Sofiane Ahmed Ali

M2 SMART AEROSPACE AND AUTONOMOUS

Course Lab2: UAV-UGV control approaches

Exercise 1 UAV control structure :

Consider the following UAV control structure:

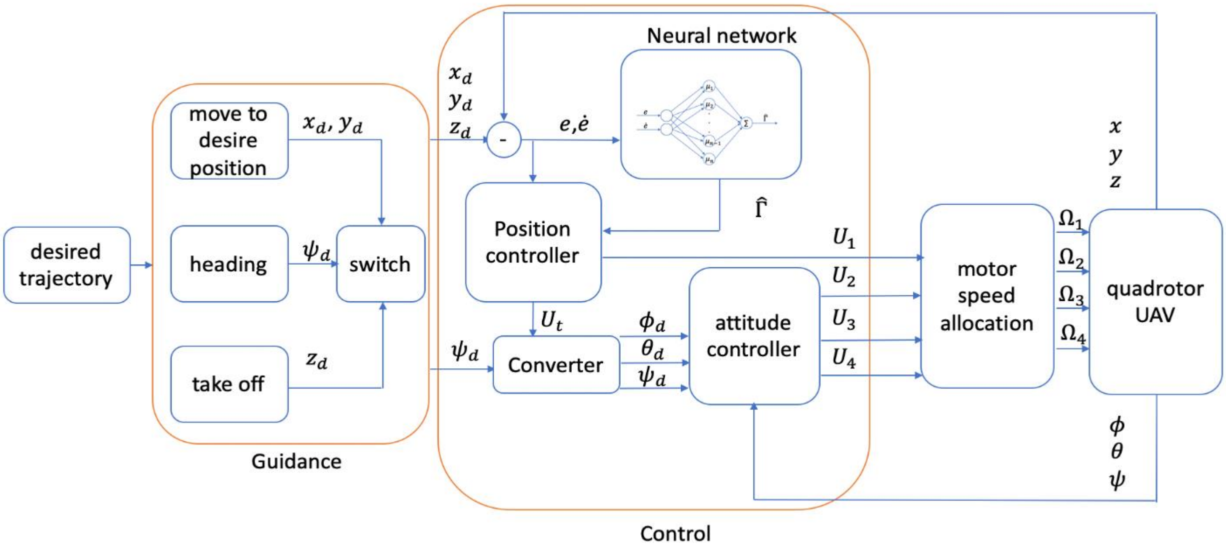


Figure 1: UAV control structure

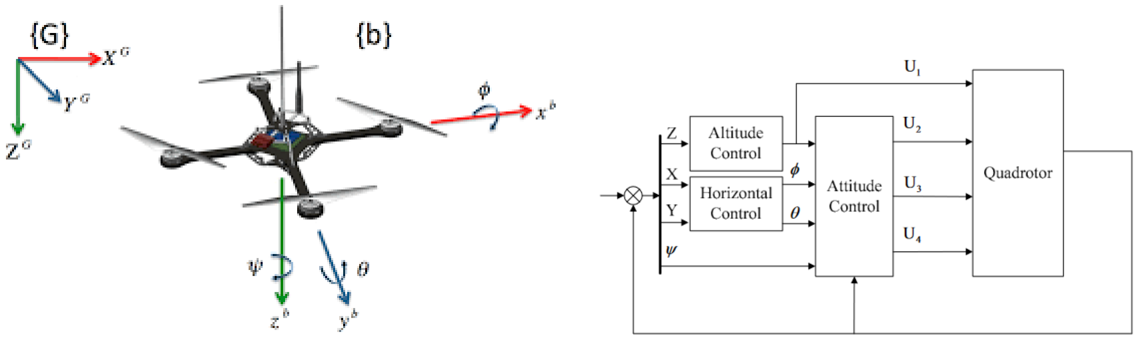
1. Explain briefly the role of the guidance and the control loop
2. What the role of the motor speed control application?
3. What is the role of the neural network bloc in this control structure.

Exercise 2 : UAV PID control design :

Consider the following UAV device and its position and attitude control loop as shown in Figure 2:

1. Explain what is the altitude position control loop?
2. What we do mean by horizontal control

3. What do we mean by altitude control



<u>Figure 2: UAV control structure</u>

4. Given a position desired trajectory vector $[x_d, y_d, z_d]$, propose a PID (proportional-Integral- derivative) control law structure.

5. What is the role of the integral action in the PID position control structure?.

6. If the desired control position trajectory are constants, rewrite the PID control structure.

7. What are the desired attitude $(\psi,\theta,\boldsymbol{\Phi})$ references generated from the position control structure?

