NELSON MANDELA UNIVERSITY

Faculty of Engineering, the Built Environment & IT
Technology for Tomorrow

Control System 3B – ECSV302

Assignment 01:
MAKE USE OF THE FREQUENCY BASED METHODOLOGY TO DESIGN AND ANALYZE AN ANTENNA CONTROL SYSTEM USING CASCADE (Lead/Lag) COMPENSATION

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Complied by: TI van Niekerk

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Total time taken: +- 40 hrs

Question 1.1: Real-time communication aspects of control between the UAV and Ground station.

a) Directional antennas provide crucial advantages for UAV communication performance. Signal quality is improved by generating highly focused beams with increased power in the main lobe. A concentrated signal minimizes power leakage. The small footprint of directional antennas reduces interference, enhancing the overall UAV network performance. [1]

b) One of the aspects that need to be considered when choosing a flight controller for a UAV is whether or not it needs to incorporate GPS tracking. Popular GPS flight controllers include the Pixhawk PX4 with a high performance processor, the F7 AIO with a built in Bluetooth module, the OMNINXT F7 Airbot, built on the new NXT flatform. [2] Simpler options like Arduino and Raspberry Pi can be used as flight controllers if the necessary packages and components were to be installed.

c) Communication protocols are used to exchange messages, containing UAV status information and control commands, to and from the ground control station (GCS) and the UAV. External communication protocols vary between radio frequency, satellite, Wi-Fi, Bluetooth and cellular. [3] Internal communication protocols include UART, SPI, I^2C and PWM. Messaging protocols for communicating with drones include UAVCan, MAVLink and UranusLink.

d) A UAV without a GPS feedback is commonly referred to as a GPS-denied UAV and relies on numerous sensors to operate. Obstacle avoidance and onboard visual sensors can provide reference points, allowing the UAV to hover in one place and stabilize itself while in flight.

Onboard optical sensors, providing reference points and data regarding the UAV's altitude and location is one form of feedback that can be used. LiDAR sensors can provide real-time location by sending laser light pulses in its path, effectively creating 3D maps of the UAV's environment. [4]

Emesent's Hovermap is a device that captures accurate data using Lidar mapping and has a sensing range of up to 300 meters. Its pilot assist mode provides stability control, line of sight capability and collision avoidance. [5]

e)

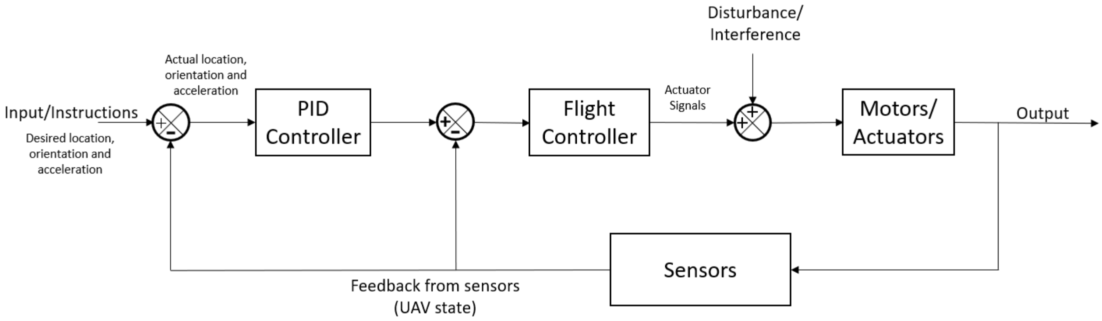


Figure 1: Block Diagram of a UAV Autonomous Control Flight System

Question 1.2: Block diagram representing the electrical and mechanical system components.

