Department of Electrical Engineering
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Assignment

ELL225 – Control Engineering I

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Part 1: Carnivorous Plants as Control Systems

1. Introduction

Carnivorous plants are plants that derive some or most of their nutrients from trapping and consuming animals or protozoans, typically insects and other arthropods, and occasionally small mammals and birds. One such plant is the Venus flytrap. The plant grows in waterlogged, acidic soil that is poor in nutrients, specifically nitrogenous compounds. The Venus flytrap traps insects to obtain nutrients like nitrogen and phosphorous, which are lacking in its soil. It uses a liquid to digest the trapped insects and absorb their nutrients. The plant produces sugar through photosynthesis but relies on insects for essential nutrients not found in its environment.

2. Venus Flytrap as a Control System

i. Specific Objective: The specific objective of the Venus flytrap's control system is to optimise its nutrition intake by efficiently capturing and digesting insects to obtain essential nutrients. It achieves this by dynamically responding to the presence and behaviour of prey through a feedback loop mechanism.

ii. Sensors: Tiny hairs on the trap's surface act as sensors, detecting the touch of insects. These highly sensitive trigger hairs can detect the slightest touch or movement, allowing the plant to distinguish between prey and non-prey stimuli. When an insect touches one of the trigger hairs, it sends an electrical signal to the plant.

iii. Actuators: This actuator is responsible for closing the trap. It consists of specialized cells that contract rapidly in response to the electrical signal from the sensors.

iv. Controllers:
- Closing the trap tighter: Specialized cells secrete adhesive enzymes inside the trap and close it tighter on the basis of movement feedback of the insect inside the trap.
- Digestive Enzymes: Based on the feedback from the Digestion feedback loop, the amount of digestive juices is controlled to save energy. Once there is nothing left to obtain from the prey, it stops the secretion.
- Trap Reopening: These cells also control the trap reopening based on the feedback if nothing more can be extracted from the trapped insect's body.

v. Feedback Loops:
- Trap Closure Feedback Loop: This loop regulates the amount of adhesive secreted and the tightness of the trap closure by analysing the movement of the trapped insect.
- Digestion Feedback Loop: Regulates the secretion of digestive juices by analysing the insect body. Sends information to completely stop secretion to the controllers once nothing is left and also Reopen the trap for catching more insects.

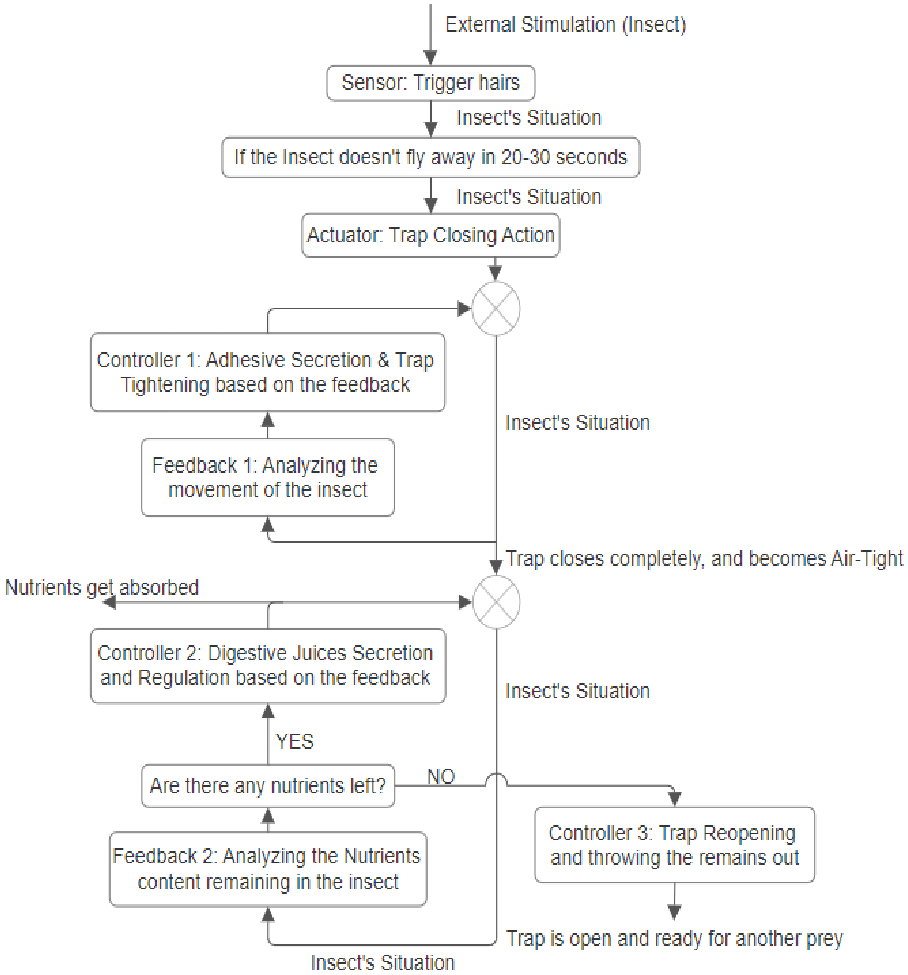
vi. Interconnections:
- Trigger hairs send signals to the actuators which process the signal and initiate trap closing action.
- A Feedback Loop analyses the movement of insect inside the trap and triggers the secretion of adhesive and closing the trap tighter.
- Controllers secrete digestive enzymes regulated by another feedback loop, the secretion stops and trap reopening is triggered if no more nutrients are left.