8. Based on your course document hive the structure of the PD attitude control structure.

Exercise 3 : Sliding mode control design :

we consider the following dynamical model whose equations for the translational position dynamics as :

$$\ddot{x} = \frac{-k_{tdx}\dot{x}}{m} + \frac{c(\phi)s(\theta)c(\psi) + s(\phi)s(\psi)}{m}U_1 + \delta_{tx}$$
$$\ddot{y} = \frac{-k_{tdy}\dot{y}}{m} + \frac{c(\phi)s(\theta)s(\psi) - s(\phi)c(\psi)}{m}U_1 + \delta_{ty}$$
$$\ddot{z} = \frac{-k_{tdz}\dot{z}}{m} - g + \frac{c(\phi)c(\theta)}{m}U_1 + \delta_{tz}$$

and for the attitude dynamics as

$$\ddot{\phi} = \frac{I_y - I_z}{I_x}\dot{\psi}\dot{\theta} - \frac{J_r}{I_x}\Omega\dot{\theta} - \frac{k_{afx}}{I_x}\dot{\phi}^2 + \frac{U_2}{I_x} + \delta_{rx}$$
$$\ddot{\theta} = \frac{I_z - I_x}{I_y}\dot{\phi}\dot{\psi} - \frac{J_r}{I_y}\Omega\dot{\phi} - \frac{k_{afy}}{I_y}\dot{\theta}^2 + \frac{U_3}{I_y} + \delta_{ry}$$
$$\ddot{\psi} = \frac{I_x - I_y}{I_z}\dot{\phi}\dot{\theta} - \frac{k_{afz}}{I_z}\dot{\phi}^2 + \frac{U_4}{I_z} + \delta_{rz}$$

1. Consider the following states vector, $X_1 = [x, y, z]^T$, $X_2 = [\dot{x}, \dot{y}, \dot{z}]^T$, write the state space of the position control loop under the following form:

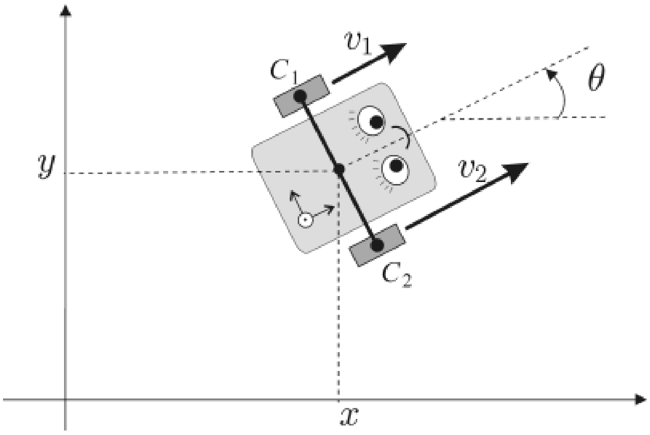
$$\begin{cases} \dot{X}_1 = X_2 \\ \dot{X}_2 = F(X) + GU + \delta \end{cases}$$

2. Give the expression of F, G and U
3. Consider now the following dynamics of the sliding surface:

$$e = X_{1d} - X_1 \qquad \dot{e} = X_{2d} - X_2 \qquad S = \dot{e} + ce$$

4. What the definition of S, gives its order what does mean?
5. Gives the expression of the position control law U which steers the sliding surface S toward 0.
6. Based on your course express the desired attitude (ψ,θ,$\boldsymbol{\Phi}$) references generated from the position control structure?
7. Propose PD control loop for the attitude controller

<u>Exercise 4: Autonomous UGV controller :</u> consider the following UGV scheme



<u>Figure 3: UGV model</u>

The **UGV** in the figure **3** includes two parallel driving tracks (or wheels) whose accelerations namely u_1 and u_2 are controlled by two independent motors. The state variables of the UGV system are respectively x and y which represents the center of the axle. Θ is the orientation of the UGV and the speeds v_1 and v_2 are the speeds of each wheel with respects to the CG of the UGV. The state space representation of the UGV is given as follows

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \\ \dot{v}_1 \\ \dot{v}_2 \end{pmatrix} = \begin{pmatrix} \frac{v_1+v_2}{2}\cos\theta \\ \frac{v_1+v_2}{2}\sin\theta \\ \frac{v_2-v_1}{\ell} \\ Ru_1 \\ Ru_2 \end{pmatrix}$$

1. What is the type of this state space representation?
2. Consider now the following outputs y_1 and y_2 defined as follows:

$$y_1 = \theta$$

$$y_2 = \frac{v_1 + v_2}{2}$$

3. Compute the second derivative of $\ddot{y}_1$ and the first order derivative $\dot{y}_2$
4. Write these derivatives under the following matrix form:

$$\begin{pmatrix} \ddot{y}_1 \\ \dot{y}_2 \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} u_1 \\ u_2 \end{pmatrix} \quad (1)$$

