Shaikh Rashidali Alaudddin. International Journal of Engineering Research and Applications
www.ijera.com
ISSN: 2248-9622, Vol. 15, Issue 8, August 2025, pp 06-10

RESEARCH ARTICLE OPEN ACCESS

Design and Development of a Digital Limit and Torque Sensing System for Electrical and Pneumatic Actuators

Shaikh Rashidali Alaudddin
Department of Electrical Maintenance, Gujarat Industries Power Company Limited, Gujarat, India

ABSTRACT
This paper presents the design and development of an intelligent dual-PCB embedded system for replacing mechanical limit switches and torque cams in electrical and pneumatic actuators. The proposed system features a Logic cum Control Card and a Power cum Relay Card. It employs an Autonics incremental rotary encoder to provide digital position feedback and an ACS712-30A Hall-effect current sensor to estimate torque based on motor current draw. A key innovation is the use of a rechargeable battery with built-in charging and automatic switchover, maintaining feedback even during power outages. An ATmega328P microcontroller is embedded in the Relay Card to monitor encoder pulses during power-off conditions. It enters a low-power sleep mode to preserve battery and wakes only upon detecting encoder pulses, ensuring accurate position tracking without power. Once power is restored, it transmits the stored position to the ATmega2560 on the Logic Card for conversion into the last operated percentage. Additionally, the system includes two multifunction latching relays for customizable output feedback, enhancing integration with existing industrial systems. The actuator is also equipped with a 4–20 mA receiving module which interprets analog control commands and automatically positions the actuator based on the received current. The system offers a simple and precise digital limit setting procedure using front panel pushbuttons and LCD guidance. Successfully retrofitted into over 50 actuators—including Rotork, AUMA, Limitorq, and Chinese models—the system demonstrated high accuracy, safety, and compatibility with existing PLC and SCADA systems. This paper covers the complete hardware architecture, signal processing methodology, field deployment strategy, and observed operational benefits.

Keywords: Digital Feedback, Autonics Encoder, Torque Sensing, Battery Backup, Actuator Automation, Hall Effect Sensor, Latching Relay, 4–20 mA Control, Digital Limit Setting

---

Date of Submission: 26-07-2025 Date of acceptance: 05-08-2025

I. Introduction

In industrial automation systems, actuators such as Motor Operated Valves (MOVs) are widely used for regulating mechanical operations and fluid flow. Conventional actuator feedback systems typically employ mechanical cams and switches to detect stroke limits and overload conditions. These systems are prone to wear and require frequent manual calibration. Furthermore, they lack the digital interface and real-time monitoring capabilities required for modern Industry 4.0 environments.

This paper proposes a smart feedback and control system using a dual-PCB configuration. The Logic cum Control Card integrates an ATmega2560 microcontroller, Autonics rotary encoder, ACS712 Hall-effect current sensor, RS-485 communication, and 4–20 mA analog output. The Power cum Relay Card handles high-voltage switching via MOC3041 opto-triacs and ULN2003 relay drivers. Additionally, the system includes a rechargeable battery that functions as a DC UPS, ensuring uninterrupted position tracking during power outages. Two multifunction latching relays offer configurable output feedback for alarms, actuator status, or interfacing with external equipment. A 4–20 mA receiving module interprets analog input commands and adjusts actuator position automatically. Successfully tested on over 50 actuators of various makes and voltages (220V and 415V AC), the system proves to be a reliable, retrofittable solution for digital actuator automation.

II. Methodology

A. Logic cum Control Card
The Logic Card is also equipped with a 5-pin DIP switch that provides essential hardware configuration settings for actuator operation. In addition to control and feedback configurations, the DIP switch allows selection among three operational modes:

- Switch 1 – ON/OFF Mode: Enables binary open/close operation. Turn ON Dip Switch 1 to activate.
- Switch 2 – INCHING Mode: Enables step-by-step jogging operation. Turn ON Dip Switch 2 to activate.
- Switch 3 – CONTINUOUS Mode: Enables proportional continuous control of the actuator. Turn ON Dip Switch 3 to activate.

