Control and Systems Project

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The Project's Part I : SFG Program

Introduction :

- This program implements a computational tool for analyzing Signal Flow Graphs (SFGs).
- It automates the application of Mason's Gain Formula to determine the transfer function of linear control systems represented by SFGs.

Methodology :

- The program identifies key components of the SFG, including forward paths between specified input and output nodes.
- It detects all individual feedback loops within the graph.
- The algorithm accounts for non-touching loops of various orders.
- Mason's Gain Formula is applied by calculating the path gains and the determinant (Δ) of the graph, along with the cofactors (Δk) for each forward path.

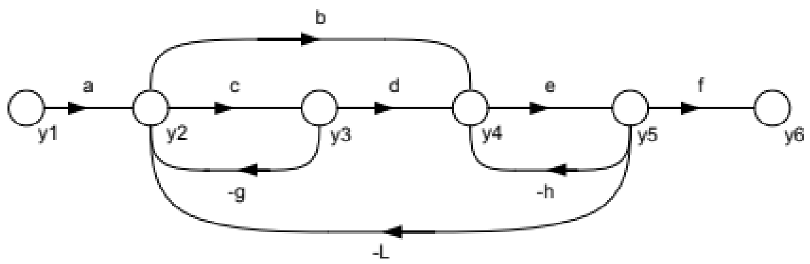
Program Features/Functionality :

- Users can graphically construct SFGs through a friendly interface.
- The program allows for the definition of nodes and the assignment of gains (forward and feedback)to branches.
- It identifies forward paths and loops based on the graph structure.
- Calculates the overall transfer function in symbolic or numeric form.

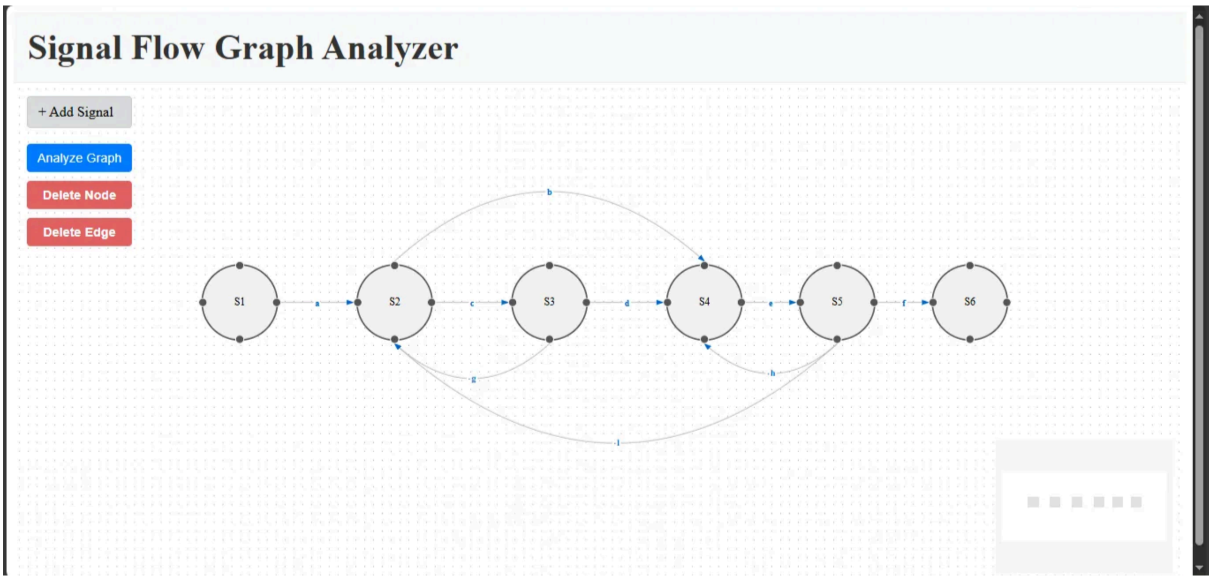
- Intermediate steps, such as the identification of loops, forward paths, and the Delta are presented to the user.
- Results are displayed clearly

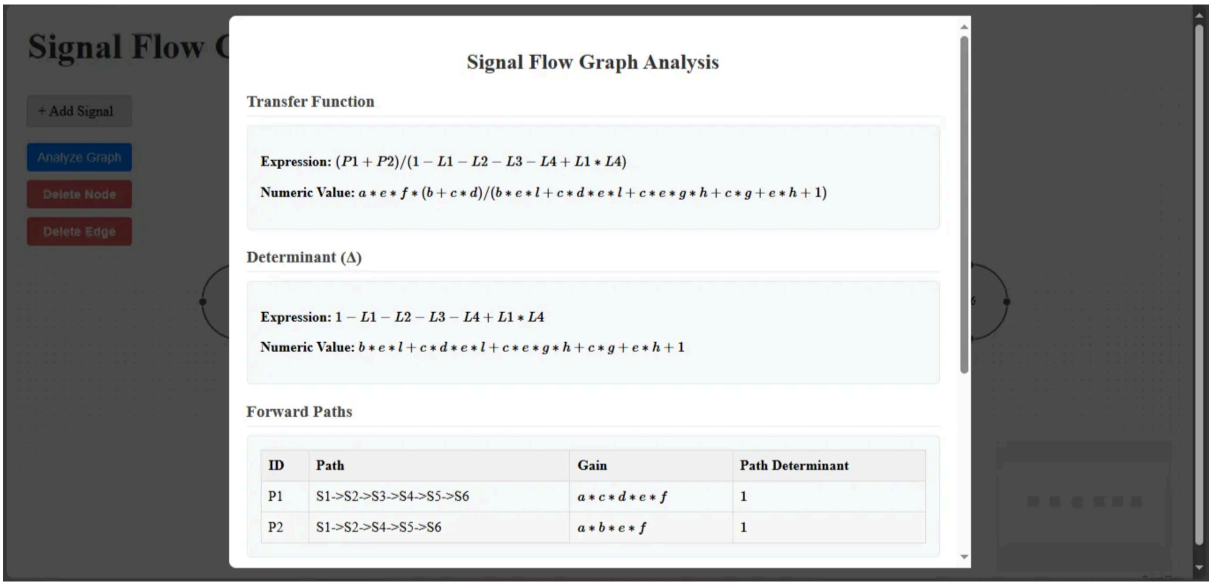
Example 1 :

[2]Find the gains $\frac{y_6}{y_1}$, $\frac{y_3}{y_1}$ and $\frac{y_5}{y_2}$ for the signal flow graph in the following figure.