Where a,b,c and d are the coefficients of matrix A_y

5. Compute the value of the coefficients a,b,c and d of the matrix A.

6. Consider the following state feedback control law defined as follows:

$$\begin{pmatrix} u_1 \\ u_2 \end{pmatrix} = A_y^{-1} \begin{pmatrix} v_1 \\ v_2 \end{pmatrix}$$

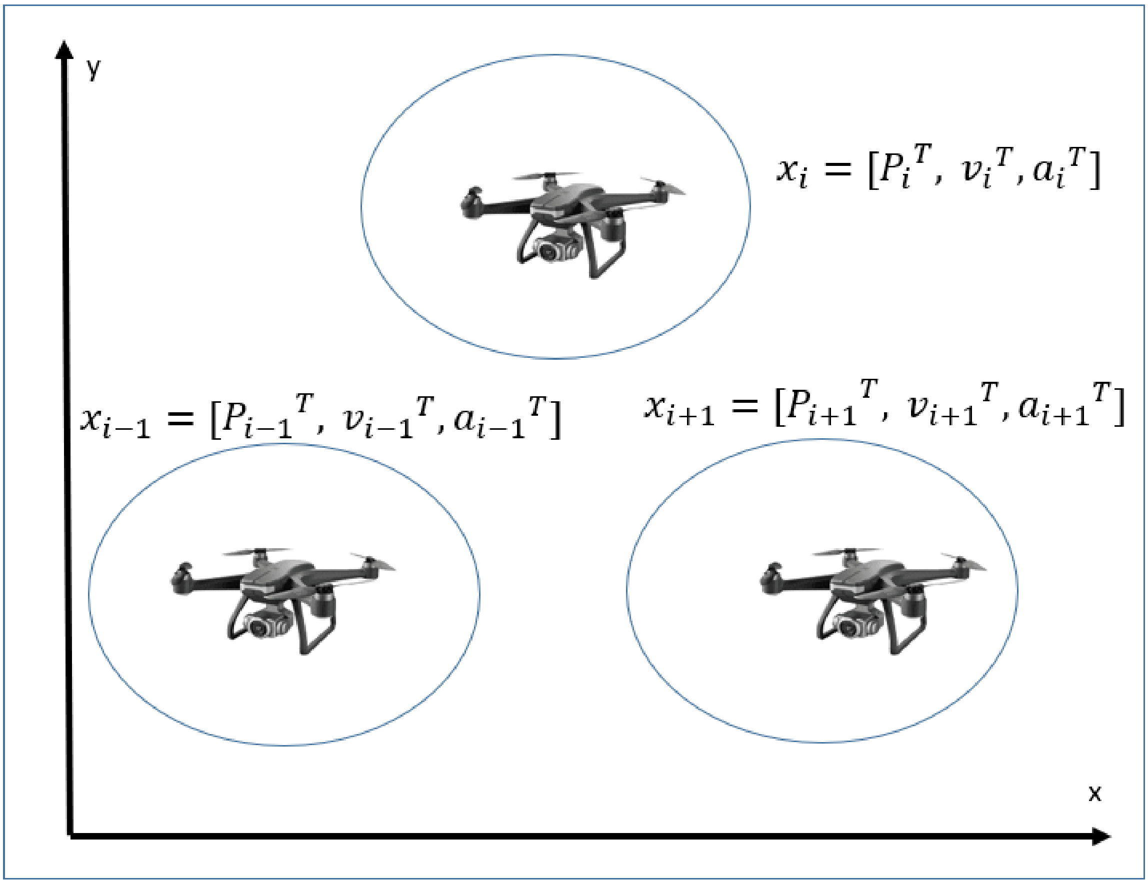
7. Rewrite the system outputs (1) and with its new inputs v_1, v_2.?

8. Is this system linear ? explain.

9. Propose a PD controller law that track for the output y_1 the reference y_{1d} and for system output y_2 the reference y_{2d}

<u>Exercise 5: Multi UGV control design law :</u>

Given a Multi-UAV swarm is described by the following structure depicted in Figure 3:



<u>Figure 3: UAV control structure</u>

The kinematic state space model of the UAV swarm

$$\begin{cases} \dot{p}_\imath(t) = v_i \\ y(t) = x_i + \boldsymbol{\xi}(t) \end{cases}$$

- y: Sensor measurements i^{th} UAV
- $\boldsymbol{\xi}(t)$: *measurements noise*

Consider that v_i is the control input of the ith UAV:

1. Express the state space presentation of the multi-UAV swarm under the linear form:

   $$\begin{cases} \dot{x}_i = Ax_i + BU \\ Y = cx_i + \boldsymbol{\xi}(t) \end{cases}$$

2. Gives the expression of A, B, and C

3. Propose a linear controller design for the swarm fleet U=-Kx. What is the condition of the control gain K?.