Only one of these mode switches should be active at a time based on the required control behaviour. Switches 4 and 5 can be assigned additional configuration roles as per user preference or future system updates.
These DIP switch settings are configured during installation or maintenance to suit the actuator's intended operational logic.

The system also supports two modes of operation:

- Local Mode: The actuator can be manually operated using pushbuttons mounted on the faceplate. These allow operators to command open/close actions directly from the actuator location.
- Remote Mode: Control is handed over to an external PLC or SCADA system. Commands are received via wired signals or serial communication.

The system also generates a real-time Local/Remote feedback signal that is transmitted back to the PLC to reflect the active mode of operation, improving system transparency and control logic integration.
The Logic Card performs all signal acquisition, processing, and communication functions. Major components include:

- ATmega2560 microcontroller: Core processor for signal handling and control logic.
- Autonics Incremental Rotary Encoder: Provides high-resolution position feedback via A/B channels.
- ACS712-30A Current Sensor: Measures actuator current, enabling torque estimation.
- PC817 Optocouplers: Isolate input signals for safety and noise immunity.
- RS-485 Communication: Enables integration with SCADA/PLC.
- XTR110KP Transmitter: Provides calibrated 4–20 mA analog feedback.
- 4–20 mA Receiving Module: Accepts analog input commands and translates them into actuator position percentages for automatic operation.
- LCD & Buttons: Local diagnostics and configuration interface.

B. Power cum Relay Card
This card controls actuator movement and power distribution:

- MOC3041 Opto-Triacs: Trigger DOL AC contactors for OPEN and CLOSE commands. These opto-triacs are phase-synchronized to operate at the zero-crossing point of the AC waveform, significantly reducing electrical arcing and contactor wear. This zero-cross switching minimizes inrush current and mitigates sparking during contactor engagement and disengagement, thereby extending the life of switching components and enhancing safety.
- ULN2003 Relay Drivers: Energize relays with flyback protection.
- LM2596, 7812, 7805: Provide 24V to 5V/12V regulated supplies.
- 6N137 Optocouplers: Isolate relay feedback signals.
- ATmega328P Microcontroller: Operates as a backup encoder pulse counter in power-off conditions. It runs in ultra-low-power sleep mode to conserve battery and wakes upon detecting encoder pulses. It stores position data and transmits it to the ATmega2560 upon power restoration, enabling accurate post-outage position calculation.
- Multifunction Latching Relays: Two programmable latching relays provide user-defined feedback outputs, including open/close position status, fault indication, or PLC interfacing. The latching functionality ensures feedback state retention during power interruptions.
- Field Fault Relay: An additional common relay is provided specifically to indicate field faults. This relay activates when any operational fault is detected—such as actuator stall, overcurrent, torque failure, position mismatch, or temperature/humidity anomalies. The field fault relay output can be connected to an alarm system or PLC for immediate notification and response.

C. Battery Backup and Charging Circuit
A rechargeable battery module ensures continuous system operation during power failures. When external power is lost, the system automatically switches to battery mode. The ATmega328P continues monitoring encoder pulses in sleep-interrupt mode. Upon restoration, an onboard charging circuit recharges the battery, and stored encoder data is handed off to the Logic Card to determine the last operated actuator percentage.

D. Digital Limit Setting Procedure
The system provides a user-friendly digital limit setting process via its local interface. To configure actuator limits:

1. Enter setup mode using the designated front panel pushbutton.
2. Manually jog the actuator to the fully CLOSED position.
3. Press the 'Set Close Limit' button to store the encoder value.
4. Repeat the process for the fully OPEN position using the 'Set Open Limit' button.
5. The system stores both limit values in non-volatile memory.
6. Once limits are set, the actuator calculates position feedback in real-time and reflects it as a percentage of travel.

This method ensures precise and drift-free calibration without the need for mechanical cams or tools.

III. Results and Discussion

The system was installed and tested on over 50 actuators, including makes such as Rotork, AUMA, Limitorq, and various Chinese-manufactured units. It operated reliably on both 220V single-phase and 415V three-phase AC systems.