First : Get Y6/Y1 of the Problem :



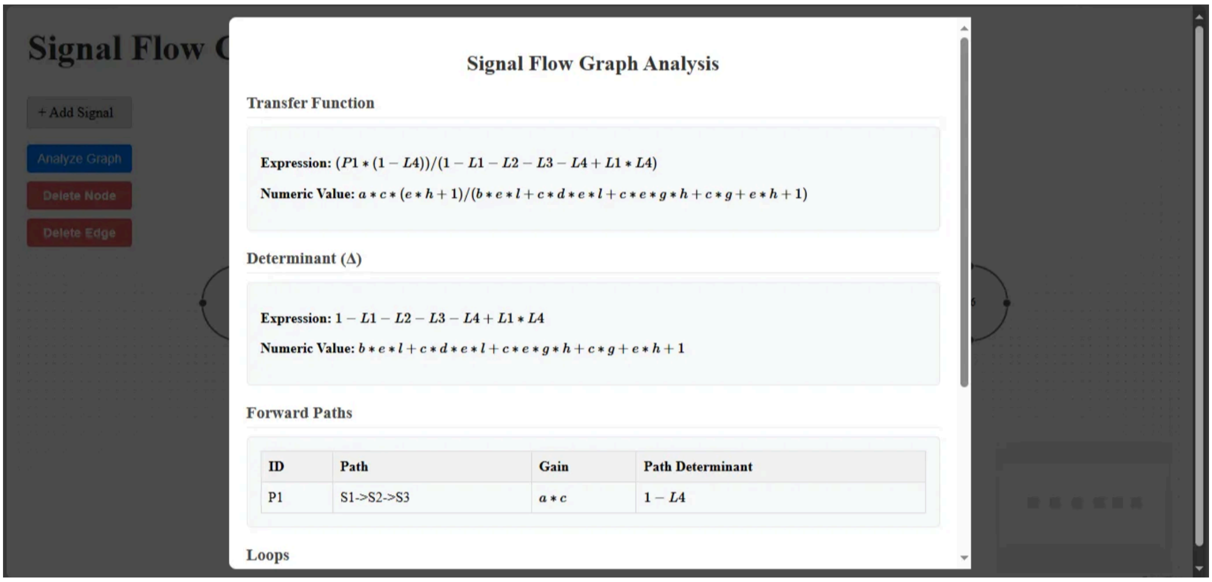


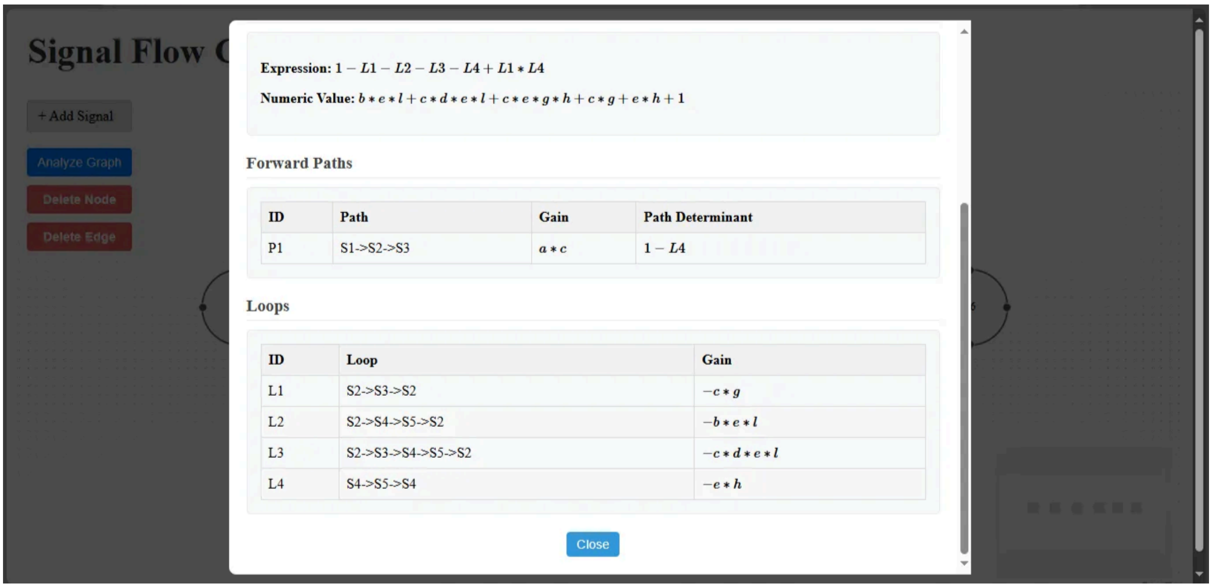
The correct Answer From Sheet :

$$\frac{y_6}{y_1} = \frac{M_1\Delta_1 + M_2\Delta_2}{\Delta} = \frac{acdef + abef}{1 + cg + eh + cdeL + beL + cgeh}$$

The Program's Answer and the Sheet Answer are Same
The Program Successfully Answered Manson's Formula Correct of **Y6/Y1**

Second : Get Y3/Y1 of the same Problem :





$$\frac{y_3}{y_1} = \frac{M_1 \Delta_1}{\Delta} = \frac{ac(1+eh)}{1+cg+eh+cdel+bel+cgeh}$$

In Conclusion : The program and the Sheet answer are the Same

The Program Correctly Calculated Manson's Formula to get the Characteristic Equation

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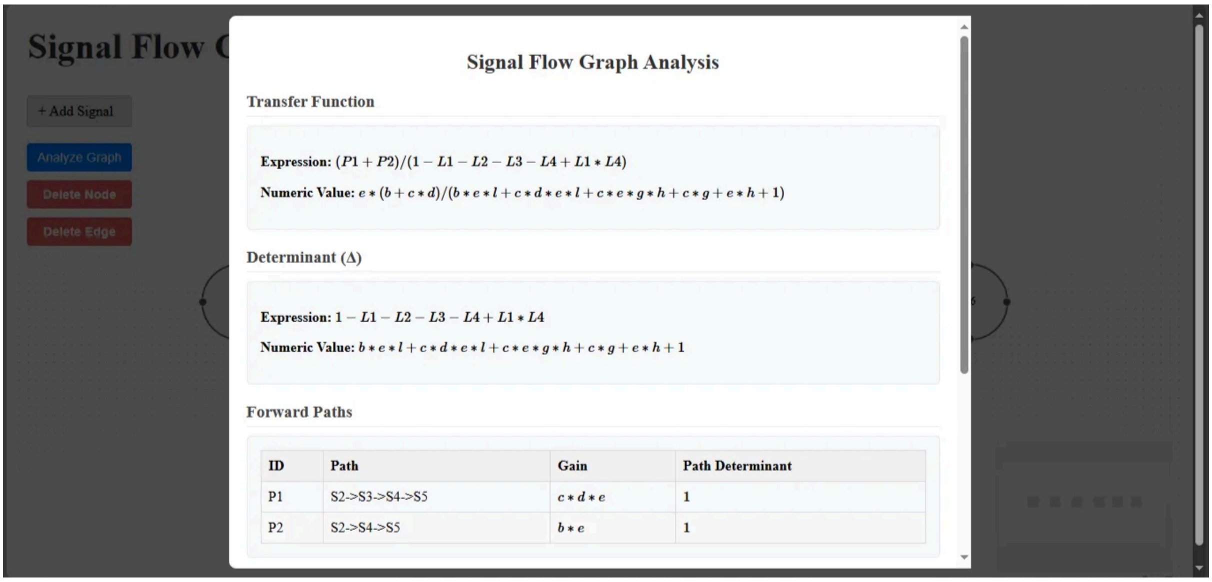
Third : Get Y5/Y2 of the Same Problem :



