Intro to UAV Design

Assignment - 1

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(Q2) Given system,

$$G(s) = \frac{y(s)}{u(s)} = \frac{4}{s^2+3s+10} = \frac{M(s)}{N(s)}.$$

(2nd order)

Zeros of $G(s)$ are at infinity

Zeros of $s^2+3s+10=0$ (are poles of $G(s)$)

$$s = \frac{-3 \pm \sqrt{9-40}}{2}$$

ie, $s = -1.5 \pm i\frac{\sqrt{31}}{2}$.

(Both poles lie on left s-plane)

Comparing with $-\xi\omega_n \pm j\omega_n\sqrt{1-\xi^2}$ &

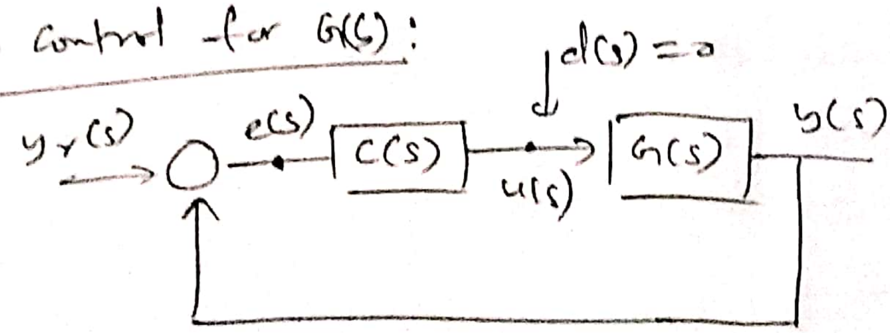
$\xi \rightarrow$ Damping ratio
& $\omega_n \rightarrow$ natural frequency.

$s^2 + 2\xi\omega_n s + \omega_n^2 = 0$
($N(s)$)

we have, $\omega_n = \sqrt{10}$, $2\xi\omega_n = 3 \Rightarrow \xi = \frac{3}{2\sqrt{10}} < 1$

$N(s)$ has complex roots & is underdamped.

PID Control for $G(s)$:



$$e(s) = y_r(s) - y(s)$$

$$u(s) = e(s)\cdot c(s)$$
$$= \left[y_r(s) - y(s)\right] c(s)$$

for $c(s)$ as PID controller,

$$c(s) = A_p + \frac{A_i}{s} + A_d \cdot s.$$

let $\frac{A_p}{A_i} = g_1$, $\frac{A_d}{A_i} = g_2$ (May need to be tuned).

$$\therefore c(s) = A_i\left(\frac{A_p}{A_i} + \frac{1}{s} + \frac{A_d}{A_i}\cdot s\right)$$

for the given closed loop system,

$$y(s) = \frac{c(s)\cdot G(s)}{1 + c(s)G(s)} \cdot y_r(s).$$

Given $y_r(s) = \frac{2}{s}$ (ie $M=2$). & $c(s)$ is defined above.

<u>Steady state Response</u>:

$$y_{ss} = \lim_{s\to 0} s\cdot y(s)$$

$$= \lim_{s\to 0} \frac{\cancel{s}\left(\frac{2}{\cancel{s}}\right) A_i\left(\frac{A_p}{A_i} + \frac{1}{s} + \frac{A_d}{A_i}\cdot s\right)\left(\frac{4}{s^2+3s+10}\right)}{1 + A_i\left(\frac{A_p}{A_i} + \frac{1}{s} + \frac{A_d}{A_i} s\right)\left(\frac{4}{s^2+3s+10}\right)}$$

$$\left(\because y(s) = G(s)\cdot \underset{u(s)}{y_r(s)}\right).$$

$$= \lim_{s\to 0} \frac{2A_i\left(g_1 + \frac{1}{s} + g_2 s\right)\left(\frac{4}{s^2+3s+10}\right)}{1 + A_i\left(g_1 + \frac{1}{s} + g_2 s\right)\left(\frac{4}{s^2+3s+10}\right)}$$

$$= \frac{2A_i(1)\left(\frac{4}{10}\right)}{1 + A_i(1)\left(\frac{4}{10}\right)}$$

$$y_{ss} = \frac{2\left(\frac{2}{5}A_i\right)}{1 + \left(\frac{2}{5}A_i\right)}$$

make A_i very high so that $y_s \cong 2$.

