each step, there is a small flat, portion of the form when the stepper motor stops in a specific detent (during which printing occurs). We want to analyze this waveform and make sure we are in each detent for a certain amount of time (to be determined later). If the motor is stepped too fast, the waveform begins to look like a sawtooth pattern, with a lower amplitude, and steps begin to be missed, which negatively impacts print quality. If this is seen in test, the team will cancel the motor test and report the waveform as unacceptable.


Setup 2 (Stepper Motor Tester)
Magnetic Particle Brake
Raspberry PI / PC w/ USB GPIO
Motor Step Output (Digital Logic)
Custom Fixture Stepper Motor Driver
Bi-Polar Stepper Motor (Used in Printers)
Monitor Step output to sync with transducer encoder
Torque Transducer (Torque Measurement)
Torque Transducer (Encoder / Position)


Fixture Motor Controller Board
Step Signal
Thermocouple
Test Settings
Thermocouple Data
Stepper Waveform Data
Data- Interface to Host / Peripherals
Motor Voltage Boost Control
Motor Current Control
Thermocouple Readout
Stepper Motor Waveform Capture
Allegro A4988
TI DRV8846
Generic Stepper interface

Hardware/Electrical Tasks:

- Understand how each electrical interface will work between all items in the system
- Design custom motor controller board
    - Define voltage boost, motor current, and driver to run for each test
    - Analyze stepper motor waveform for missed steps
    - Choose thermocouple and magnetic particle brake
- Create blank, generic interface to accept daughter board to test future stepper drivers
- Define best data interface between Raspberry PI and motor controller board
- Spec out GPIO interface board / Raspberry Pi to connect peripherals
    - Ensure proper bandwidth to capture data

Firmware/Software/Computer Tasks:

- Create graphic user interface for test
- Post-process torque data and overlay on top of printed label image
- Convert bipolar step rate to hybrid motor step rate
- Create software toggles for all motor parameters on motor controller board

Key Configuration Details

- **Fixture Setup**:
    - The system will mount a bipolar stepper motor like those used in Zebra printers.
    - Magnetic particle brakes will be installed on either side of the torque transducer.
    - The stepper will be actively driven, while the brakes will apply controlled loads to simulate operational stress.
- **Custom Stepper Motor Driver Board**:
    - A custom board will be designed to control the stepper motor drivers.
    - The board will support:
        - Adjustable motor voltage boosting and current control, which are critical for determining motor torque and speed.
        - Software-driven parameter adjustments to allow consecutive testing scenarios (e.g., voltage boosts of 10V, 12V, 14V with motor currents of 650mA and 750mA).
    - Compatibility with multiple motor driver ICs such as Allegro A4988, TI DRV8846, and a placeholder for future driver integrations.
- **Software and GUI Integration**:
    - A graphical user interface (GUI) will be developed to:
        - Control the motor voltage, current, and load application rates.
        - Toggle between different motor drivers for testing.

        - Monitor and document the load applied via the particle brake.
        - Capture and analyze the stepper motor waveform during operation.
    - The software will ensure the tests are repeatable and provide clear graphical outputs for torque data.
- **Additional Features**:
    - **Thermocouple Integration**: A thermocouple will monitor the motor temperature, ensuring safe operation during high-current and high-voltage tests.
    - **Waveform Analysis**: The stepper motor's waveform will be analyzed to detect missed steps or performance degradation. If the waveform deviates significantly (e.g., transitioning to a sawtooth pattern), the test will automatically terminate to prevent damage.
    - **Data Archiving**: The system will output detailed reports documenting torque performance and waveform characteristics.

Benefits to Zebra Technologies

- **Enhanced Testing Capabilities**:
    - The new configuration will provide precise torque data under simulated operational conditions, allowing for better evaluation of stepper motor performance.
    - It will enable Zebra engineers to identify and address torque-related issues more effectively.
- **Improved Efficiency**:
    - The integrated GUI and streamlined testing process will reduce setup time and complexity for technicians.
    - Automated data capture and analysis will enhance the reliability and accuracy of test results.
- **Future-Proof Design**:
    - The modular approach to motor driver compatibility ensures the system remains adaptable to new technologies and requirements.

Composition of Team: 1 Electrical Engineer & 1 Computer Engineer

Skills Required:

- **Electrical Engineering:** Use of lab equipment such as oscilloscope and logic analyzer; knowledge of stepper motors and driver IC's; working knowledge of USB / serial communication protocols
- **Computer Engineering:** Experience creating graphical user interfaces; Python experience; Knowledge of data analysis (Fourier transforms)

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

Updating the torque measurement fixture will allow Zebra engineers to collect better system data faster and more reliably. It would take far less time to set up the test and provide more accurate data that will reduce issues coming up later in development cycles. This will also allow for faster issue troubleshooting, determination of whether acceptable printing can occur under specific customer conditions, and determination of customer-specific adjustments to accommodate unknown printing conditions.

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

Zebra is the market leader in mobile printing technology. Continually advancing data collection and test procedures helps improve product quality. It is very difficult to predict all printing conditions encountered from third party (uncontrolled and undocumented) media, but this project's success will allow for agility in responding to customer issues.