Signal Flow Graph Analysis

Transfer Function

Expression: $(P1 + P2)/(1 - L1 - L2 - L3 - L4 + L1 * L4)$

Numeric Value: $e * (b + c * d)/(b * e * l + c * d * e * l + c * e * g * h + c * g + e * h + 1)$

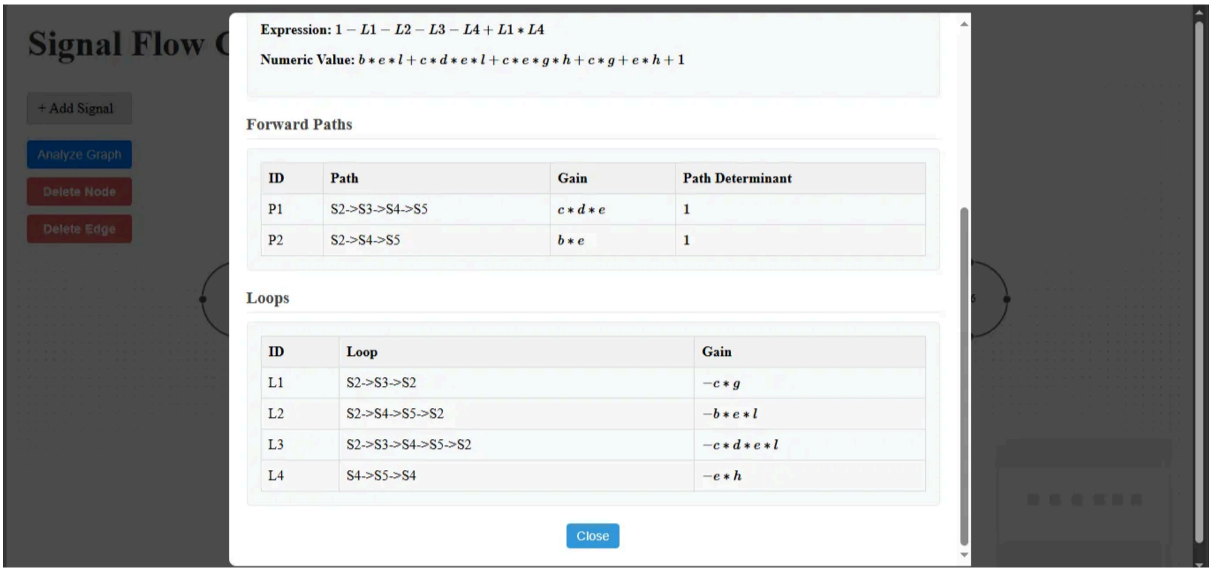
Determinant (Δ)

Expression: $1 - L1 - L2 - L3 - L4 + L1 * L4$

Numeric Value: $b * e * l + c * d * e * l + c * e * g * h + c * g + e * h + 1$

Forward Paths

ID	Path	Gain	Path Determinant
P1	S2->S3->S4->S5	$c * d * e$	1
P2	S2->S4->S5	$b * e$	1



Expression: $1 - L1 - L2 - L3 - L4 + L1 * L4$

Numeric Value: $b * e * l + c * d * e * l + c * e * g * h + c * g + e * h + 1$

Forward Paths

ID	Path	Gain	Path Determinant
P1	S2->S3->S4->S5	$c * d * e$	1
P2	S2->S4->S5	$b * e$	1

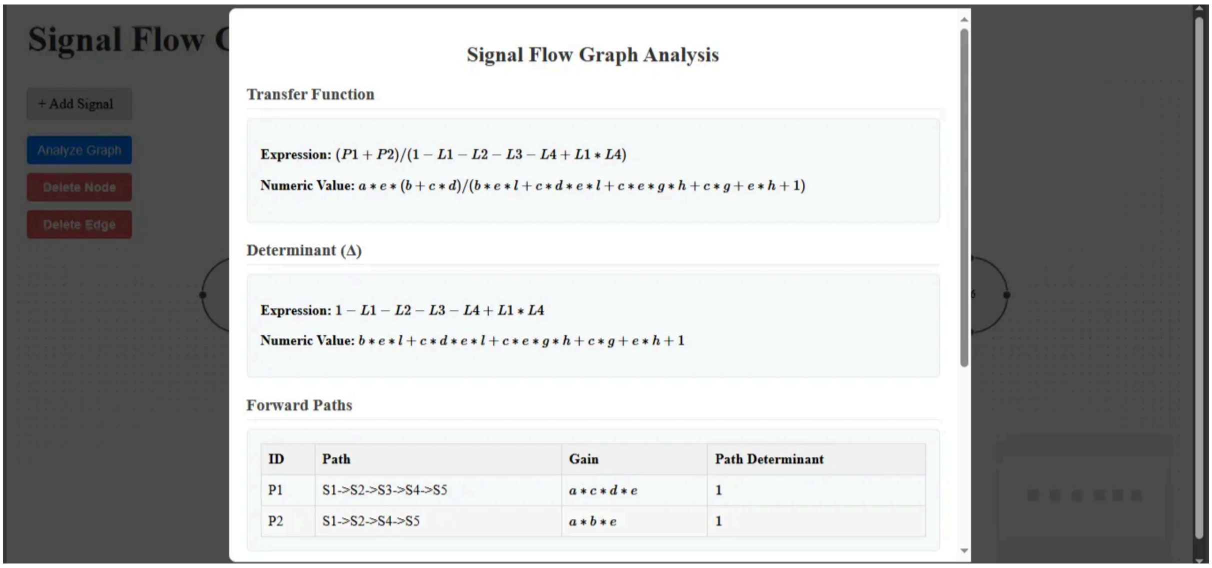
Loops

ID	Loop	Gain
L1	S2->S3->S2	$-c * g$
L2	S2->S4->S5->S2	$-b * e * l$
L3	S2->S3->S4->S5->S2	$-c * d * e * l$
L4	S4->S5->S4	$-e * h$