3. Challenges

i. Precision, Efficiency, Feedback Loops: The Venus Flytrap's control system relies on precise detection and rapid response to the presence and movements of prey. Ensuring that the trigger hairs are sensitive enough to detect even small insects while avoiding false alarms from non-prey stimuli is a significant challenge. Achieving a rapid closure within milliseconds requires precise coordination of different components, which can be challenging. Coordinating multiple feedback loops like the Trap Closure, Digestion, Trap Reopening Feedback Loops is really important and can be challenging.

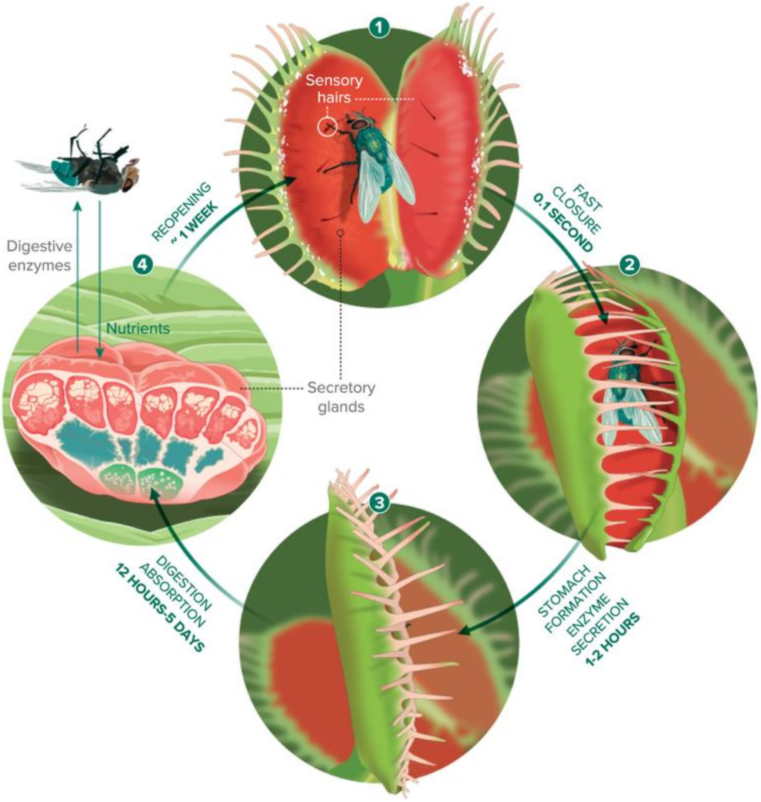
ii. Environmental Adaption: The Venus Flytrap's Control System must be adaptable to variations is environmental conditions, such as changes in temperature, humidity, and other factors like ageing of the plant etc.

4. Block Diagram



5. Conclusion

In conclusion, the Venus flytrap's control system is a remarkable example of nature's ingenuity, designed to optimize the plant's nutrition intake and enhance its reproductive success. By employing a sophisticated feedback loop mechanism, the Venus flytrap dynamically responds to the presence and behaviour of prey, efficiently capturing and digesting insects while conserving energy. Through the coordination of sensors, actuators, controllers, and feedback loops, the Venus flytrap ensures precise detection, rapid response, and effective utilization of captured prey. However, implementing such a complex control system poses challenges, including ensuring precision and sensitivity, achieving speed and efficiency, coordinating multiple feedback loops, and adapting to environmental variations. Overcoming these challenges is essential to mimic the Venus flytrap's functionality in artificial systems.