- Digital Feedback Accuracy: Position feedback was accurate within ±2° mechanical rotation, providing superior repeatability over mechanical cams.
- Torque Monitoring: The ACS712 provided effective current-based torque estimation, detecting stall and overload events without mechanical sensors.
- Battery Backup: Maintained encoder position tracking during outages. Onboard auto-charging resumed normal function seamlessly. The ATmega328P continued to monitor actuator movement in sleep-wake mode.
- 4–20 mA Analog Input Control: The actuator's logic system interpreted incoming analog signals and translated them into percentage-based actuator movements, enabling precise positioning based on PLC commands.
- Digital Limit Setting: The system's pushbutton-based procedure allowed intuitive, drift-free limit configuration without mechanical adjustments.
- Retrofitting: The system adapted to existing actuator wiring using a universal wiring diagram, with no mechanical modification needed.
- Integration: 4–20 mA and RS-485 outputs were successfully linked to PLCs/SCADA.
- Multifunction Latching Feedback Relays: Offered robust and versatile feedback outputs for actuator state and alarms. The latching mechanism preserved relay state during power loss, enhancing system reliability.
- Diagnostics: Real-time fault codes were displayed on the LCD. Errors such as stall, overcurrent, high temperature, and humidity were detected reliably.

IV. Conclusion

The developed digital actuator feedback system effectively replaces mechanical limit switches and torque sensing cams with a smart, programmable alternative. Its modular dual-PCB architecture, rechargeable battery support, multifunction latching relays, and compatibility with existing actuator wiring make it ideal for retrofit and new installations. Extensive field testing confirmed its reliability, accuracy, and ease of integration. The inclusion of a secondary microcontroller (ATmega328P) to preserve position tracking during power-off conditions, a responsive 4–20 mA input module for analog control, and a simple digital limit setting procedure makes the system highly adaptable and intelligent for modern industrial environments.

References

[1]. Autonics Rotary Encoder Datasheet. [Online: www.autonics.com]
[2]. ACS712 Current Sensor Technical Reference. Allegro Microsystems.
[3]. MOC3041 Opto-Triac Driver Datasheet. ON Semiconductor.
[4]. ATmega2560 Microcontroller Datasheet. Microchip Technology.
[5]. ATmega328P Microcontroller Datasheet. Microchip Technology.
[6]. XTR110KP 4–20mA Transmitter IC Datasheet. Texas Instruments.
[7]. IEEE Std 1815-2012, Standard for Electric Power Systems Communications—DNP3.
[8]. Shaikh R. A., "Instruction Manual: Ingenious Actuator Control System," Gujarat Industries Power Company Ltd., 2025.
[9]. 6N137 High-Speed Optocoupler Datasheet. ON Semiconductor.
[10]. AMS1117 Voltage Regulator Datasheet. Advanced Monolithic Systems.
[11]. DW01 Lithium Battery Protection IC Datasheet. Fortune Semiconductor.
[12]. FP6298 Synchronous Step-Down Converter Datasheet. Feeling Technology.
[13]. FS8205 Dual N-Channel MOSFET Datasheet. Fortune Semiconductor.
[14]. LM2596 Buck Converter IC Datasheet. Texas Instruments.
[15]. MAX485 RS-485 Transceiver Datasheet. Maxim Integrated.
[16]. MCP4921 DAC Datasheet. Microchip Technology.

[17]. PC817 Optocoupler Datasheet. Sharp Corporation.
[18]. TP4056 Lithium Battery Charging IC Datasheet. NanJing Top Power ASIC Corp.
[19]. ULN2003A Relay Driver Datasheet. Texas Instruments.
[20]. LM7824 Voltage Regulator Datasheet. Texas Instruments.