Close

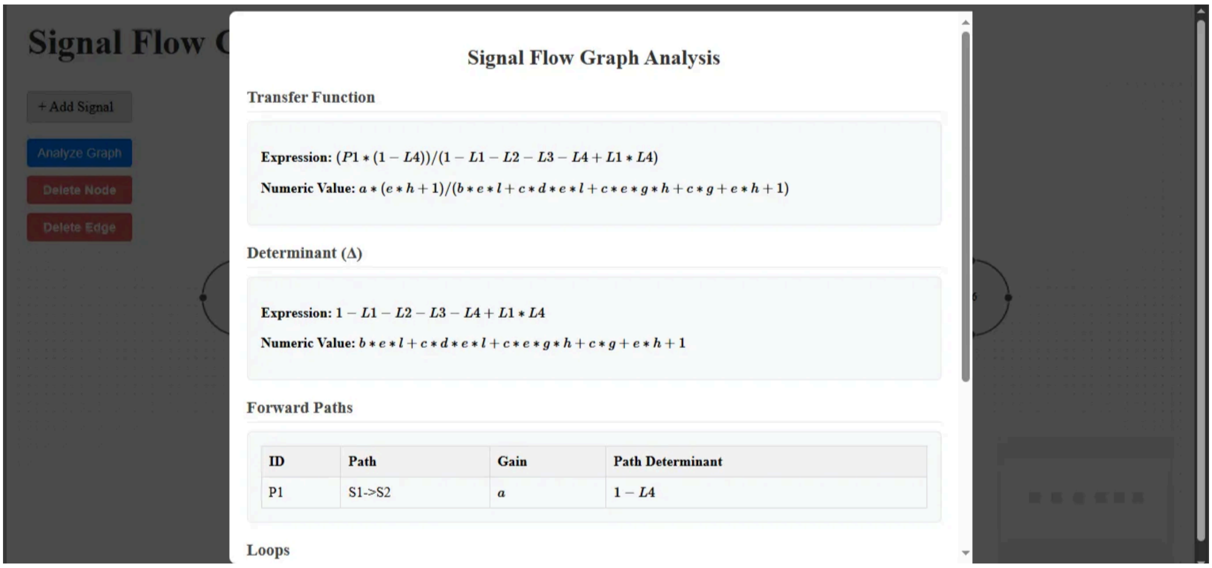
Get Y5/Y1 For extra Checking as the Sheet Solution

Y5/Y1 →


Signal Flow G
+ Add Signal
Analyze Graph
Delete Node
Delete Edge
Signal Flow Graph Analysis
Transfer Function
Expression: $(P1 + P2)/(1 - L1 - L2 - L3 - L4 + L1 * L4)$
Numeric Value: $a * e * (b + c * d)/(b * e * l + c * d * e * l + c * e * g * h + c * g + e * h + 1)$
Determinant (Δ)
Expression: $1 - L1 - L2 - L3 - L4 + L1 * L4$
Numeric Value: $b * e * l + c * d * e * l + c * e * g * h + c * g + e * h + 1$
Forward Paths
ID
Path
Gain
Path Determinant
P1
S1->S2->S3->S4->S5
$a * c * d * e$
1
P2
S1->S2->S4->S5
$a * b * e$
1


Signal Flow G
+ Add Signal
Analyze Graph
Delete Node
Delete Edge
Expression: $1 - L1 - L2 - L3 - L4 + L1 * L4$
Numeric Value: $b * e * l + c * d * e * l + c * e * g * h + c * g + e * h + 1$
Forward Paths
ID
Path
Gain
Path Determinant
P1
S1->S2->S3->S4->S5
$a * c * d * e$
1
P2
S1->S2->S4->S5
$a * b * e$
1
Loops
ID
Loop
Gain
L1
S2->S3->S2
$-c * g$
L2
S2->S4->S5->S2
$-b * e * l$
L3
S2->S3->S4->S5->S2
$-c * d * e * l$
L4
S4->S5->S4
$-e * h$
Close

Y2/Y1→



Sheet's Formula Y5/Y2 = Y5/Y1 * Y1/Y2

BY applying Manson's Formula Directly we were able to get Y5/Y2 By identifying the forward Paths from Y2 to Y5 and the non-touching loops in the entire graph to determine the common delta

Skipping Y1 instruction would then apply to the identification of the forward paths from Y2 to Y5

So, The sheets Answer and the Program are Exactly the same putting into consideration
→ after applying the sheets formula we divide by "Delta" after Multiplication