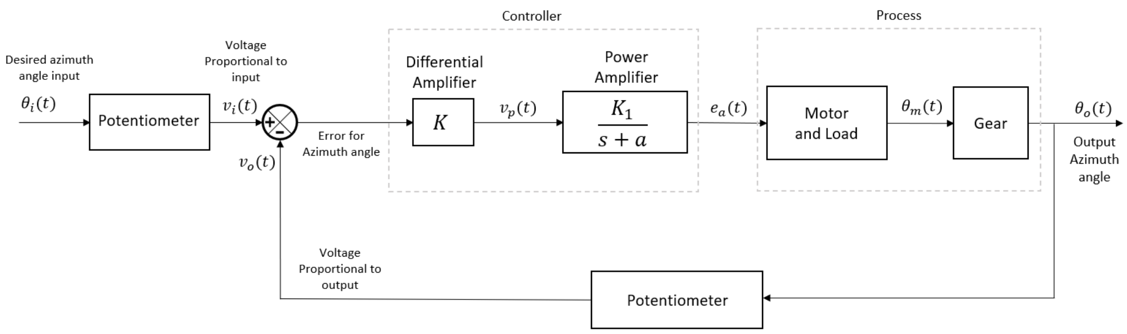


Figure 2: Block diagram representing the electrical and mechanical system components.

Question 1.3: Forward path transfer function using the given parameters.

Input Potentiometer angle and voltage: $\frac{V_i(s)}{\theta_i(s)} = \frac{V_i}{2\pi n} = \frac{10}{2\pi \cdot 10} = \frac{1}{2\pi}$

Power Amplifier: $\frac{E_a(s)}{V_p(s)} = \frac{K_1}{s+a} = \frac{100}{s+100}$

J_m & D_m : $$J_m = J_a + J_L\left(\frac{N_1}{N_2}\right)^2 = 0.02 + 1\cdot\left(\frac{25}{250}\right)^2 = 0.03$$

$$D_m = D_a + D_L\left(\frac{N_1}{N_2}\right)^2 = 0.01 + 1\cdot\left(\frac{25}{250}\right)^2 = 0.02$$

K_m & a_m : $$K_m = \frac{K_t}{R_a J m} = \frac{0.5}{8\cdot 0.03} = 2.083$$

$$a_m = \frac{1}{Jm}\left(D_m + \frac{K_t K_b}{R_a}\right) = \frac{1}{0.03}\left(0.02 + \frac{0.5\cdot 0.5}{8}\right) = 1.708$$

Motor and Load: $$\frac{\theta_o(s)}{E_a(s)} = \frac{K_m}{s^2 + a_m s}\cdot K_{Gear} = \frac{2.083}{s^2+1.708s}\cdot K_{Gear}$$

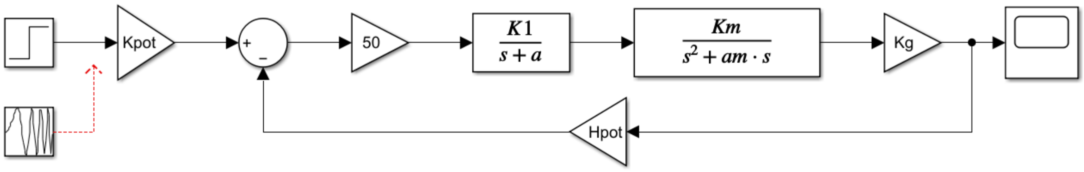


Figure 3: Simulink model to obtain step and frequency response.

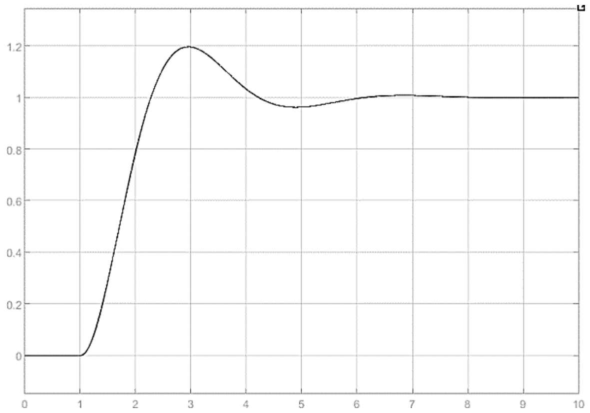


Figure 4: Step response graph

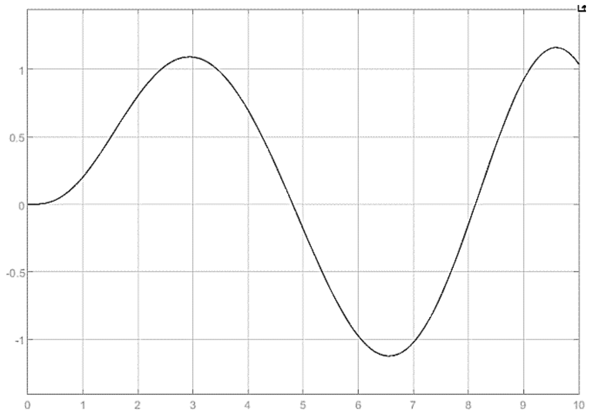


Figure 5: Frequency sweep graph

Question 1.4: determine the range of gain, K, required for stability.