<u>Stability & Root locus:</u>

$$R(s) = 1 + C(s)\,G(s)$$

we can consider

$$P(s) = 1 + K \cdot G(s) = 0.$$

$$P(s) = 1 + A_i \underbrace{\left(g_1 + \frac{1}{s} + g_2 s\right) G(s)}_{G_1(s)}$$

$$P(s) = 1 + A_i\, G_1(s)$$

$$G_1(s) = \left(g_1 + \frac{1}{s} + g_2 s\right)\left(\frac{4}{s^2+3s+10}\right)$$

$$G_1(s) = \frac{(g_1 s + g_2 s^2 + 1)\,4}{s(s^2+3s+10)}$$

poles of $G_1(s)$ are $-1.5 \pm i\frac{\sqrt{31}}{2}$, 0.

zeros are $-\frac{1}{2} \pm \frac{\sqrt{5}}{10}$.

Required conditions are

→ 90% y_r (~ 1.8) before 6 sec.

→ $y(t)_{max} < 2.2$.

→ Plot of root locus is given in the end (please find)

We need to tune for the gains g_1 & g_2 (fixed them) & select an A_i value from Root locus plot.

→ from the Root locus plot, $A_i > 0$ all values will satisfy the system stability.

Choosing $A_i = 10$, $g_1 = 0.5$, $g_2 = 0.05$

we have achieved the output well within the given requirements.

Observations:

$$P(s) = 1 + A_i G_1(s) = 0$$

$$A_i = \frac{-1}{G_1(s)}$$

$A_i = 0 \rightarrow$ poles of $P(s)$

$A_i = \infty \rightarrow$ ~~poles of ze~~ zeros of $P(s)$.

At a given s point, $|A_i| = \left|\frac{-1}{G_1(s)}\right|$.

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$$1 + A_i \left(\frac{4g_1 s^2 + 4g_2 s + 4}{s^3 + 3s^2 + 10s} \right) = 0$$

Selecting A_i such that all roots lie in left s-plane.

$A_i = 10$, $g_1 = 0.5$, $g_2 = 0.05$.

$$\frac{A_p}{A_i} = 0.5 \Rightarrow A_p = 5$$

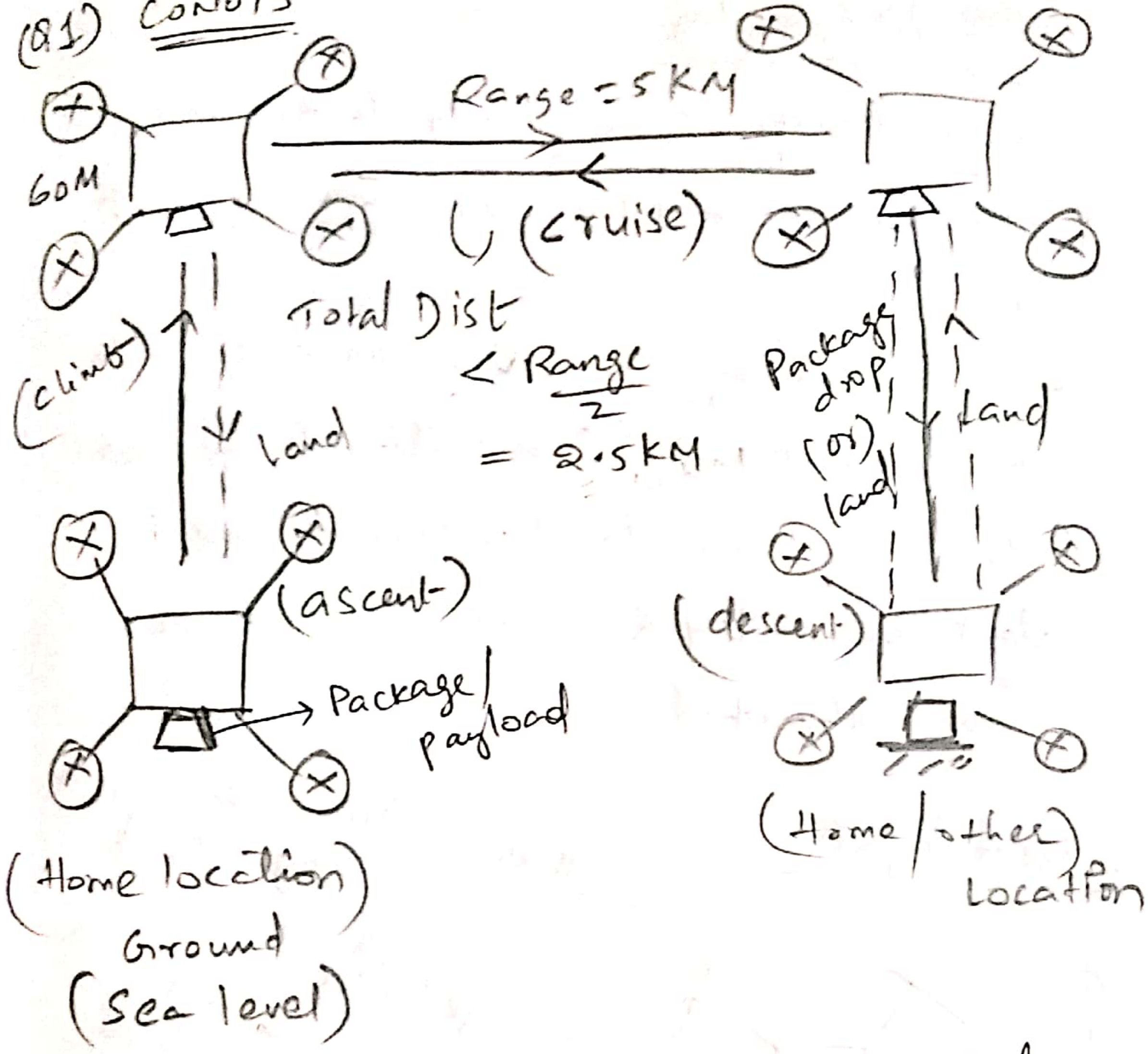
$$\frac{A_d}{A_i} = 0.05 \Rightarrow A_d = 0.5$$