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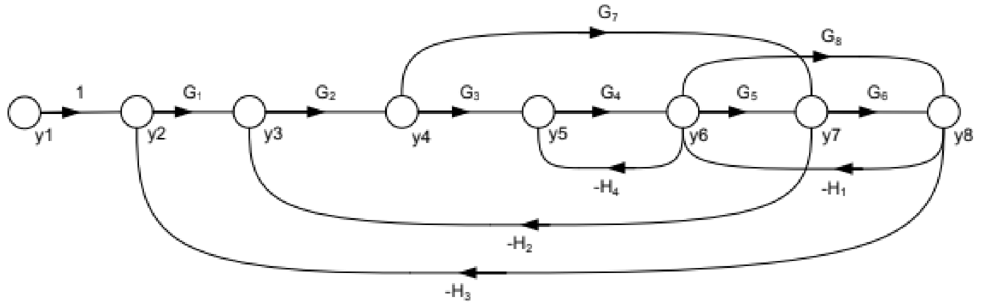
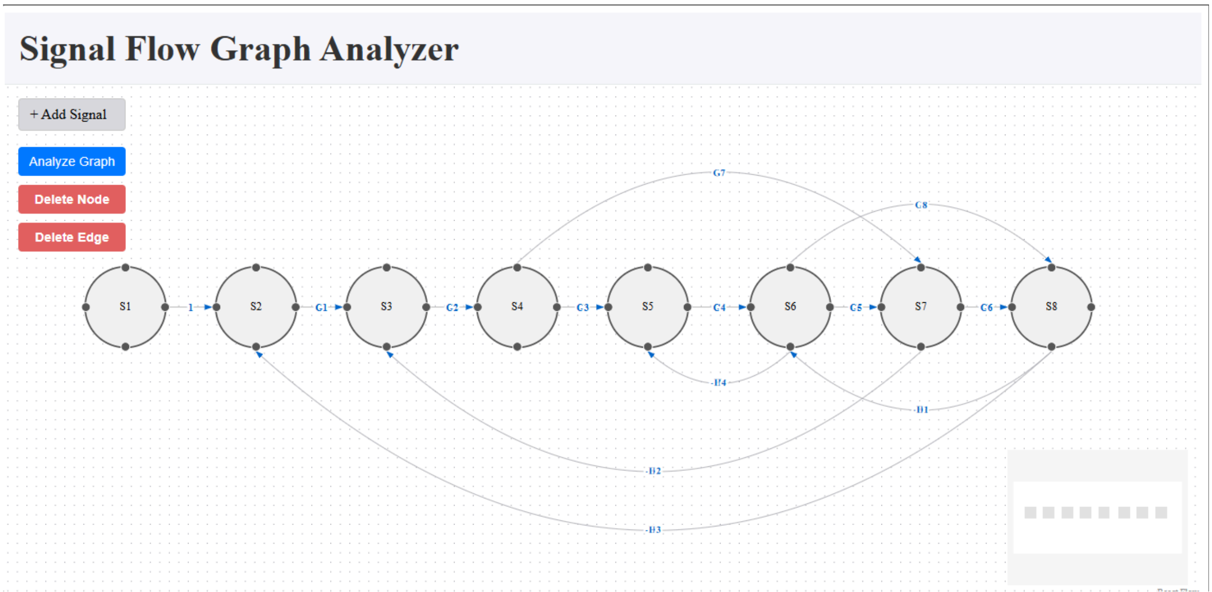
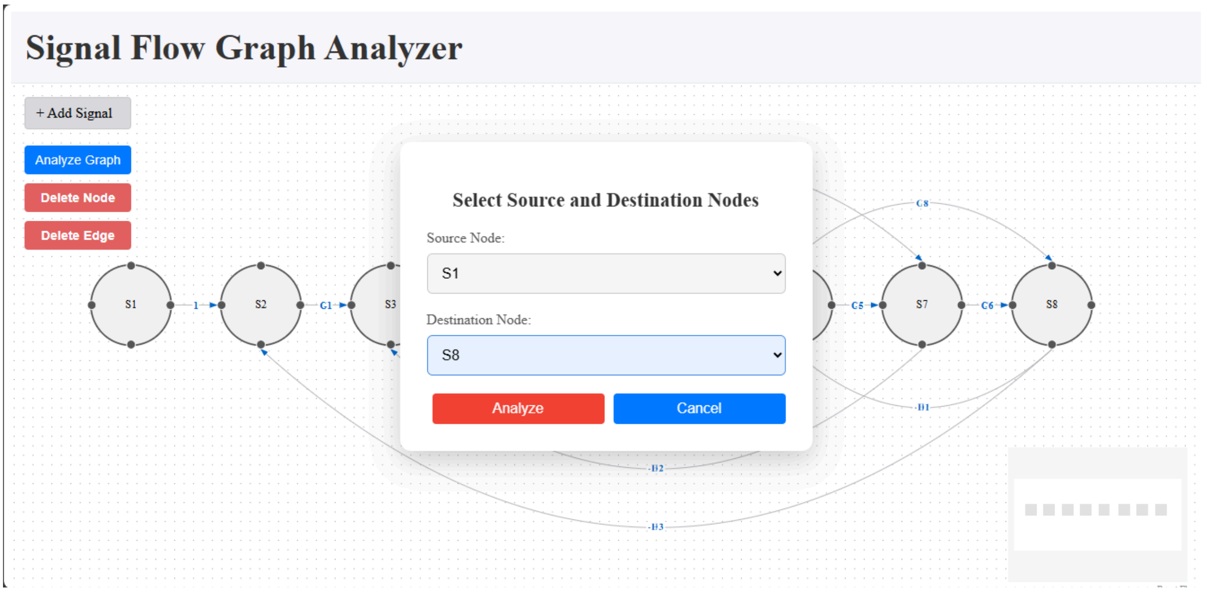
Example 2 From Sheet :

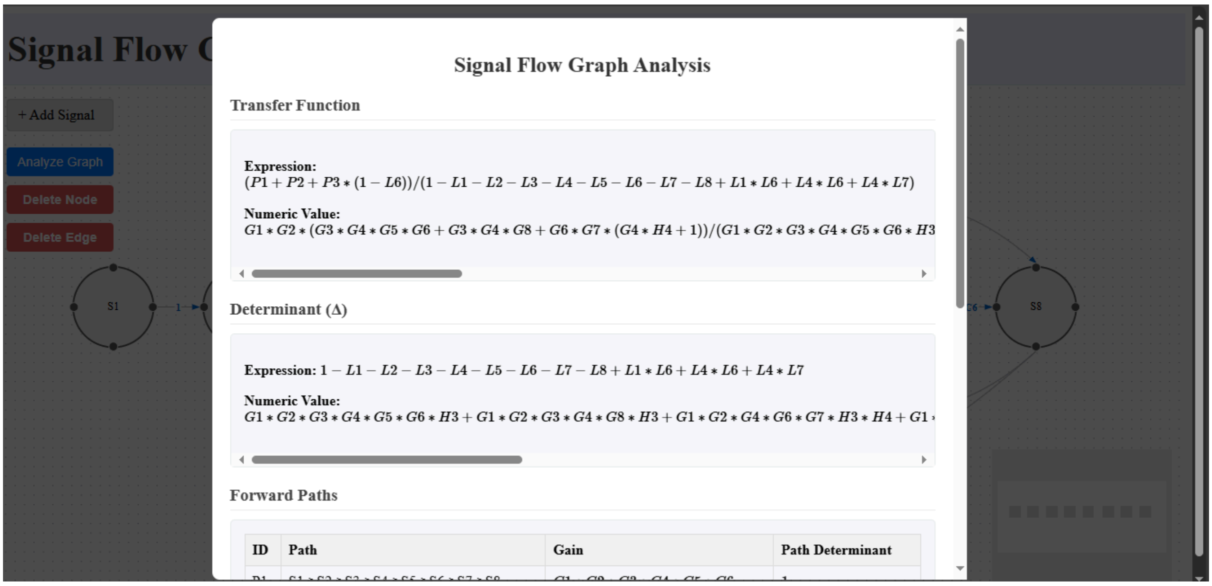
[5]Find the gains $\frac{y_8}{y_1}$ for the signal flow graph in the following graph.

