Programming Assignment Report:

Signal Flow Graphs &
Routh Stability Criterion

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1.Problem Statement:

- **Part 1**: Analyze a signal flow graph (SFG) to compute:

  o Forward paths, loops, and non-touching loops.

  o Determinants and the overall transfer function using Mason's Gain Formula.

- **Part 2**: Determine system stability using the Routh-Hurwitz criterion for a given characteristic equation.

2.Main Features:

- **Signal Flow Graph Solver:**

    - Parses SFG input (nodes, edges, gains) using **SignalFlowGraphSolverSchema.**

    - Computes paths/loops using graph traversal (implied by **networkx**).

    - Calculates determinants and transfer function symbolically (**sympy**).

- **Routh Stability Analyzer:**

    - Parses polynomial input ($s^5 + s^4 + 10s^3$).

    - Constructs Routh array and checks for sign changes.

    - Handles edge cases.

- **Additional Features:**

    - Input validation by **marshmallow**.

    - Symbolic math for precise calculations (**sympy**).

3.Data Structures:

- **Signal Flow Graph:**

    - Represented as a directed multigraph (**networkx.MultiDiGraph**).

    - Nodes: Strings ("A", "B").

    - Edges: Tuples (source, target, gain) with **sympy**-parsed gains.

- **Paths/Loops:**

    - **Path** class stores nodes/edges and computes gains.

    - **ForwardPath** extends **Path** with determinant tracking.

- **Routh Table:**

    - 2D NumPy array for coefficients.

    - Auxiliary polynomial handling for zero rows.

4.Main Modules:

1. Signal Flow Graph (SFG) Solver Module

- **Files**: sfg.py, marshaller.py, path.py, classes.py (implied).

- **Responsibilities:**

  - **Input Validation**: Uses **marshmallow** (**SignalFlowGraphSolverSchema**) to validate JSON input for nodes, edges, and gains.

  - **Graph Representation**: Constructs a directed multigraph (**networkx.MultiDiGraph**) from validated input.

  - **Path/Loop Analysis**:

    - **Path** and **ForwardPath** classes store nodes/edges and compute gains.

    - Algorithms (DFS/BFS) traverse the graph to find forward paths and loops.

  - **Mason's Gain Formula**: Computes determinants (Δ, Δk) and transfer function symbolically (**sympy**).

2. Routh Stability Analyzer Module

- **Files**: solver.py.

- **Responsibilities**:

  - **Polynomial Parsing**: Converts input strings to sympy expressions.

  - **Routh Table Construction**:

    - Builds the Routh array from polynomial coefficients.

    - Handles edge cases.

  - **Stability Check**: Counts sign changes in the first column of the Routh table to determine stability.

3. Data Marshalling Module

- **Files**: marshaller.py.

- **Responsibilities**:

- o **Input/Output Standardization**:
  - ▪ **marshall_input:** Validates and converts raw input (JSON) into a graph object.
  - ▪ **marshall_output:** Formats results (paths, determinants, etc.) for display/storage.

4. Core Utilities

- **Dependencies**:
  - o **sympy**: Symbolic math for determinants and transfer functions.(v1.13.1)
  - o **networkx**: Graph traversal and cycle detection.
  - o **numpy**: Numerical operations for Routh array.

5.Algorithms:

Part 1: Signal Flow Graph

1. **Graph Traversal**:
   - o **Forward Paths**: DFS/BFS from input to output node.
   - o **Loops**: Cycle detection in **networkx**.

2. **Mason's Gain Formula**:
   - o $\Delta = 1 - \sum L_i + \sum L_i L_j - \sum L_i L_j L_k + \ldots$
   - o Δk: Determinant for the k-th forward path.

3. **Non-Touching Loops:**
   - o Combinations of loops with no common nodes (combinatorial search).

Part 2: Routh-Hurwitz Criterion

1. **Polynomial Parsing:**
   - o Convert input string to **sympy** expression.