Uncompensated System: $$G_{forward\ path} = (K)\left(\frac{6.6}{s+100}\right)\left(\frac{1}{s+1.7}\right)\left(\frac{1}{s}\right) = \frac{6.6K}{s(s+100)(s+1.7)} = \frac{6.6K}{s^3+101.7s^2+170s}$$

Multiply Controller: $$\left(\frac{1+aTs}{1+Ts}\right)^2 \text{ x } \frac{6.6K}{s^3+101.7s^2+170s}$$

Given $e_{ss} < 0.1$: $$K_v = \frac{1}{0.1} = 10$$

Determining K: $$K_v = \lim_{s\to 0} sG(s) = \frac{6.6K}{170} = 10 \qquad \therefore \quad K = 257.58$$

Determine range of K for marginally stable system using the characteristic equation:

$$s^3 + 101.7s^2 + 170s + 6.6K$$

s^3	1	170
s^2	101.7	$6.6K$
s^1	$\frac{17289 - 6.6K}{101.7}$	
s^0	$6.6K$	

$$17289 - 6.6K > 0$$

$$K < 2620 \quad \text{or}$$

$$K > 0$$

System stable for:

$$0 < K > 2620$$

The Routh-Hurwitz criterion shows that the gain $K = 257.58$ is acceptable as it falls between the range of K for a marginally stable system.

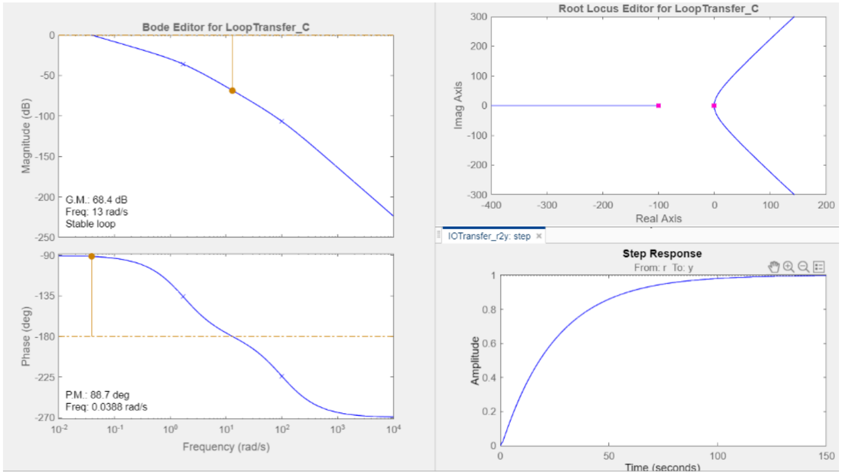


Figure 4: Graphs for uncompensated system (K = 1)

Conclusion: From Bode diagram we get GM = 68.4 dB and PM = 88.7 dB.

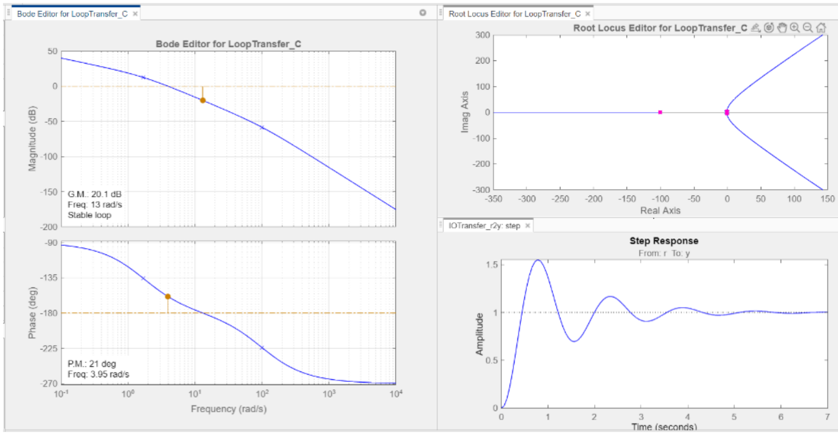


Figure 5: Graphs for response when K = 257.58 (within the range of stability)