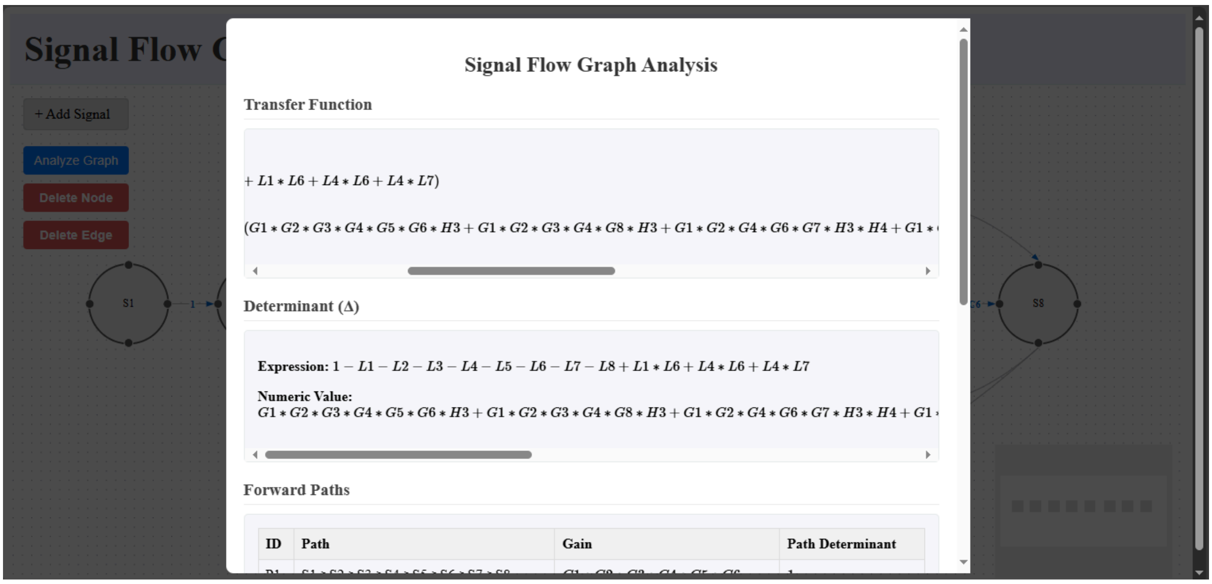


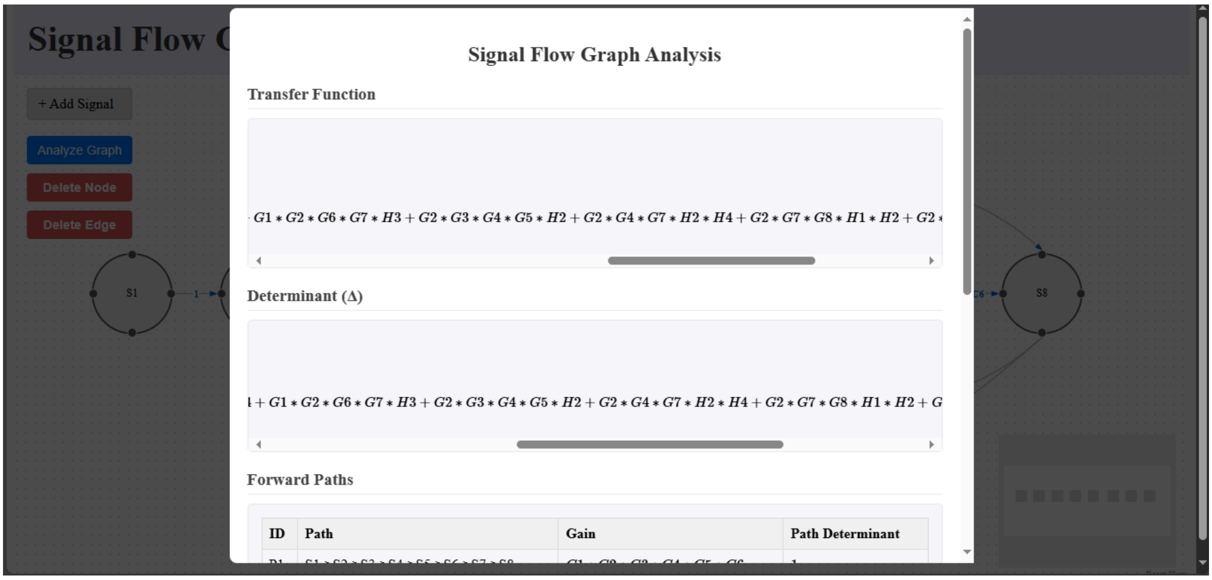
Get Y8/Y1 :