Part 2:

1. <u>Case 1: v = 0 m/s</u>

a) Transfer Function:

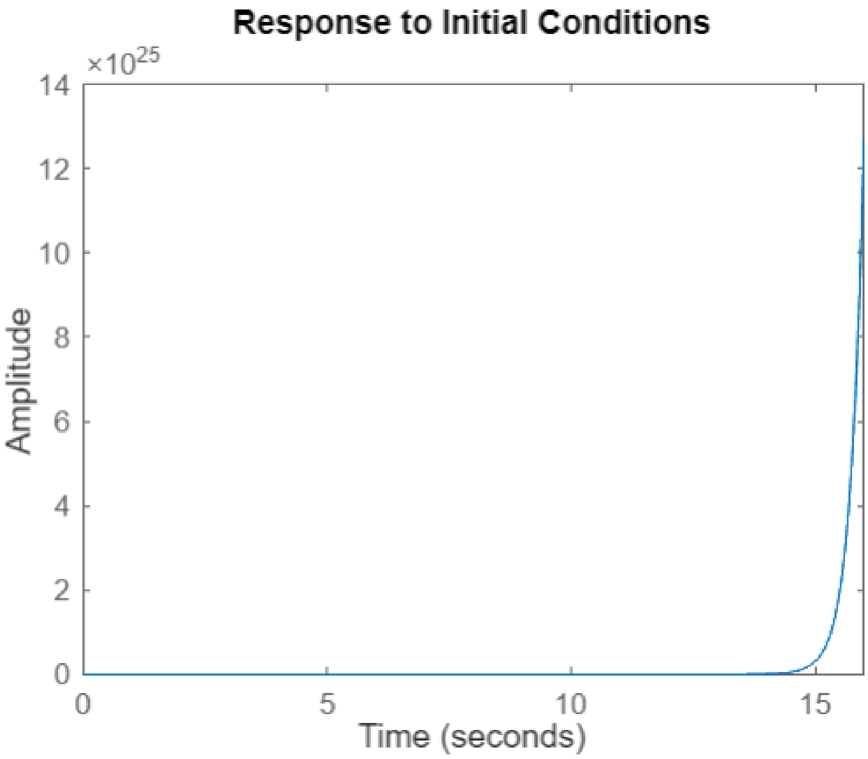
$$G(s) = \frac{-0.339s^2 + 5.342}{s^4 - 24.48s^2 + 146.7}$$

b) Zeroes, Poles, Eigenvalues:

i. Zeroes: 3.9698, -3.9698
ii. Poles: -3.7432, -3.2355, 3.7432, 3.2355
iii. Eigenvalues: -3.7432, -3.2355, 3.7432, 3.2355

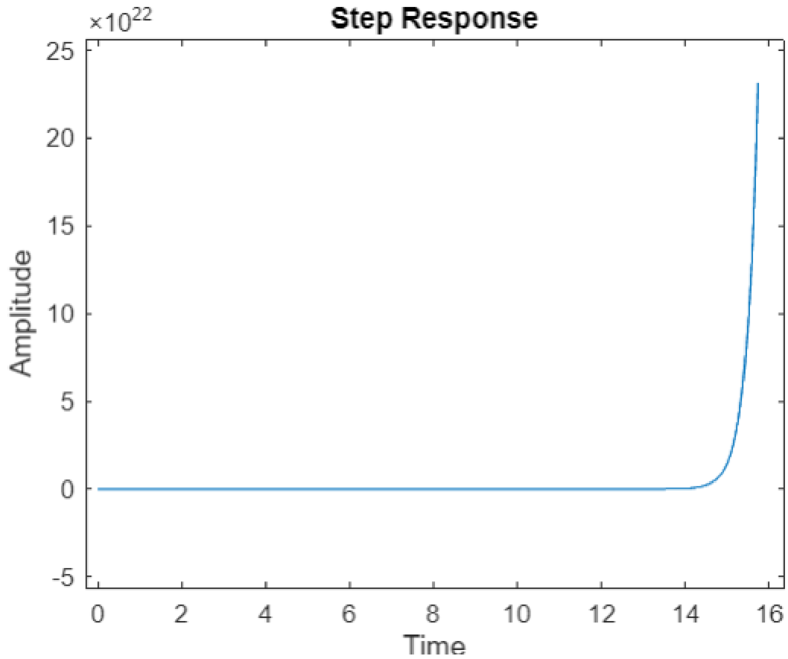
c) Time response for open loop system:

I. Zero input response with non-zero initial condition:
Taking arbitrary initial condition :- u0 = [1;1;6;4]



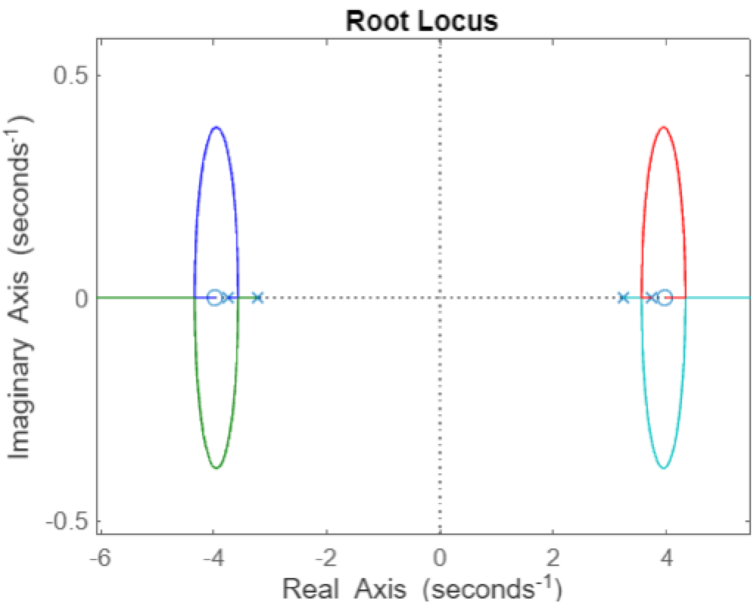
Zero input response for initial non zero condition u0 = [1;1;6;4]

II. Unit Step response with zero initial condition:



d) Stability Analysis:
We know that for Zero Input Stability of an Open Loop System, all the eigenvalues of matrix A should have negative real part (lie in the left half plane). Here, 2 of the eigenvalues are positive, thus the open loop system is unstable.

e) Root Locus Plot:



This is the root locus plot for v = 0 case and we find that the some part of the root locus plot always lies in the Right half plane no matter of the values of k. The root locus plot also doesn't cut the imaginary axis for any value of a, thus the closed loop unity feedback system is always unstable and no value of k ensures marginal stability or stability.

f) No values of k ensures stability or marginal stability.

2. <u>Case 2: v = 3.5 m/sec</u>

a) Transfer Function:

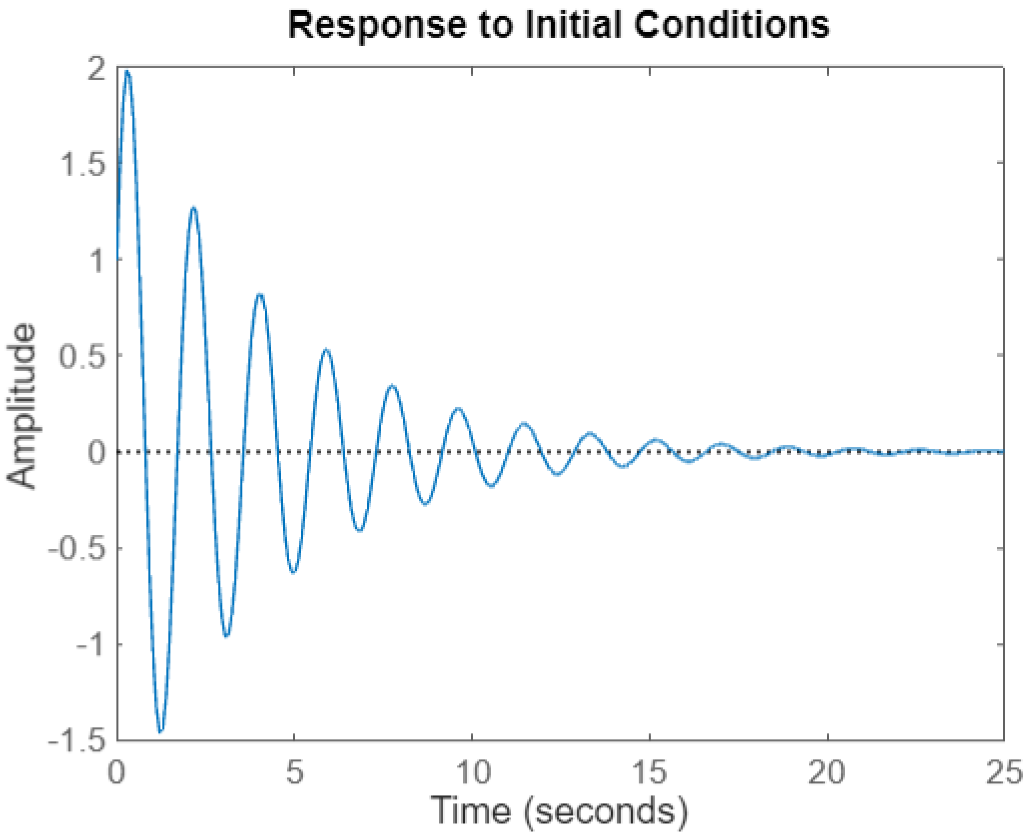
$$G(s) = \frac{-0.339s^2 - 17.24s - 119.8}{s^4 + 8.932s^3 + 18.58s^2 + 98.76s + 36.77}$$

b) Zeroes, Poles, Eigenvalues:

i. Zeroes: -42.5497, -8.3066
ii. Poles: -8.0753, -0.3965, -0.2301 + 3.3809i, -0.2301 + 3.3809i
iii. Eigenvalues: -8.0753, -0.3965, -0.2301 + 3.3809i, -0.2301 - 3.3809i

