Digital Modeling and Performance Evaluation of a Portable Environmental Monitoring Instrument Using MATLAB/Simulink

Duration of Project – 12 Weeks

Learning Goals

Context and Instrumentation Learning Goals

1. Design a digital environmental monitoring instrument capable of measuring and displaying a physical variable.
2. Investigate how calibration improves measurement accuracy and system performance.
3. Analyze sources of measurement uncertainty and their impact on instrument reliability.
4. Evaluate the effects of signal noise and filtering techniques on measurement quality.
5. Explore the dynamic response characteristics of sensors used in instrumentation systems.
6. Compare theoretical, simulated, and experimental instrument performance.
7. Apply engineering principles to improve measurement-system performance.

Computational Thinking Learning Goals

1. Use MATLAB and Simulink as engineering tools for modeling and analyzing measurement systems.
2. Develop computational solutions for calibration, error analysis, and system evaluation.
3. Use data to support engineering decision-making.
4. Validate computational models using experimental evidence.
5. Communicate engineering findings using quantitative analysis and graphical representations.

Learning Outcomes

By the end of this activity, students will be able to:

Instrumentation Outcomes

- Develop a Simulink model of a measurement system.
- Generate and apply sensor calibration models.
- Quantify measurement accuracy using engineering performance metrics.
- Evaluate the effectiveness of calibration procedures.
- Analyze the effect of noise on measurements.
- Assess the dynamic response of first-order sensors.
- Compare simulated and experimental results.
- Recommend improvements to instrumentation systems.

Computational Thinking Outcomes

- Develop MATLAB algorithms for instrumentation analysis.
- Apply computational methods to solve engineering problems.
- Interpret computational outputs and graphical results.
- Validate simulation results using measured data.
- Draw engineering conclusions from quantitative evidence.

Assessment Focus

Students will be assessed on their ability to:

- Develop a valid Simulink measurement-system model
- Perform calibration and error analysis
- Evaluate instrument performance using MATLAB
- Interpret simulation and experimental results
- Communicate engineering findings through graphs, calculations, and technical discussion
- Use MATLAB and Simulink as tools for validation, testing, and troubleshooting of a measurement system.

Software Requirements

- MATLAB R2024a or later
- Simulink
- Control System Toolbox

Part A: Measurement System Design and Simulink Modelling

Objective

Develop a measurement-system model for monitoring an environmental variable such as temperature, humidity, or light intensity.

Task A1

Create a block diagram showing:

- Measurand
- Sensor
- Signal Conditioning
- Signal Processing
- Output Display

Task A2

Develop a Simulink model representing the complete instrument.

Required Discussion

1. Explain the function of each subsystem.
2. Describe the signal flow through the system.
3. Identify possible sources of measurement uncertainty.

Deliverables

- System block diagram
- Simulink model
- Design discussion

Part B: Sensor Calibration

Objective

Objective

Develop a calibration equation that improves sensor accuracy.

Student Tasks

1. Complete the missing MATLAB statements.
2. Determine the calibration equation.
3. Add the calibration equation to the figure.
4. Assess the quality of the calibration model.
5. Explain why the chosen calibration model is appropriate.

Useful Functions

```
polyfit
polyval
scatter
plot
legend
```

Deliverables

- MATLAB code
- Calibration curve
- Calibration equation
- Discussion

Part C: Measurement Error Analysis

Objective

Evaluate sensor accuracy before calibration.

Student Tasks

1. Complete all calculations.
2. Create an additional error graph.
3. Determine whether errors are random or systematic.
4. Identify likely sources of error.

Useful Functions

```
1  mean
2  max
3  abs
4  bar
5  plot
```

Deliverables

- Error calculations
- Error plots
- Summary table

Discussion

PART D: Post-Calibration Error Analysis

Objective

Quantify calibration effectiveness.

Student Tasks

1. Calculate performance before and after calibration.
2. Quantify the improvement in accuracy.
3. Determine whether calibration was successful.
4. Explain any remaining error after calibration.

Useful Functions

```
polyval
mean
max
abs
plot
```

Deliverables

- MATLAB code
- Error comparison graph
- Improvement calculations
- Engineering discussion

Part E: Noise Analysis and Signal Filtering

Investigate the effects of measurement noise.

Student Tasks

1. Generate a noisy measurement signal.
2. Select a suitable filtering technique.
3. Compare signal quality before and after filtering.
4. Evaluate filtering effectiveness.
5. Discuss filtering trade-offs.

Useful Functions

```
randn
movmean
filter
plot
```

Deliverables

- MATLAB code
- Signal plots
- Noise analysis
- Filtering evaluation

Part F: Dynamic Response Analysis

Analyze the response of a first-order sensor.

Student Tasks

1. Create the transfer-function model.
2. Generate and analyze the step response.
3. Determine dynamic response characteristics.
4. Explain their engineering significance.

Useful Functions

```
tf
step
stepinfo
```

Deliverables

- MATLAB code
- Response graph
- Dynamic performance calculations
- Discussion sensor response

PART G: Simulation versus Prototype Validation

Objective

Compare the performance predicted by simulation with measured performance.

Student Tasks

1. Complete the comparison calculations.
2. Identify the largest discrepancy.
3. Explain why differences occurred.
4. Evaluate modelling assumptions.
5. Recommend improvements.

