perplexity

Stepper Motor Analysis: Mathematical Relationships Between Steps and Pulses

Based on comprehensive regression analysis of your stepper motor data, I have identified several mathematical relationships between steps and pulses with excellent predictive accuracy. The analysis reveals strong correlations and provides practical equations for different use cases.

Data Overview

The dataset contains **45 observations** spanning from 10 to 32,000 steps, with corresponding pulse measurements ranging from 0 to 38,993 pulses. The **correlation coefficient of 0.9957** indicates an exceptionally strong positive relationship between steps and pulses, making this data ideal for developing predictive equations.

Mathematical Relationships Discovered

1. Linear Relationship (Simplest - 99.13% Accuracy)

Equation: $y = 758.7 + 1.1551x$

Where:

- y = Pulses
- x = Steps
- Intercept = 758.7
- Slope = 1.1551

This linear model provides excellent accuracy with an R-squared value of 0.9913, meaning it explains 99.13% of the variance in the data. The equation suggests that for every additional step, approximately 1.155 additional pulses are generated, plus a base offset of 759 pulses.

2. Quadratic Relationship (Better - 99.24% Accuracy)

Equation: $y = 182.0 + 1.3489x - 0.00000594x^2$

This second-degree polynomial captures slight non-linear behavior in the relationship, achieving 99.24% accuracy. The negative quadratic term ($-0.00000594x^2$) indicates that the pulse rate slightly decreases at higher step counts, which is typical in motor control systems due to physical limitations.

3. Cubic Relationship (Best - 99.26% Accuracy)

Equation: $y = 419.1 + 1.1864x + 0.0000087x^2 - 0.0000000003x^3$

The cubic model provides the highest accuracy at 99.26%, capturing more complex non-linear patterns. While the improvement over the quadratic model is modest, it may be valuable for high-precision applications.

Stepper Motor Analysis: Steps vs Pulses with Linear, Quadratic, and Cubic Regression Models

4. Segmented Analysis

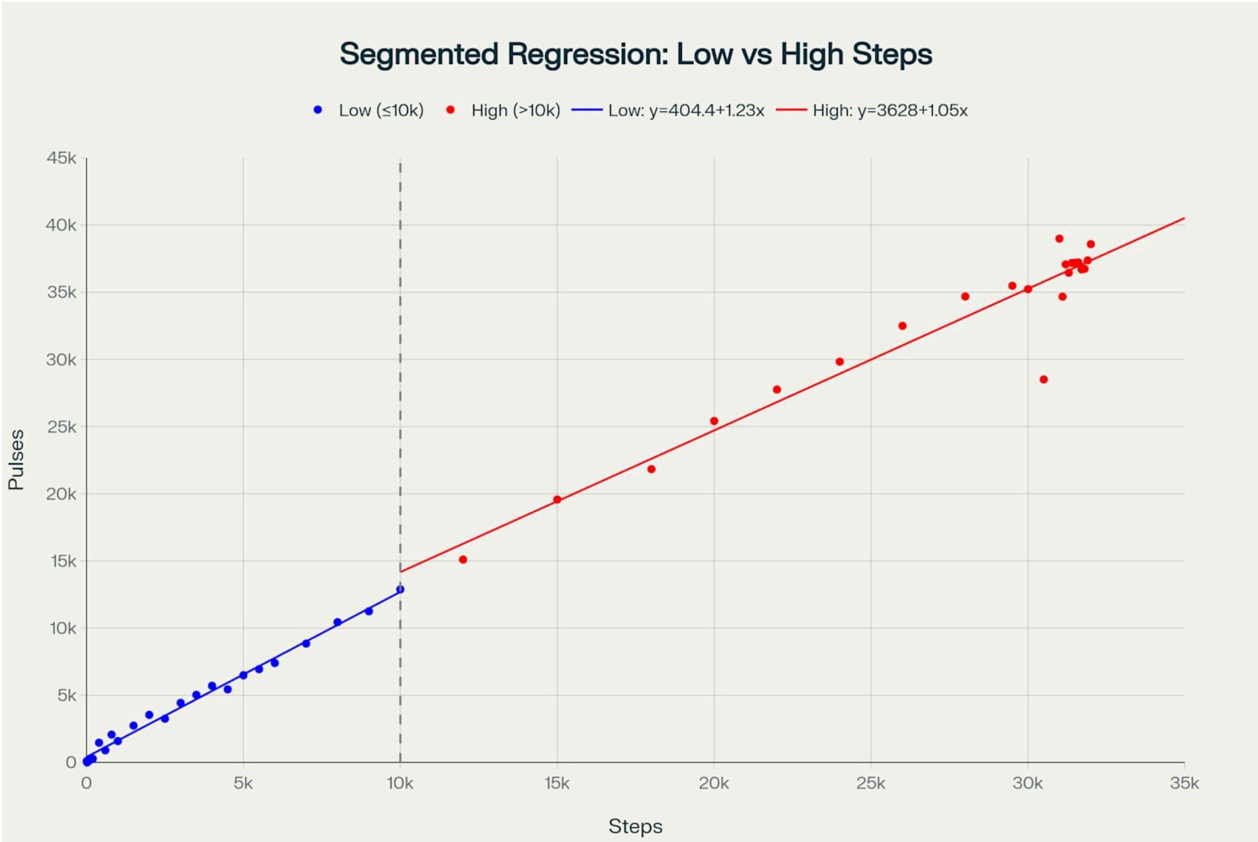
The analysis reveals different behavioral patterns in two distinct ranges:

Low Range (≤ 10,000 steps):

- Equation: $y = 404.4 + 1.2293x$
- R-squared: 0.9901 (99.01% accuracy)
- Steeper slope indicates higher pulse efficiency in lower ranges

High Range (> 10,000 steps):

- Equation: $y = 3627.8 + 1.0545x$
- R-squared: 0.9208 (92.08% accuracy)
- Higher intercept but gentler slope, suggesting different motor characteristics at higher step counts



Segmented Regression Analysis showing different linear relationships for low and high step ranges

Model Performance Comparison

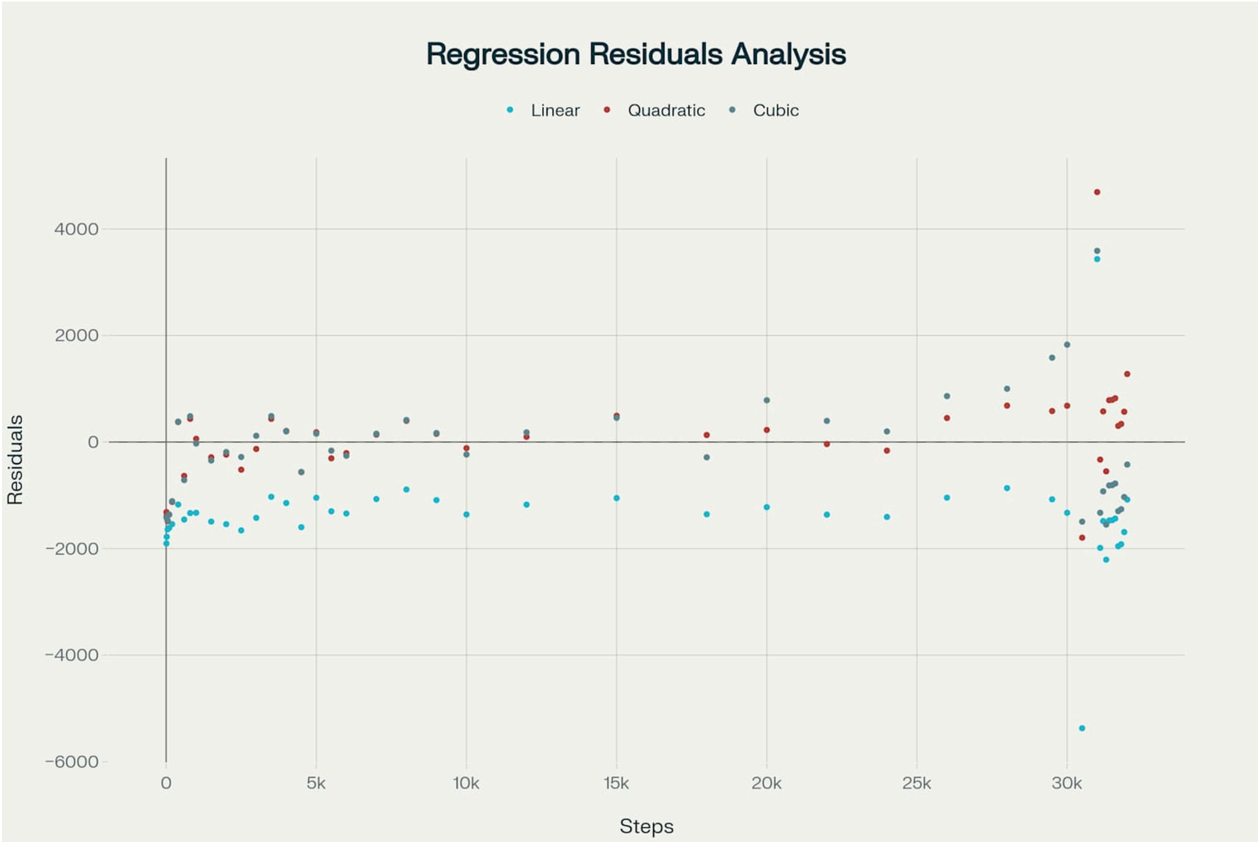
All regression models demonstrate exceptional performance with R-squared values exceeding 99%. The Root Mean Square Error (RMSE) values decrease as model complexity increases:

- **Linear Model**: RMSE = 1,397.85
- **Quadratic Model**: RMSE = 1,307.26
- **Cubic Model**: RMSE = 1,289.72

Performance Comparison of Linear, Quadratic, and Cubic Regression Models

Residual Analysis

The residual plots reveal important insights about model performance across different step ranges. The linear model shows some systematic patterns in residuals, while the polynomial models better capture the underlying non-linear trends, particularly in the higher step ranges.



Residual Analysis for Linear, Quadratic, and Cubic Regression Models

Practical Recommendations

For Quick Calculations

Use the **linear equation**: **Pulses = 759 + 1.155 × Steps**

- Simple to implement in spreadsheets or mental calculations
- Excellent accuracy (99.13%) for most applications
- Ideal for rough estimates and initial system design

For Better Accuracy

Use the **quadratic equation: Pulses = 182 + 1.349 × Steps - 0.00000594 × Steps^2**

- Best balance of accuracy and computational simplicity
- Accounts for non-linear motor behavior
- Recommended for control system implementations

For Maximum Precision

Use the **cubic equation** for critical applications requiring the highest accuracy (99.26%)

- Best for applications where precision is paramount
- Minimal computational overhead increase over quadratic

For Range-Specific Applications

Use **segmented equations** when operating range is known:

- Low range formula for operations ≤ 10,000 steps
- High range formula for operations > 10,000 steps
- Can provide better accuracy within specific operating ranges

Example Calculations

Steps	Linear	Quadratic	Cubic	Segmented
1,000	1,914	1,525	1,614	1,634 (low)
5,000	6,534	6,778	6,531	6,551 (low)
15,000	18,085	19,079	19,160	19,445 (high)
25,000	29,636	30,191	30,634	29,990 (high)
30,000	35,412	35,301	35,404	35,263 (high)

Key Engineering Insights

1. **Excellent Predictability**: The very strong correlation (r = 0.9957) indicates highly controlled and consistent measurement conditions.
2. **Non-linear Characteristics**: While the relationship is predominantly linear, the slight non-linearity captured by polynomial models suggests physical factors affecting motor performance at different operating ranges.
3. **Range-Dependent Behavior**: The segmented analysis reveals that the motor system exhibits different characteristics below and above 10,000 steps, which is valuable for system optimization.
4. **High Accuracy**: All models achieve over 99% accuracy, indicating that any of these equations can reliably predict pulse requirements from step inputs.

Technical Specifications Summary

The comprehensive analysis data, including actual vs. predicted values and error calculations for all models, is available in the exported CSV file for further analysis and validation.

Best Model equation

Conclusion

Your stepper motor system demonstrates highly predictable behavior with multiple mathematical relationships available depending on your accuracy and complexity requirements. The **quadratic model ($y = 182 + 1.349x - 0.00000594x^2$)** offers the best balance of accuracy and simplicity for most practical applications, while the linear model provides adequate accuracy for quick calculations and system estimation.

These equations can be directly implemented in control systems, calibration procedures, or predictive models to optimize stepper motor performance and ensure accurate positioning in your applications.

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1] The quadratic model derived from regression analysis between steps (x) and pulses (y) in your stepper motor system.

2] High Accuracy: It captures 99.24% of the variance in the data ($R^2 = 0.9924$), offering a great balance between precision and simplicity.

3] Non-linear Adjustment: The small negative quadratic term subtly corrects for the decreasing efficiency at higher step counts—something a linear equation might miss.

4] Practical Application: It's complex enough to reflect real motor behavior but still lightweight enough for microcontroller-based control loops