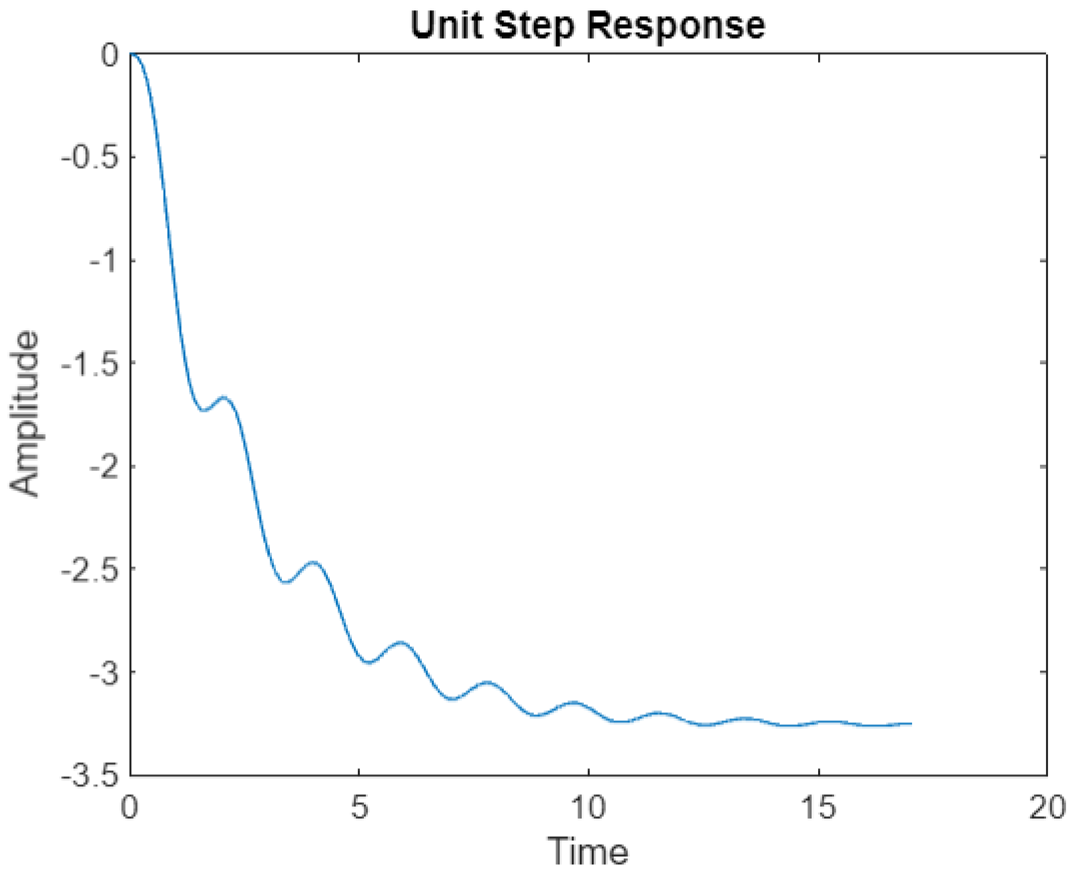
c) Time Response for open loop system:

I. Zero Input Response with non zero initial condition
Taking arbitrary initial condition :- u0 = [1;1;6;4]



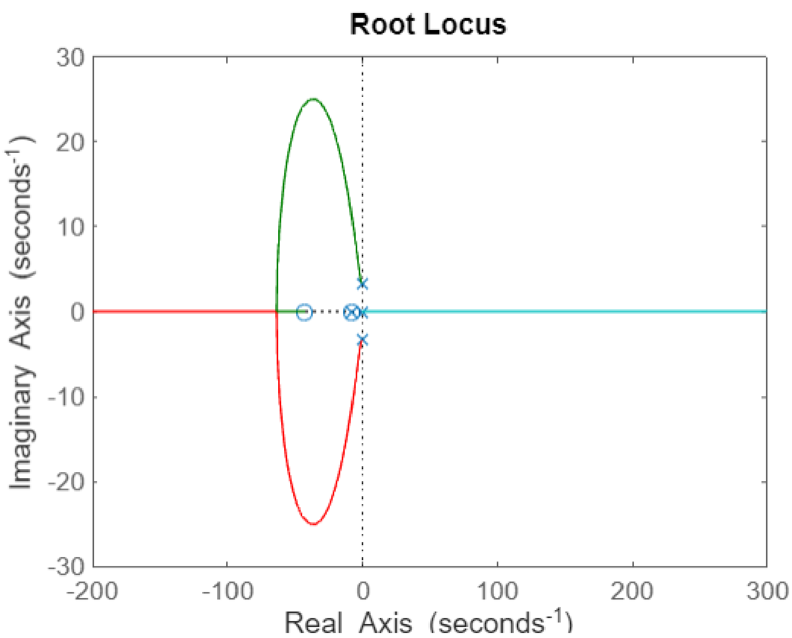
Zero input response for initial non zero condition u0 = [1;1;6;4]

II. Unit Step Response with Zero Initial Conditions:



d) Stability Analysis:
We know that for Zero Input Stability of an Open Loop System, all the eigenvalues of matrix A should have negative real part (lie in the left half plane). Here all the of the eigenvalues lie in the left half plane, so the open loop system is stable.

e) Root Locus Plot:



We find that the root locus plot cuts the imaginary axis at the origin only. Now, the

Closed Loop Transfer Function = $\frac{KG(s)}{1 + KG(s)}$

The poles of the closed loop system are the roots of the char equation : 1 + KG(s) = 0.

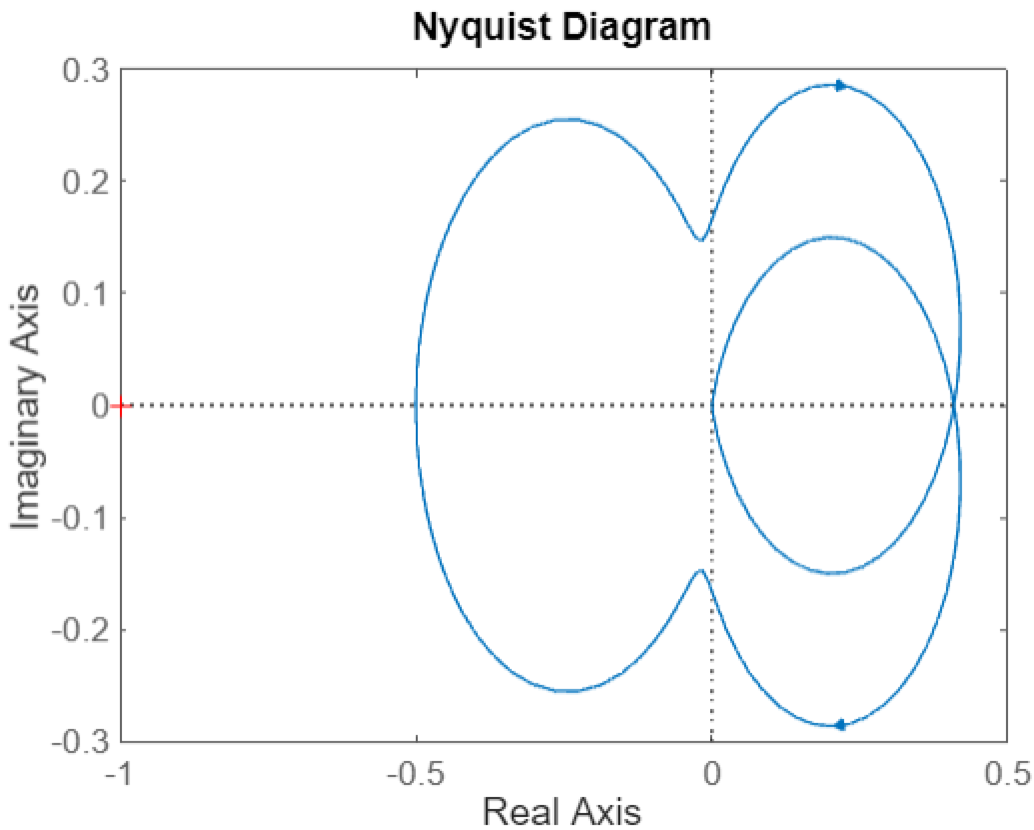
Now, as we know the root locus plot cuts the imaginary axis at the origin only, we find the corresponding K for marginal stability by using s = 0 (origin) in the characteristic equation.

We find K = 0.3069 at which the root locus plot cuts the imaginary axis (at origin).