Deliverables

- Comparison table
- Calculations
- Engineering discussion
- Reflection

Project Schedule

Week	In-Class Activities	Student Deliverables
1	Project introduction; review of measurement systems, sensors, and project requirements; team formation.	
2	Measurement-system architecture; block diagrams; instrumentation subsystems	
3	Simulink workshop; modelling sensors, signal conditioning, and displays.	Project proposal identifying the environmental variable, sensor(s), and intended measurement system.
4	Simulink testing and troubleshooting.	Initial Simulink model.
5	Calibration principles; data collection methods; MATLAB curve fitting techniques.	Calibration dataset collected or imported.
6	Calibration modelling workshop.	Calibration graph and calibration equation.
7	Measurement error analysis; engineering performance metrics; uncertainty discussion.	Error analysis results and supporting plots.
8	Post-calibration validation; quantifying calibration improvement.	Post-calibration analysis and on calibration effectiveness.
9	Noise sources in instrumentation systems; filtering techniques; MATLAB implementation.	Noise-analysis plots and filtering evaluation.
10	Dynamic response of first-order sensors; time constants; response characteristics.	Dynamic response analysis and interpretation.
11	Model validation; simulation versus prototype comparison; engineering decision-making.	Simulation-versus-prototype comparison table and improvement recommendations.
12	Project presentations; peer discussion; project review; course integration.	Final report, MATLAB code, Simulink model, presentation slides, and final reflection.

Summary of Marks

Criterion	Marks
Measurement System Model Development	20
Calibration Analysis	15
Error Analysis and Calibration Effectiveness	20
Noise Analysis and Signal Filtering	15
Dynamic Response Analysis	10
Simulation vs Prototype Evaluation	10
Engineering Communication	10
Total	**100**

Criterion 1: Measurement System Model Development (20 Marks)

Performance Level	Description	Marks
Excellent	Complete and correctly functioning model. Sensor, signal conditioning, processing, and display elements are accurately represented. Model demonstrates strong engineering understanding.	17-20
Good	Functional model with minor omissions or modeling inaccuracies. Most subsystems correctly implemented.	13-16
Satisfactory	Basic model developed but contains several technical errors or missing elements.	9-12
Developing	Incomplete model with significant errors affecting operation.	5-8
Unsatisfactory	Minimal or no evidence of an operational model.	0-4

Criterion 2: Calibration Analysis (15 Marks)

Performance Level	Description	Marks
Excellent	Calibration curve generated correctly. Appropriate calibration equation developed and interpreted accurately. Graphs properly labeled and discussed.	13-15
Good	Calibration completed with minor calculation or interpretation errors.	10-12
Satisfactory	Calibration attempted but contains noticeable errors or limited interpretation.	7-9
Developing	Major errors in calibration procedure or equation generation.	4-6
Unsatisfactory	Calibration absent or fundamentally incorrect.	0-3

Criterion 3: Error Analysis and Calibration Effectiveness (20 Marks)

Performance Level	Description	Marks
Excellent	Correct calculation of pre- and post-calibration errors. Mean, maximum, and percentage errors presented and interpreted. Calibration improvement quantified clearly.	17-20
Good	Most error calculations correct with reasonable discussion of results.	13-16
Satisfactory	Basic error calculations completed but interpretation limited.	9-12
Developing	Errors calculated incorrectly or discussion largely missing.	5-8
Unsatisfactory	No meaningful error analysis performed.	0-4

Criterion 4: Noise Analysis and Signal Filtering (15 Marks)

Performance Level	Description	Marks
Excellent	Noise characteristics analyzed effectively. Appropriate filtering method implemented and justified. Clear comparison between noisy and filtered signals.	13-15
Good	Filtering successfully applied with adequate explanation.	10-12
Satisfactory	Filtering implemented but evaluation is limited.	7-9
Developing	Filtering attempted but contains significant errors.	4-6
Unsatisfactory	No meaningful filtering or analysis completed.	0-3

Criterion 5: Dynamic Response Analysis (10 Marks)

Performance Level	Description	Marks
Excellent	Rise time, settling time, and dynamic characteristics correctly determined and explained. Engineering implications discussed.	9-10
Good	Dynamic performance analyzed with minor interpretation errors.	7-8
Satisfactory	Basic analysis completed but lacks depth.	5-6
Developing	Partial analysis with significant errors.	3-4
Unsatisfactory	Dynamic analysis missing or incorrect.	0-2

Criterion 6: Simulation versus Prototype Evaluation (10 Marks)

Performance Level	Description	Marks
Excellent	Detailed comparison of simulation and experimental results. Sources of discrepancy identified and explained using engineering reasoning.	9-10
Good	Comparison completed with reasonable discussion.	7-8
Satisfactory	Comparison presented but explanation limited.	5-6
Developing	Minimal comparison conducted.	3-4
Unsatisfactory	No comparison provided.	0-2

Criterion 7: Engineering Communication and Documentation (10 Marks)

Performance Level	Description	Marks
Excellent	Report is professionally structured. Figures, tables, equations, and references are correctly presented. Conclusions are clear and evidence-based.	9-10
Good	Well-organized report with minor presentation issues.	7-8
Satisfactory	Adequate report but lacks clarity in some sections.	5-6
Developing	Poor organization and incomplete documentation.	3-4
Unsatisfactory	Report largely incomplete or difficult to follow.	0-2