2. **Routh Array Construction:**

- o Fill rows recursively:

$$r_{i,j} = (r_{i-1,0} * r_{i-2,j+1} - r_{i-2,0} * r_{i-1,j+1}) / (r_{i-1,0})$$
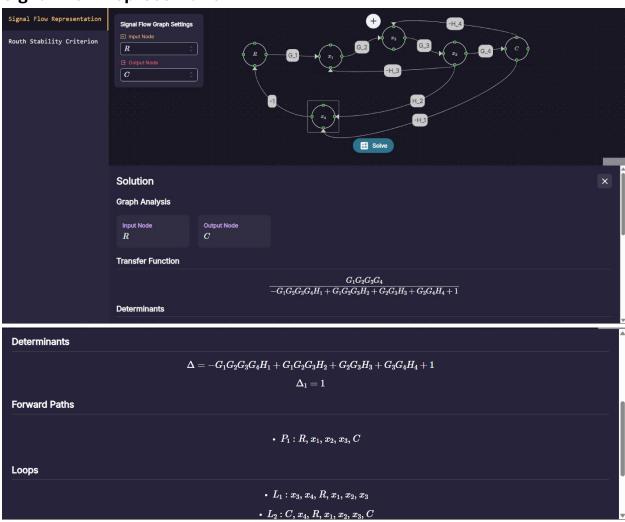
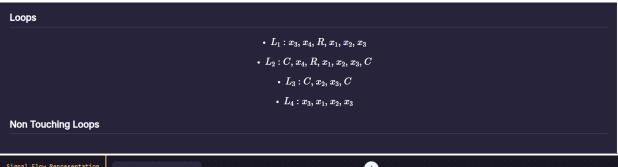- o Handle zero rows with auxiliary polynomials.
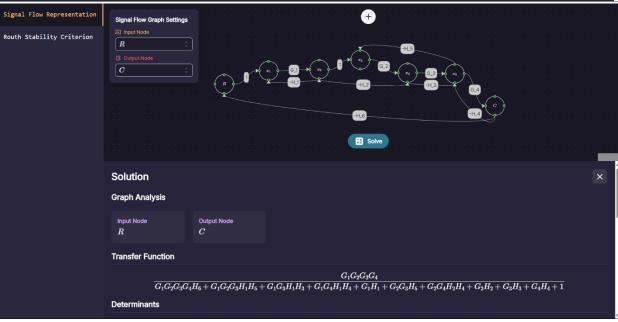
3. **Stability Check:**

- o Count sign changes in the first column (unstable if > 0).
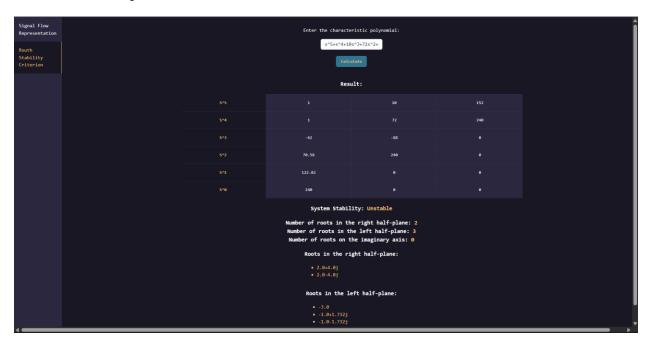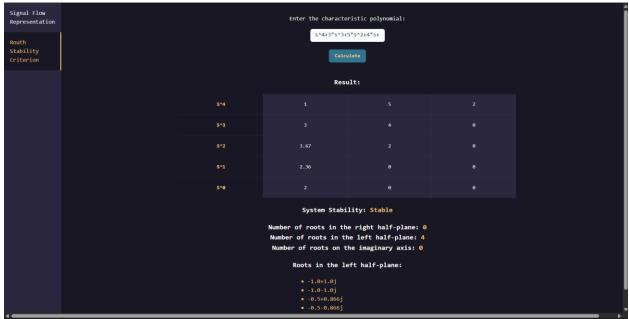
6.Sample Runs:

Signal Flow Representation:

Loops

- $L_1 : x_3, x_4, R, x_1, x_2, x_3$
- $L_2 : C, x_4, R, x_1, x_2, x_3, C$
- $L_3 : C, x_2, x_3, C$
- $L_4 : x_3, x_1, x_2, x_3$

Non Touching Loops

Signal Flow Graph Settings

Input Node
R

Output Node
C

Solve

Solution

Graph Analysis

Input Node
R

Output Node
C

Transfer Function

$$\frac{G_1 G_2 G_3 G_4}{G_1 G_2 G_3 G_4 H_6 + G_1 G_2 G_3 H_1 H_5 + G_1 G_3 H_1 H_3 + G_1 G_4 H_1 H_4 + G_1 H_1 + G_2 G_3 H_5 + G_2 G_4 H_2 H_4 + G_2 H_2 + G_3 H_3 + G_4 H_4 + 1}$$

Determinants

Determinants

$$\Delta = G_1 G_2 G_3 G_4 H_6 + G_1 G_2 G_3 H_1 H_5 + G_1 G_3 H_1 H_3 + G_1 G_4 H_1 H_4 + G_1 H_1 + G_2 G_3 H_5 + G_2 G_4 H_2 H_4 + G_2 H_2 + G_3 H_3 + G_4 H_4 + 1$$

$$\Delta_1 = 1$$

Forward Paths

- $P_1 : R, x_1, x_2, x_3, x_4, x_5, C$

Loops

- $L_1 : C, x_5, C$
- $L_2 : x_3, x_4, x_2, x_3$

Loops

- $L_1 : C, x_5, C$
- $L_2 : x_3, x_4, x_2, x_3$
- $L_3 : x_2, x_1, x_2$
- $L_4 : C, R, x_1, x_2, x_3, x_4, x_5, C$
- $L_5 : x_3, x_4, x_5, x_3$
- $L_6 : x_4, x_5, x_4$

Non Touching Loops

- Combinations of 2 non-touching loops:

Routh Stability Criterion:

Signal Flow
Representation

Routh
Stability
Criterion

Enter the characteristic polynomial:

`s^5+s^4+10s^3+72s^2+`

Calculate

Result:

s^5	1	10	152
s^4	1	72	240
s^3	-62	-88	0
s^2	70.58	240	0
s^1	122.82	0	0
s^0	240	0	0

System Stability: Unstable

Number of roots in the right half-plane: 2
Number of roots in the left half-plane: 3
Number of roots on the imaginary axis: 0

Roots in the right half-plane:

- 2.0+4.0j
- 2.0-4.0j

Roots in the left half-plane:

- -3.0
- -1.0+1.732j
- -1.0-1.732j

Signal Flow
Representation

Routh
Stability
Criterion

Enter the characteristic polynomial:

`s^4+3*s^3+5*s^2+4*s+`

Calculate

Result:

s^4	1	5	2
s^3	3	4	0
s^2	3.67	2	0
s^1	2.36	0	0
s^0	2	0	0

System Stability: Stable

Number of roots in the right half-plane: 0
Number of roots in the left half-plane: 4
Number of roots on the imaginary axis: 0

Roots in the left half-plane:

- -1.0+1.0j
- -1.0-1.0j
- -0.5+0.866j
- -0.5-0.866j

7.User Guide:

1. **Installation**:

    o Run "pip install networkx sympy numpy marshmallow".
    o Note: make sure the version of **sympy** is **1.13.1**.

2. **Running the Program:**

    o **Run frontend:**

    While in the "react-frontend" folder:

    1. Run "npm install" in the terminal.

    2. Run "npm run dev" to run the front end.

    o **Run backend:**

    While in the "flask-backend" folder:

    1. Run pip install –r requirements.txt

    2. Run "python app.py" in the terminal to run the back end.

       Note: make sure port 5000 is free on the machine.

3. **Input Format:**

    o **SFG:** the input is in the form of graph, so the user draws the signal flow graph using the (+) sign on top and connects using the small colored dots.

    o **Polynomial:** String with **^** or ****** for exponential relations (example: s^5 + 10s^3).

Repo: [GitHub - Abdelrahman-Nasr6161/SignalFlowChartSolver](#)