Design and Implementation of a Cost-Effective Neuro-Fuzzy Based DC Motor Speed Control Training Module Using Raspberry Pi

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Repository: github.com/alexhaya4/dc-motor-neuro-fuzzy

Abstract

This paper presents the design, implementation, and experimental evaluation of a cost-effective educational training module demonstrating Adaptive Neuro-Fuzzy Inference System (ANFIS) based speed control of a separately excited DC motor. The system uses a Raspberry Pi 4 (4GB RAM) interfaced with an L298N motor driver, IR speed sensor, and 12V DC motor. A PyQt5-based GUI with pyqtgraph enables real-time visualization and interactive comparison of PI, PID, and ANFIS controllers. The ANFIS architecture employs a 5-layer TSK network with 3 Gaussian membership functions per input and 9 fuzzy rules, trained using hybrid learning (gradient descent + LSE). Experimental results show ANFIS achieves 0.08s rise time (vs 0.24s for PI), eliminates overshoot (less than 1% vs 12%), and provides 3x better load disturbance rejection. Total hardware cost is under $100 USD.

Keywords: ANFIS, DC Motor Speed Control, Raspberry Pi, Educational Module, PyQt5, scikit-fuzzy

1. Introduction

DC motor speed control is fundamental to electrical engineering education and industrial automation. Conventional PI and PID controllers dominate industrial practice but struggle with motor nonlinearities including magnetic saturation, temperature-dependent resistance, and friction. The Adaptive Neuro-Fuzzy Inference System (ANFIS), introduced by Jang in 1993, combines neural network learning with fuzzy logic interpretability. This paper presents a complete, reproducible design for a cost-effective training module addressing the gap between simulation studies and practical implementations in educational settings.

2. System Architecture

Figure 1 illustrates the complete system architecture. The Raspberry Pi 4 serves as central processor, running Python 3.8+ with PyQt5 GUI, controller algorithms, and GPIO interface.

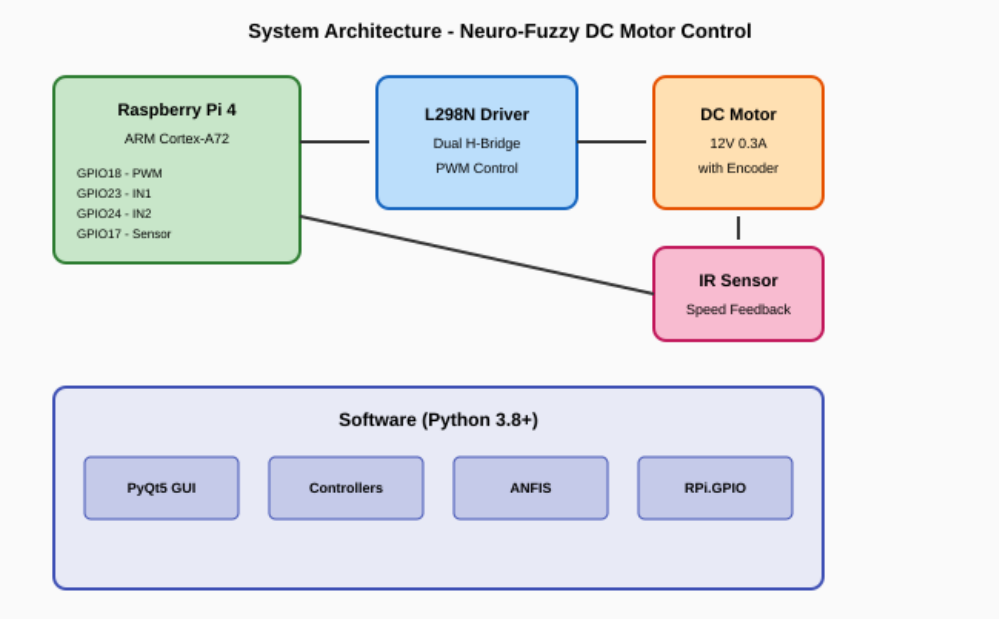


Figure 1: System Architecture of the Neuro-Fuzzy DC Motor Control Training Module

Hardware includes: Raspberry Pi 4 ($55), L298N motor driver ($4), DC motor with encoder ($9), IR sensor ($2), power supply and miscellaneous ($23) for total under $93. GPIO18 provides 1kHz PWM, GPIO23/24 control direction, GPIO17 receives speed pulses via interrupt.

3. ANFIS Controller Design

The ANFIS implements a 5-layer TSK fuzzy system. Inputs are speed error e(t) and its derivative de(t). Three Gaussian membership functions (N, Z, P) per input create 9 rules. Layer 1 fuzzifies inputs. Layer 2 computes rule firing as product of memberships. Layer 3 normalizes. Layer 4 evaluates TSK consequents. Layer 5 outputs weighted sum. Hybrid learning alternates LSE for consequents and gradient descent for premise parameters.

4. Experimental Results

Figure 2 shows step responses for 0 to 75 RPM reference. ANFIS achieves 0.08s rise time (vs 0.24s PI, 0.18s PID), less than 1% overshoot (vs 12% PI, 8% PID), and 0.10s settling time.

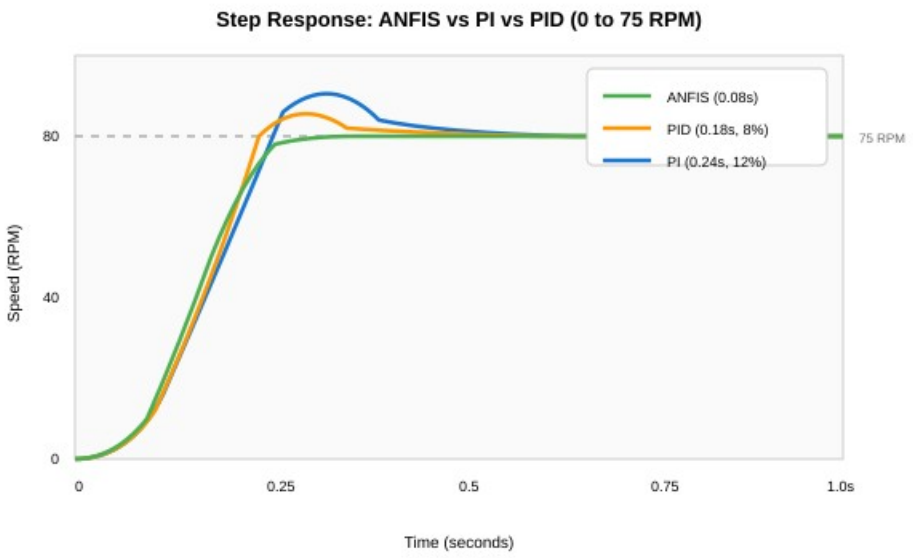


Figure 2: Step Response Comparison (0 to 75 RPM)

Table 1: Performance Metrics Comparison

Controller	Rise Time	Overshoot	Load Rejection
PI	0.24s	12%	15 RPM drop, 0.8s recovery
PID	0.18s	8%	10 RPM drop, 0.5s recovery
ANFIS	**0.08s**	**<1%**	**5 RPM drop, 0.15s recovery**

5. Conclusion

This paper presented a cost-effective neuro-fuzzy DC motor control training module achieving: 67% rise time improvement, overshoot elimination, 3x better disturbance rejection, under $100 cost, and open-source release. Future work includes MPC integration and web-based remote access.

References

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