→ output peak = 2.15, reached at 0.8 sec.

→ y_{ss} is reached as 3.5 sec (using the ~~[illegible]~~ above gains).

(please find plots, code & responses at the end)

(Q.1) CONOPS



In cruise, when the destination is reached, the package is dropped or landed. (from a reasonable height, therefore some descent is still there).

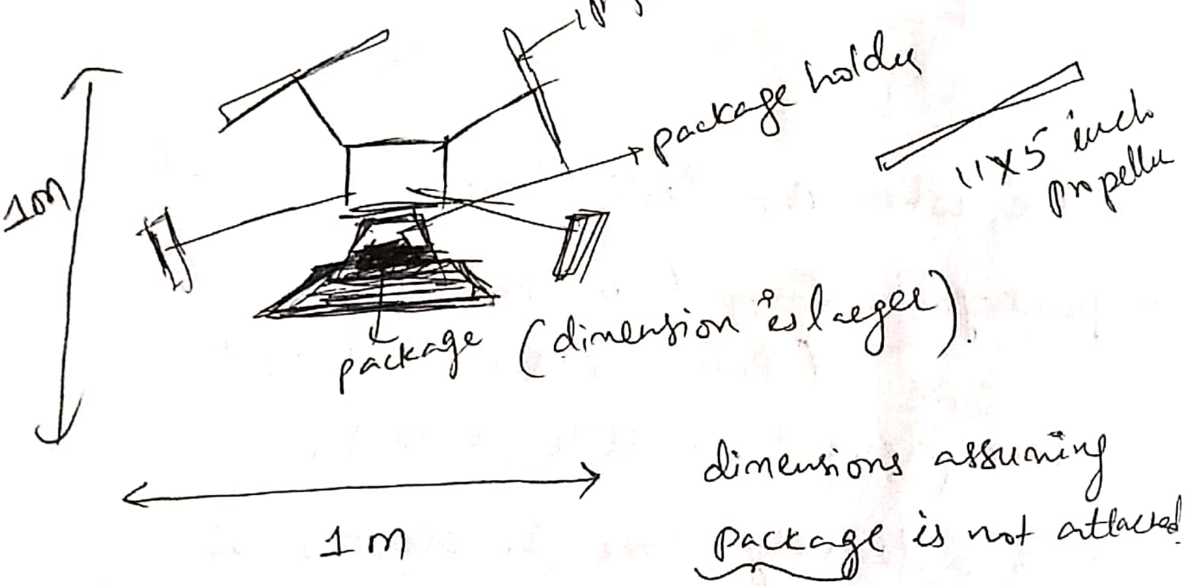
→ This is a delivery drone. It has to use camera to cruise (if ~~poss~~ spray tank is there to spray on fields then constant monitoring with camera needs to be done during cruise (as spraying will be done during ~~cruise~~ cruise). This drone is just for

~~Sizing & layout~~

Package delivery since spray-tank drone will involve much complex dynamics as weight varies.