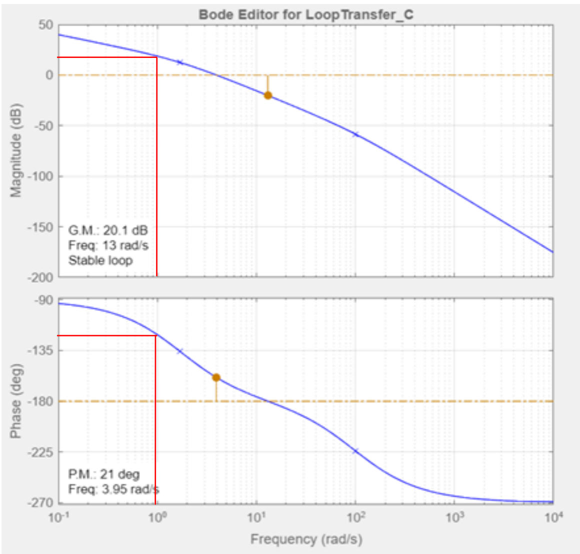
Question 1.5: Stage 1 Design a phase – lag controller

Using gain K from 1.4: $$GP = \frac{257.58 \cdot 6.6}{s^3+101.7s^2+170s} = \frac{1700}{s^3+101.7s^2+170s}$$

Finding ζ & ω_n : $$\%OS = 20 = 100e^{\frac{\pi\zeta}{\sqrt{1-\zeta^2}}} \qquad \therefore\ \zeta = 0.456$$

$$t_{peak} = 3 = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} \qquad \therefore\ \omega_n = 1.177\ rad/sec$$

For a PM of 60 degrees we get $\omega_g' = 0.98\,rad/sec$. This yields a new dB = 19.5



$$G_c(s) = \frac{1+aTs}{1+Ts} \qquad a < 1$$

$$a = 10^{\frac{-|G_P(j\omega_g')|}{20}} = 10^{\frac{-|G_P(j0.98)|}{20}} = 10^{\frac{-|19.5|}{20}} = 0.105$$

$$\frac{1}{aT} = \frac{\omega_g'}{10} \quad => \quad \frac{1}{0.105T} = \frac{0.98}{10} \quad \therefore\ T = 97.2$$

Controller: $$G_c(s) = \frac{1+(0.105)(97.2)s}{1+97.2s} = \frac{1+10.2s}{1+97.2s}$$

$$zero:\ -\frac{1}{aT} = -\frac{1}{(0.105)(97.2)} = -0.09798$$

$$pole:\ -\frac{1}{T} = -\frac{1}{97.2} = -0.010288$$

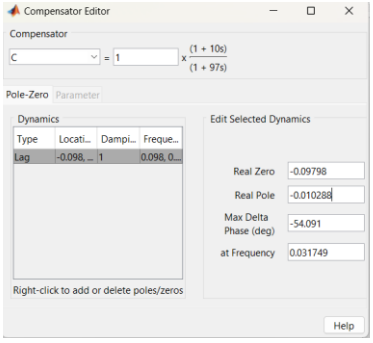


Figure 6: Adding Lag compensator.