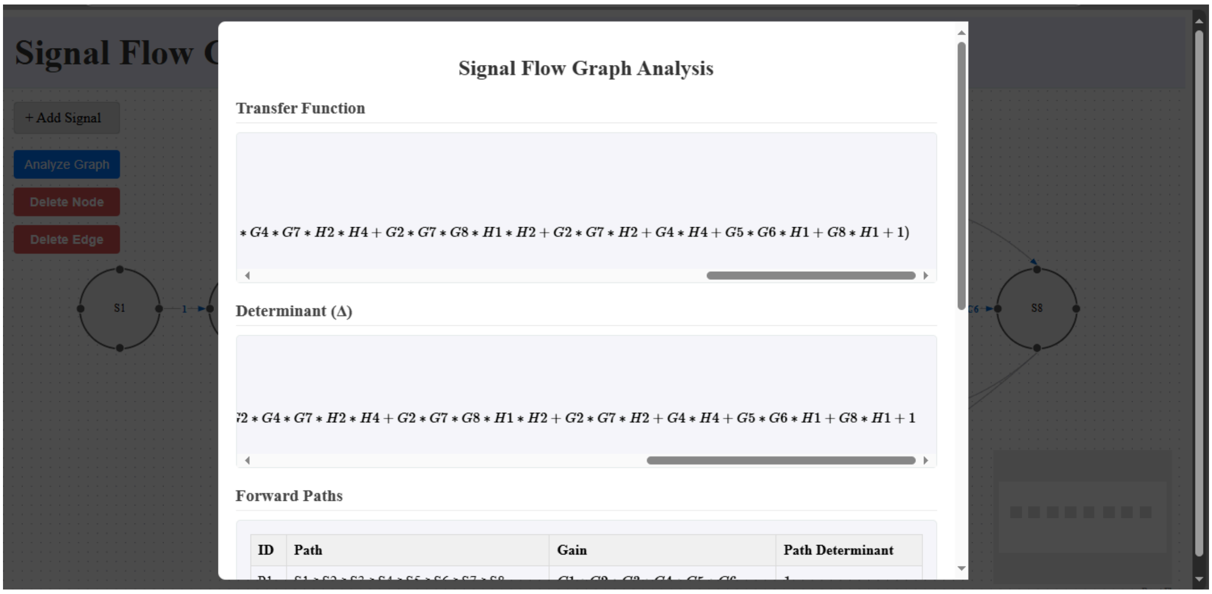


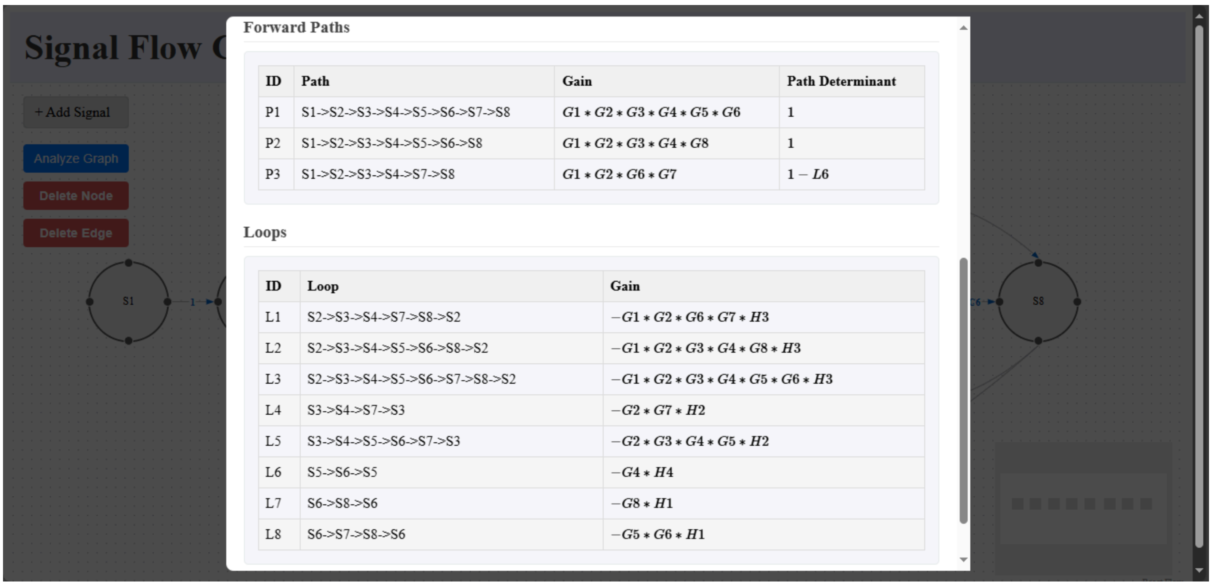

Signal Flow Graph Analyzer
+ Add Signal
Analyze Graph
Delete Node
Delete Edge
Select Source and Destination Nodes
Source Node:
S1
Destination Node:
S8
Analyze
Cancel
S1
S2
S3
S7
S8


Signal Flow Graph Analysis
Transfer Function
Expression:
(P1 + P2 + P3 * (1 − L6))/(1 − L1 − L2 − L3 − L4 − L5 − L6 − L7 − L8 + L1 * L6 + L4 * L6 + L4 * L7)
Numeric Value:
G1 * G2 * (G3 * G4 * G5 * G6 + G3 * G4 * G8 + G6 * G7 * (G4 * H4 + 1))/(G1 * G2 * G3 * G4 * G5 * G6 * H3
Determinant (Δ)
Expression: 1 − L1 − L2 − L3 − L4 − L5 − L6 − L7 − L8 + L1 * L6 + L4 * L6 + L4 * L7
Numeric Value:
G1 * G2 * G3 * G4 * G5 * G6 * H3 + G1 * G2 * G3 * G4 * G8 * H3 + G1 * G2 * G4 * G6 * G7 * H3 * H4 + G1
Forward Paths
ID
Path
Gain
Path Determinant


Signal Flow Graph Analysis
Transfer Function
+ L1 * L6 + L4 * L6 + L4 * L7)
(G1 * G2 * G3 * G4 * G5 * G6 * H3 + G1 * G2 * G3 * G4 * G8 * H3 + G1 * G2 * G4 * G6 * G7 * H3 * H4 + G1
Determinant (Δ)
Expression: 1 − L1 − L2 − L3 − L4 − L5 − L6 − L7 − L8 + L1 * L6 + L4 * L6 + L4 * L7
Numeric Value:
G1 * G2 * G3 * G4 * G5 * G6 * H3 + G1 * G2 * G3 * G4 * G8 * H3 + G1 * G2 * G4 * G6 * G7 * H3 * H4 + G1
Forward Paths
ID
Path
Gain
Path Determinant







Forward Paths

ID	Path	Gain	Path Determinant
P1	S1->S2->S3->S4->S5->S6->S7->S8	$G1*G2*G3*G4*G5*G6$	1
P2	S1->S2->S3->S4->S5->S6->S8	$G1*G2*G3*G4*G8$	1
P3	S1->S2->S3->S4->S7->S8	$G1*G2*G6*G7$	$1-L6$

Loops

ID	Loop	Gain
L1	S2->S3->S4->S7->S8->S2	$-G1*G2*G6*G7*H3$
L2	S2->S3->S4->S5->S6->S8->S2	$-G1*G2*G3*G4*G8*H3$
L3	S2->S3->S4->S5->S6->S7->S8->S2	$-G1*G2*G3*G4*G5*G6*H3$
L4	S3->S4->S7->S3	$-G2*G7*H2$
L5	S3->S4->S5->S6->S7->S3	$-G2*G3*G4*G5*H2$
L6	S5->S6->S5	$-G4*H4$
L7	S6->S8->S6	$-G8*H1$
L8	S6->S7->S8->S6	$-G5*G6*H1$

$$\frac{y_8}{y_1} = \frac{M_1 \Delta_1 + M_2 \Delta_2 + M_3 \Delta_3}{\Delta}$$

$$= \frac{G_1 G_2 G_3 G_4 G_5 G_6 + G_1 G_2 G_7 G_6 (1 + G_4 H_4) + G_1 G_2 G_3 G_4 G_8}{\begin{aligned}(1 &+ G_4 H_4 + G_5 G_6 H_1 + G_8 H_1 + G_2 G_3 G_4 G_5 H_2 + G_2 G_7 H_2 + G_1 G_2 G_7 G_6 H_3 \\ &+ G_1 G_2 G_3 G_4 G_8 H_3 + G_1 G_2 G_3 G_4 G_5 G_6 H_3 \\ &+ G_4 H_4 G_2 G_7 H_2 + G_4 H_4 G_1 G_2 G_7 G_6 H_3 \\ &+ G_8 H_1 G_2 G_7 H_2)\end{aligned}}$$

The Program's Answer is the Same Exactly as the Sheet's Answer

The Project's Part II : Routh Stability Criterion

Introduction:

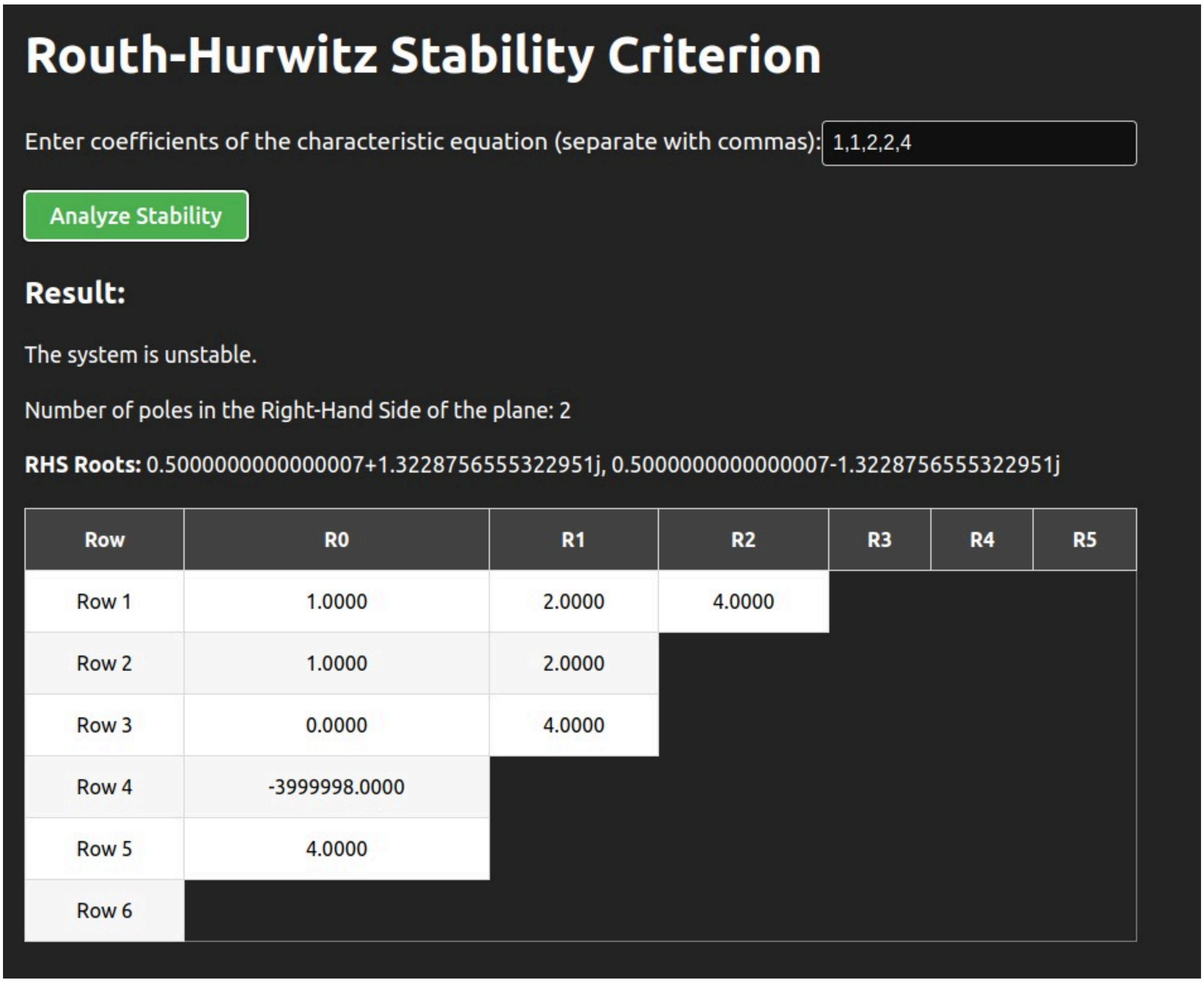
- This program implements the Routh Stability Criterion, a fundamental method in control systems analysis for determining the stability of a linear time-invariant (LTI) system.
- It analyzes the characteristic equation of a system to assess whether all its poles lie in the left-half of the s-plane (for continuous-time systems), indicating stability.

Methodology :

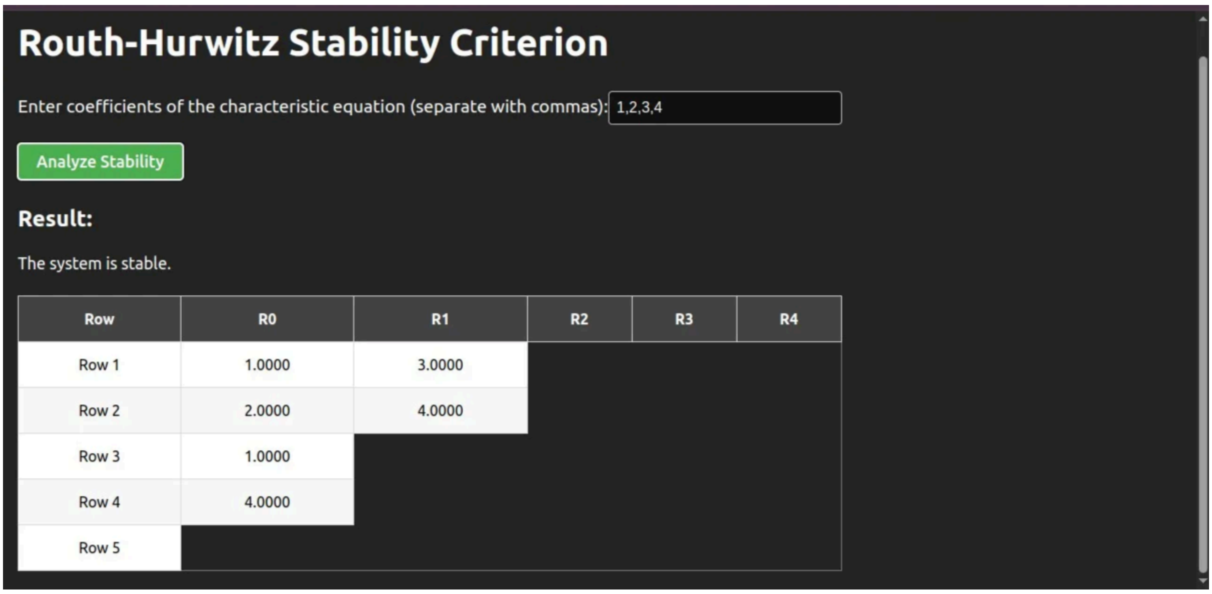
- It takes the coefficients of the characteristic equation as input.
- It constructs the Routh array based on these coefficients, following the specific rules of the Routh Stability Criterion.
- It analyzes the first column of the Routh array to determine the stability of the system.
- It identifies the number of sign changes in the first column, which corresponds to the number of roots of the characteristic equation in the right-half of the s-plane (unstable poles).
- Special cases, such as a zero in the first column or an entire row of zeros, are handled

- For the case of an entire row of zeros, It forms an auxiliary polynomial to further analyze the roots on the imaginary axis.

Examples :



Row	R0	R1	R2	R3	R4	R5
Row 1	1.0000	2.0000	4.0000			
Row 2	1.0000	2.0000				
Row 3	0.0000	4.0000				
Row 4	-3999998.0000					
Row 5	4.0000					
Row 6						



Row	R0	R1	R2	R3	R4
Row 1	1.0000	3.0000			
Row 2	2.0000	4.0000			
Row 3	1.0000				
Row 4	4.0000				
Row 5					

Routh-Hurwitz Stability Criterion

Enter coefficients of the characteristic equation (separate with commas): 1,-3,2,5

Analyze Stability

Result:

The system is unstable.

Number of poles in the Right-Hand Side of the plane: 2

RHS Roots: 1.9520804295674594+1.3112480440771221j, 1.9520804295674594-1.3112480440771221j

Row	R0	R1	R2	R3	R4
Row 1	1.0000	2.0000			
Row 2	-3.0000	5.0000			
Row 3	3.6667				
Row 4	5.0000				
Row 5					