→ our drone has to deliver package, take a snapshot for confirmation & go back to the home location (or) its next task if battery & endurance limit are not exhausted.

Size & layout (Quadrotor configuration)



↳ 0.5 X 0.5 X 0.2.

(assuming shape is like this)

↳ Because package is large, we need larger wing span.

Wing span = (1.2 → 1.3 m).

↳ say 1.25 m

Package holder height → 0.1 m.
Span or width → 0.2 m
attached to the package
~~(area)~~
⇒ Area = $0.2 \times 0.2\ M^2$

Drone height → 0.01 – 0.2 m
say 0.1 m
(without payload)
& including payload holder.

Drone Dimensions : 1 × 1 × 0.1 m

→ From Conops,

Drone first climbs, (takeoff), then cruises for 5KM, then descends & then delivers. (& then takes off again) (then hover for picture etc)

is operations performed by the drone are
→ Take off, climb, Cruise, Hover, Descent, Landing. (No aggressive flight manoveurs)

Propeller Thrust & Dimensions :

Assume hovering occurs at 50 – 60% max. Thrust value.

Take off : (with package)

(→PTO)

$4T > mg$ (5kg → max Wt) while takeoff

$4T > (5)\,9.8$

$T > 0.25 \times 5 \times 9.8$

$T > 12.25\ N$.

→ we need larger propellers for this high take off thrust.

[say 15 x 10 inches propellers (as mentioned in specifications).]

↳ can try in next iteration

But now,

Consider 11 x 5 inch propellers due to market availability.

for climb (2 m/s) with payload.

mass = 5 kg.

$$T_{climb} = \frac{mg - 0.1021 w^2 \operatorname{sgn}(w)}{4} \qquad w = -2\,m/s$$

$$\therefore T_c = \frac{5 \times 9.8 - 0.1021(4)(-1)}{4}$$

$$= \frac{49 + 0.4084}{4} = 12.3521\ N.$$

(Required thrust to climb).

~~without~~
without payload:

$m = 4\,kg.$

$w = -2.$

$$T_c = \frac{4 \times 9.8 + (0.1021)4}{4}$$

$$= 9.8 + 0.1021 = 9.9021\,N.$$

for Cruise:

(lesser speed).

with payload:

$V = \cancel{10}\,5\,m/s.$ assume

$$\theta = \tan^{-1}\left(\frac{K_d V^2}{mg}\right).$$

~~(max cruise speed)~~

$K_d = 0.1021.$

$$\therefore \theta = \tan^{-1}\left(\frac{0.1021 \times 25}{5 \times 9.8}\right)$$

$$= 0.0520^c = 2.9819^\circ.$$

$$T_c = \frac{mg}{\cos\theta} = \frac{5 \times 9.8}{\cos(2.9819)} = 49.0664\,N.$$

without payload:

$V = 10\,m/s$ (max cruise speed)

$$\theta = \tan^{-1}\left(\frac{10.21}{4 \times 9.8}\right)$$

$$= 14.5989^\circ$$

$$T_c = \frac{4 \times 9.8}{\cos(14.5989)} = 40.5078\,N.$$

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For Hover

with payload

$$T_h = m \cdot g = 5 \times 9.8$$
$$= 49 \text{ N}$$

without payload:

$$T_h = 4 \times 9.8 = 39.20 \text{ N}$$

For Descent

with payload $\qquad \omega = 3\,\text{m/s} \; (+)$

$$T_D = \frac{mg - 0.1021\,\omega^2 \operatorname{sign}(\omega)}{4}$$

$$= \frac{5 \times 9.8 - 0.1021(9)(1)}{4}$$

$$= 12.0203 \text{ N}$$

without payload,

$$T_D = \frac{4 \times 9.8 - 0.1021(9)(1)}{4}$$

$$= 9.5703 \text{ N}$$

Required Energy:

$$E_{total} = E_T = \left(E_{climb} + E_{cruise} + E_{hover} + E_{descent}\right)$$