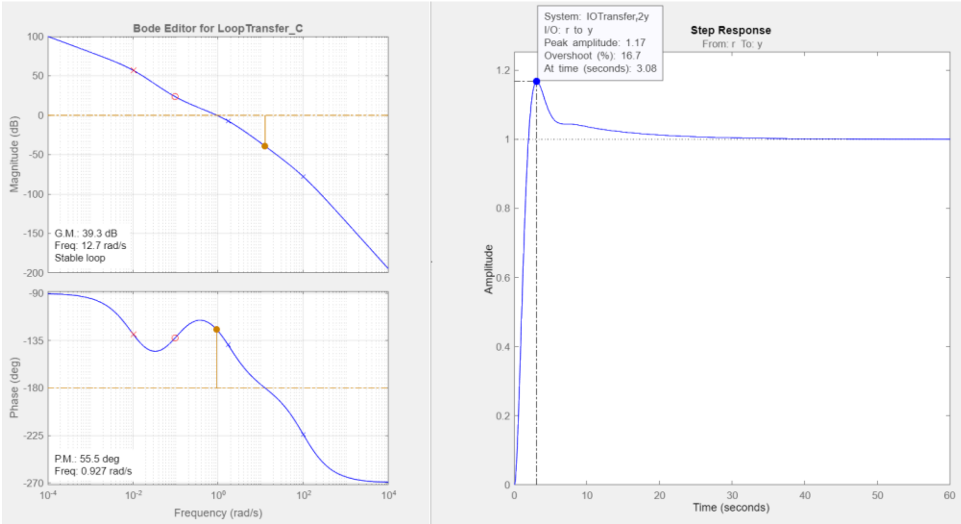
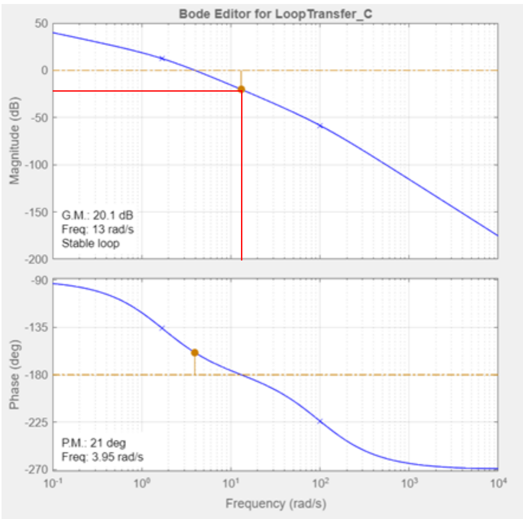


Figure 7: Bode and step response after adding the Lag compensator.

Conclusion: A percentage overshoot of 16.7% can be read off the graph, which meets the design requirement of less than 20%. The PM = 55.5 deg and the GM = 39.7 dB.

Question 1.6: Stage 2: Design a phase – lead controller with a phase margin of 80 deg.



$$(s) = \frac{1 + aTs}{1 + Ts} \qquad a > 1$$

$$a = \frac{1+\sin(80)}{1-\sin(80)} = 130.6$$

$$G_p(j\omega) = -10\log(130.6) = -21.16\ dB\ @\ 13.6\ rad/sec$$

$$T = \frac{1}{\omega_g'\sqrt{a}} = \frac{1}{13.6\sqrt{130.6}} = 0.00643413$$

Controller: $$G_c(s) = \frac{1+(130.6)(0.00643)s}{1+0.00643s} = \frac{1+0.84s}{1+0.00643s}$$

$$zero\colon\ -\frac{1}{aT} = -\frac{1}{(130.6)(0.00643413)} = -1.19$$

$$pole\colon\ -\frac{1}{T} = -\frac{1}{0.00643413} = -155.42$$

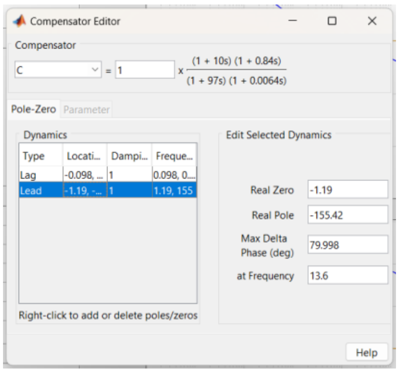


Figure 8: Adding Lead compensator.