Appendix: Block Diagram Explanation
FIG 1.(LOGIC CUM CONTROL CARD)
Logic Cum Control Card
The Logic Cum Control Card serves as the central processing and decision-making unit of the system. At the core of this card lies the ATmega2560 microcontroller, which functions as both the brain and heart of the system, managing control operations and communication.
Functional Blocks and Their Description:
4–20 mA Input Block:

This block receives a standard 4–20 mA analog signal and converts it proportionally into a 0–5 V DC signal. This voltage is then fed to the ADC (Analog-to-Digital Converter) input pin of the ATmega2560. Based on this input, the microcontroller computes the corresponding percentage value and commands the actuator to operate accordingly.
MODBUS Communication Block:

Facilitates communication with external PLC and SCADA systems via a 2-wire RS-485 interface. This setup allows multiple devices to be connected over a single communication bus.
Opto-Isolator Inputs:

This section is responsible for receiving external commands such as Local/Remote, Local Open, Local Close, Remote Open, and Remote Close. Opto-isolators provide galvanic isolation to protect the microcontroller from voltage spikes and ground loops.
16x2 LCD Module:

Acts as the Human-Machine Interface (HMI), enabling users to visualize system parameters and perform configuration settings.
Rotary Switch:

This user-interface component allows navigation and selection of various settings displayed on the LCD.
Current Sensor (ACS712): Measures actuator current to detect overcurrent and thermal loads. It also plays a role in estimating torque during opening and closing operations.
4–20 mA Output Block:

Generates an analog current output signal corresponding to the actuator's position (in percentage). This allows real-time monitoring of actuator status by external systems.
IDC Connector: Provides the communication and power interface between the Logic Cum Control Card and the Relay Cum Power Card. It enables the ATmega2560 to interact with the ATmega328P on the power card, control relay operations, and receive power supply.
FIG 2. (RELAY CUM POWER CARD)
Relay Cum Power Card
The Relay Cum Power Card performs two major functions:
Supplies power to the actuator system and logic card.
Provides feedback and control relay outputs for interfacing with PLC or DCS systems.
Functional Blocks and Their Description:
IDC Connector:

Interfaces with the Logic Cum Control Card to handle data transfer such as actuator position from the Autonics rotary encoder, command signals for relay operation, power delivery to the logic card, and communication between the ATmega328P and ATmega2560.
Relay Driver:

Acts as an intermediate driver circuit to activate relays based on commands received from the ATmega2560 via the IDC connector. This block provides isolation between the logic circuitry and relays.
MOC3041 (Opto-Triac Driver):

These devices control AC power contactors using zero-crossing switching. This technique reduces electrical noise and eliminates sparking during contactor operation.
12V Relay:

These relays are used to provide discrete output feedback to PLC or DCS systems regarding actuator status.
Power Supply Module:

Converts 24V AC from a control transformer into regulated DC outputs (24V, 12V, and 5V). It also includes functionality to charge the battery through an integrated battery charging circuit.
DC UPS Module:

Maintains continuous power supply to critical

components. It receives one 5V DC supply from the battery module and another from the power supply module. In the event of power supply failure, it seamlessly switches to the battery backup.
ATmega328P Microcontroller:

Operates as a secondary processor to record actuator position during power failures. It is powered via the UPS system. Upon power restoration, it communicates the last known actuator position to the ATmega2560 via the IDC connector.
Autonics Rotary Encoder:

Detects actuator shaft rotation and converts it into pulse signals. These signals are interpreted by both ATmega328P and ATmega2560 to monitor real-time actuator position.

Figure 1 – Block Diagram of the Logic cum Control Card illustrating ATmega2560 interfacing with 4–20 mA modules, Modbus, encoder, and display units.

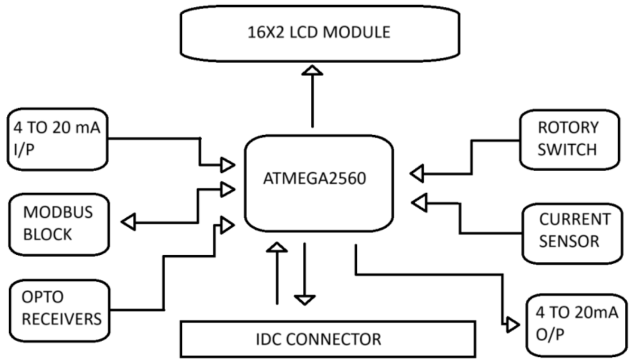

Figure 2 – Relay cum Power Card Block Diagram showing MOC3041, relay drivers, DC UPS, and ATmega328P interfaced with rotary encoder and power supply.