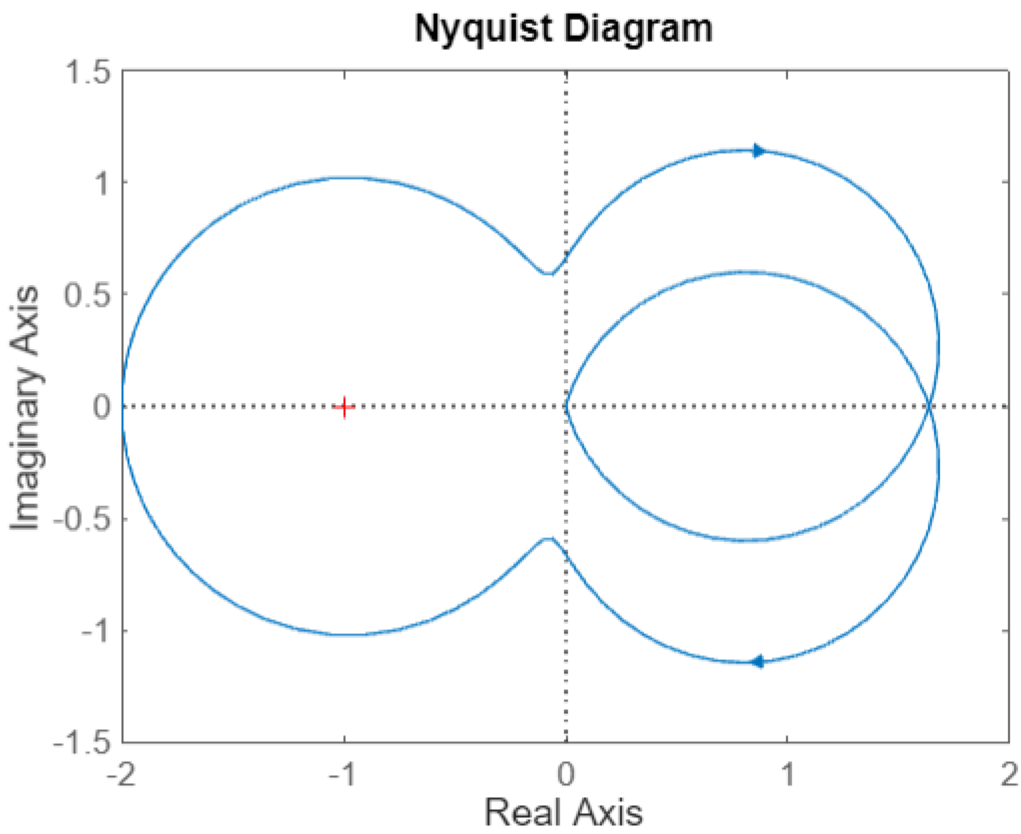
Clearly K* = 0.3069, the K for marginal stability. Since the root locus plot lies in the left half plane for all values of K such that $0 \leq K < 0.3069$. Thus,

Range of K for Stability: $0 \leq K < 0.3069$

and the K for marginal stability : K* = 0.3069.