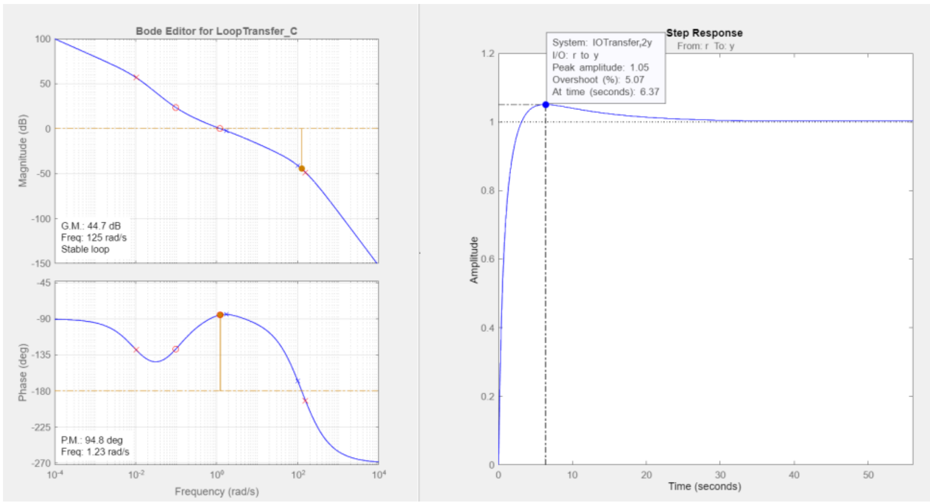


Figure 9: Bode and step response after adding the Lead compensator.

Conclusion: The compensated system has PM = 94.8 deg and GM = 44.7 dB. The percentage overshoot has reduced as a result of adding the lead controller.

Question 1.7: Convert the two-stage controller into the z-domain.

MATLAB Code:

```
Glead_num = [0.84 1];
Glead_den = [0.00643413 1];
Glead = tf(Glead_num, Glead_den);

Glag_num = [10.2 1];
Glag_den = [97.2 1];
Glag = tf(Glag_num, Glag_den);

Gp = Glead*Glag;
display(Gp);

freq = 100;
T = 1/freq;

Gz = c2d(Gp,T,'tustin');
display(Gz);
```

```
Gp =

  8.568 s^2 + 11.04 s + 1
  ------------------------
  0.6254 s^2 + 97.21 s + 1

Continuous-time transfer function.


Gz =

  7.759 z^2 - 15.42 z + 7.659
  ---------------------------
    z^2 - 1.125 z + 0.1254

Sample time: 0.01 seconds
Discrete-time transfer function.
```

Question 1.8: Replace the 2-stage controller with a PID controller block.

To simplify the system architecture, a PID controller can be used to handle both the phase-lag and phase-lead aspects. Tuning the PID controller requires adjusting the three parameters. The Proportional term controls the error response, the Integral term eliminates the steady state error, and the Derivative term helps reduce overshoot by including damping.

Design approach for a PID Controller:

1. Obtain an open-loop response to determine what is required to improve.
2. Add a Proportional control to improve rise time and error constant.
3. Add a Derivative control to improve the overshoot.
4. Add an Integral control to eliminate steady-state error.
5. Adjust each K_P, K_I and K_D until the desired overall response is achieved.

K_P, K_I and K_D effects on a Closed Loop system:

Closed Loop Response	Rise Time	Overshoot	Settling Time	Steady-State Error
K_P	Decrease	Increase	Small Change	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	Small Change	Decrease	Decrease	No Change

References

[1] (. I. ,. H. X. L. X. (. I. A. J. Y. JING ZHANG, "On the Application of Directional Antennas in Multi-Tier Unmanned Aerial Vehicle Networks," IEEE Access, 25 September 2019. [Online]. Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8830441. [Accessed 7 September 2023].

[2] J. Green, "Best Flight Controllers with GPS," StarlinkHow, 8 February 2023. [Online]. Available: https://starlinkhow.com/best-flight-controllers-with-gps/. [Accessed 7 September 2023].

[3] "Drone Communications: UAV Comms Systems: Wireless & Long Range," Unmanned Systems Technology, 12 July 2023. [Online]. Available: https://www.unmannedsystemstechnology.com/expo/drone-communications/#:~:text=The%20most%20common%20method%20of,of%2Dsight%20(LOS).. [Accessed 7 September 2023].

[4] FlyAbility, "What Is a GPS-Denied Drone?," FlyAbility, [Online]. Available: https://www.flyability.com/gps-denied-drone#:~:text=%2D%20NASA-,How%20Can%20Drones%20Fly%20without%20GPS%3F,altitude%2C%20attitude%2C%20and%20location.. [Accessed 7 September 2023].

[5] Emesent, "Hovermap Series," Emesent, 2 June 2023. [Online]. [Accessed 7 September 2023].