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with payload :

$$\text{Power} = T \times V.$$

$$E = \text{Power} \times \text{time}.$$

$$E = T \times V \times t$$

E_{climb}
$= 12.3521 \times \cancel{9}\,2 \times 30$

$= 741.1260\,J$

$V_{cruise} = \cancel{10}\,5\ m/s$

$V_{climb} = 2\ m/s$

$V_{descent} = 3\ m/s.$

$E_{cruise} = 49.0664 \times 5 \times 500$

$= 122666\ J$

$H = 60\,m$

$2 = \dfrac{H}{t} \Rightarrow t = \dfrac{60}{2} = 30\ sec$

$t_{climb} = 30\ sec$

$E_{descent} = \cancel{9.25\ldots}\ 12.0203 \times 3 \times 20$

$= 721.2180\,J$

$3 = \dfrac{60}{t} \Rightarrow t = 20\,sec$

$t_{descent} = 20\,sec.$

$5 = \dfrac{2.5\,KM}{t} \Rightarrow t = \dfrac{2500}{5}$

$t_{cruise} = 500\,sec$

$E_{hover} = ?$

$$\text{Power}_h = \sqrt{\frac{2 T_h^3}{\pi \rho D^2}}$$

(single propeller) $\pi = 3.14$, $\rho = 1$, D: for 11×5 taken propeller at $n = 100$ RPS, $D = 0.27\,m$.

$\therefore$ we choose 11×5 in propeller

$$T_h = \frac{12.25\ (\max)}{2}$$

$= 6.125\,N$

Also, more accurately,

$$T_h = 0.1606 \cdot n^2 \cdot D^{3.5} \sqrt{P_h}$$

$P_h = 5$ inch $\rightarrow P_h = 0.127$

consider this $T_h = 5.8536\,N$ ~~consider this~~

$\therefore$ power$_h$ $= \sqrt{2 \times (493)} \Big/ \sqrt{3.14 \cdot (0.27)^2}$

(each prop) $= \quad 1.9512 \times 10^3 \quad (\times 4)$

Total P_h $= \boxed{7.8047 \times 10^3}$ W

Consider hover time 2 sec for photo

(4 propellers)

$E_h = P_h \times 2 \times 4 \times 4$

$= 7.8047 \times 10 \times 2 =$

$= 6.2438 \times 10^4$ J

Without payload :

$V_{cruise} = 10$ m/s

$V_{climb} = 2$ m/s

$V_{descent} = 3$ m/s

$t_{cl} = 30$ s.

$t_{cruise} = 250$ s

$t_{descent} = 20$ s

$t_h = 2$ sec

$E_{climb} = 9.9021 \times 30 \times 2$

$= 594.1260$ J

$E_{cruise} = 40.5078 \times 250 \times 10$

$= 1.0127 \times 10^5$ J

$E_{descent} = 9.5703 \times 3 \times 20$

$= 574.280$ J

$E_{hover} = ?$

$$P_{hi} = \sqrt{\frac{2T_h^3}{\pi \rho D^2}} = \sqrt{\frac{2 \times (39.20)^3}{3.14 \times 1 \times (0.27)^2}}$$

$= 1.3962 \times 10^{3}$ J

$P = P_{hi} \times 4$

$= 5.5846 \times 10^{3}$ W

$E = P \times 2$

$= 1.1169 \times 10^{4}$ J

$E_T = 594.1260\text{J} + 1.0127 \times 10^{5}\text{J} + 574.2180\text{J} + 1.1169 \times 10^{4}\text{J} = 1.1361 \times 10^{5}$ J

without payload →

$E_T = E_{T1}$ (this value)

with payload

$E_T = 741.1260\text{J} + 122666\text{J} + 721.2180\text{J} + 6.2438 \times 10^{4}$ J.

$E_T = E_{T2}$ (this value).

$= 1.8657 \times 10^{5}$

Battery Requirements:

4 celled battery $4 \times 4.2 = 16.8$ V

$P_{mot} = VI$.

$I = 13$ Amp (max current)

for 11×5 inches,

$T_h = 6.7$

from propeller data

but $T > 12.25$N. so $n > 100$ RPS is needed.

$\eta = 0.6$

$E_{battery} = \frac{E_{total}}{\eta}$ Consider E_T with payload

$E_b = \frac{E_{T2}}{0.6} = \frac{E_{T2}}{0.6} = \frac{1.8657 \times 10^5}{0.6}$

$E_b = 3.1094 \times 10^5 J$ $\qquad E_b = \frac{E_{T2}}{0.6} J =$

Based on this we may need to change the battery or increase the No. to '6' or '8'.
We can calculate currents and also verify if they are satisfying.

→ Now, using these above calculations we need to get Endurance & Range.
If they are not satisfied, we need to alter the design & make some changes (trade offs) etc.

→ Like this we have to some number of iterations until all the specs are reached.

Design optimization for maximizing endurance:

To find ~~the~~ how much range &

endurance we are getting for the current design,

$E_b = 3.1094 \times 10^5$ J.

Available energy : E_a

If $E_b \geq E_a$ then the task cannot be completed.