Nyquist Plot for K = K*/2 = 0.153



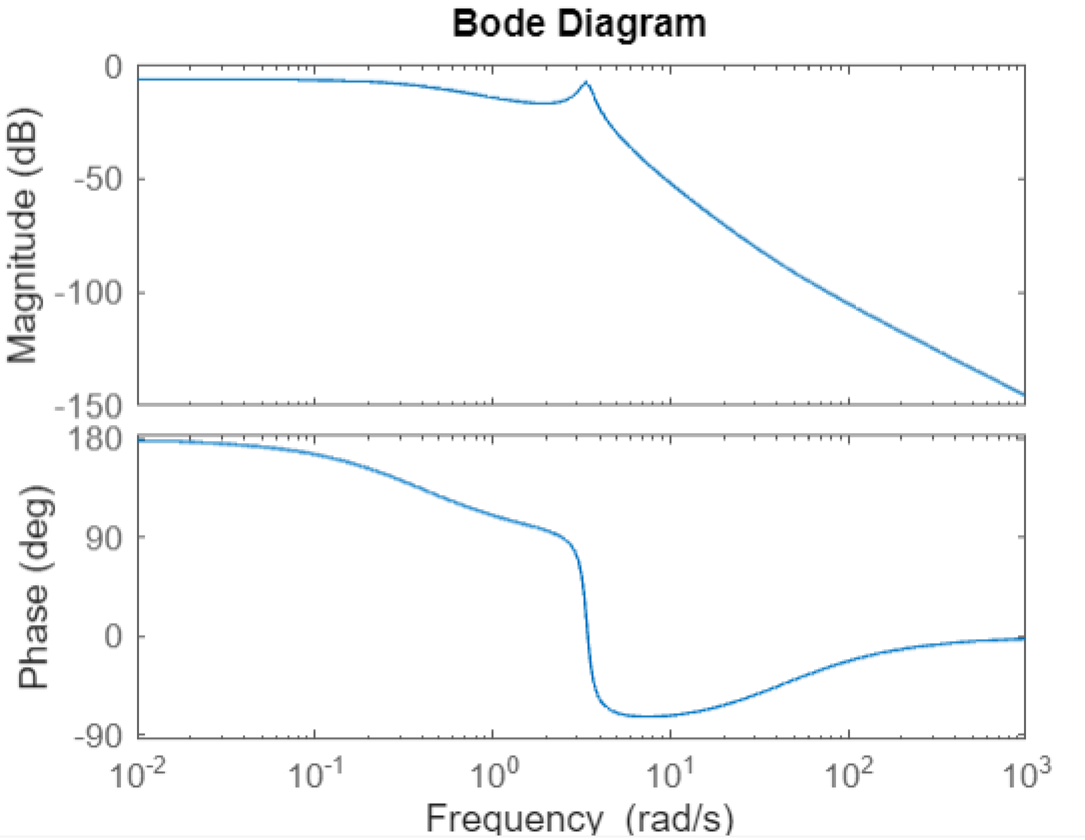
Nyquist Plot for K = 2*K* = 0.6138

As we know that the closed loop system is stable for $0 \leq K < 0.3069$, it would definitely be stable for K = K*/2 and unstable for K = 2K*. The results from the Nyquist plots are also consistent with these.

The Nyquist Theorem for the stability of closed loop system from open loop Nyquist plot says that N = Z - P; where, N = Number of clockwise encirclements of -1 + 0i by the Nyquist plot of open loop system, Z = number of Zeroes in the Right Half Plane of the Characteristic Equation 1 + KG(s)H(s) = 0 (i.e. the poles of the closed loop transfer function in the right half plane, H(s) is the Feedback which is 1 here. P = number of poles of open loop transfer function in the right half plane. For stability, Z should be 0. Thus, N should be equal to -P. Here, there are no zeroes in the right half plane of the open loop system, so P = 0 and N, the number of encirclements should also be 0.

In the first Nyquist Plot (for K = K*/2), the plot does not encircle -1 + 0i, thus it is a stable closed loop stable.
In the second Nyquist Plot (for K = 2K*), the plot encircles -1 + 0i 1 time clockwise, thus it is an unstable closed loop system.

f) Bode Plot for K = K*/2 = 0.153




```
>> disp(PM);
   Inf

>> disp(20*log10(GM));
    6.0197
```

Gain Margin = 6.0197 dB

Phase Margin = infinite degrees

3. Appendix(Code):-

1. For part 1, v = 0 m/sec:

```
>> A = [0,0,1,0; 0,0,0,1; 13.67,0.225,0,0; 4.857,10.81,0,0];
B = [0;0;-0.339;7.457];
C = [1,0,0,0];
D = [0];
sys1 = ss(A,B,C,D);
tf_sys1 = tf(sys1);
eigen1 = eig(A);
zero(tf_sys1);

u0 = [1;6;6;4];
initial(sys1, u0);

>> [y, t] = step(tf_sys1);
>> plot(t, y);
>> xlabel('Time');
>> ylabel('Amplitude');
>> title('Step Response');
>> rlocus(tf_sys1);
```

2. For part 2, v = 3.5 m/sec:

```
>> A = [0,0,1,0; 0,0,0,1; 13.67,-15.93275,-0.574,-1.932; 4.857,-2.97125,12.6735,-8.358];
B = [0;0;-0.339;7.457];
C = [1,0,0,0];
D = [0];
sys1 = ss(A,B,C,D);
tf_sys1 = tf(sys1);
eigen1 = eig(A);
zero(tf_sys1);

u0 = [1;6;6;4];
initial(sys1, u0);

>> [y, t] = step(tf_sys1);
>> plot(t, y);
>> xlabel('Time');
>> ylabel('Amplitude');
>> title('Step Response');
>> rlocus(tf_sys1);
>> tf_sys2 = (0.3069/2)*tf_sys1;
>> nyquist(tf_sys2);
>> tf_sys3 = (2*0.03069)*tf_sys1;
>> nyquist(tf_sys3);
>> bode(tf_sys2);
>> [GM,PM, ~,~] = margin(tf_sys2);
>> disp(PM);
>> disp(20*log10(GM));
```