Course No. – AS 5570

Principles of Guidance for Autonomous Vehicles

Assignment 1 **Due Date: September 2, 2024**

(For Computer Assignments: Sept 7, 2024)

Part A : Introductory Topics

1) Distinguish between different levels of autonomy.

2) Distinguish between domain-dependent and domain-independent components of autonomous systems.

3) Discuss basic differences between path planning, navigation, guidance and vehicle control.

4) Draw schematic block diagram of Lateral autopilot and describe its function.

5) Draw schematic block diagram of Guidance, Navigation and Control (GNC) system and describe its function.

6) Describe different phases of guidance in an engagement.

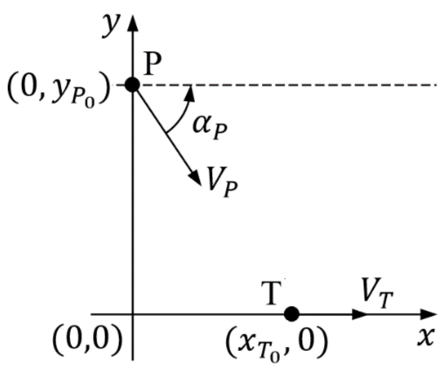
7) Describe non-homing, homing and external guidance implementation schemes.

8) What are the different categories of homing guidance in terms of seekers' modes of operation? Give examples.

Part B : Basic Engagement Scenarios

1) What is a collision triangle geometry? Prove that the closing speed of two unguided vehicles is constant when they are in a collision triangle geometry. Also, show that the time-to-go at any time t can be given as, $t_{go}(t) = -R(t)/\dot{R}(t)$, where $R(t)$ is the range between two vehicles in collision triangle geometry, and $\dot{R}(t) = dR(t)/dt$.

2) Consider the engagement between a pursuer (P) and a target (T) with speeds V_P and V_T, respectively. Both the vehicles are non-maneuvering.



i. Obtain expressions for pursuer's and target's positions $\left(x_P(t), y_P(t)\right)$, $\left(x_T(t), y_T(t)\right)$.

ii. Derive the expression of range between them $R(t)$.

iii. Derive the conditions on α_P for given $v = V_P/V_T$, x_{T_0} and y_{P_0} such that the range between them decreases for some finite time.

iv. Under the derived conditions above, obtain the expressions of the miss distance R_{miss} and the time t_{miss}, at which $R = R_{miss}$.

v. For what value of α_P is R_{miss} zero? What is the time required to achieve zero miss in that case?

vi. Plot the variation of R_{miss} with $\alpha_P \in [-\frac{\pi}{2}, 0]$ for a given $v = V_P/V_T$. **(Computer assignment)**

3) Consider the trajectories of two vehicles P and T be parameterized with respect to (w.r.t.) time as,

$$X_P(t) = (R_P \cos(\gamma_P t), R_P \sin(\gamma_P t)); \qquad X_T(t) = (R_P + R_T \cos(\gamma_T t), R_T \sin(\gamma_T t)),$$

where, γ_P and γ_T are the rate of change of heading angles of P and T. And, $R_P = V_P/\gamma_P$, while $R_T = V_T/\gamma_T$.

i. Let $\gamma_P = \gamma_T = \gamma$. Justify whether P and T can intercept each other. If 'Yes', what is the final time t_f? Else, if 'No', what is the miss distance R_{miss} and at which time(s) $R = R_{miss}$?

ii. Let $\gamma_P \neq \gamma_T$, and $\frac{\gamma_P}{\gamma_T} > 4v$, where $v = V_P/V_T$. Justify whether P and T can intercept each other. If 'Yes', what is the final time t_f? Else, if 'No', what is the miss distance R_{miss} and at which time(s) $R = R_{miss}$? (If not possible by hand, do the second half of the problem as computer assignment)

Part C : Pure Pursuit (PP) against Non-maneuvering and maneuvering Targets

1) For Pure Pursuit (PP) guidance,

i. Express range R in terms of angle $\psi \triangleq \alpha_T - \theta$, where α_T is the heading angle of target and θ is the line-of-sight (LOS) angle.

ii. Show that the trajectory of a PP-guided pursuer in an engagement against a non-stationary non-maneuvering target remains in one half-plane.

iii. For speed ratio $\nu = \frac{V_P}{V_T} = 1$, show that $R(\psi)$ is parabolic in nature. What is the final distance between the pursuer and target in that case?

iv. Express pursuer's lateral acceleration a_P as a function of $\psi \triangleq \alpha_T - \theta$ for $\nu > 1$.

v. For $1 < \upsilon \leq 2$, for which value of ψ is the pursuer's lateral acceleration maximum? And, what is the value of $a_{P_{Max}}$?

vi. Plot the curves showing variation of R with ψ for $R_0 = 5000$m and $\psi_0 = \pi/3$ and $\alpha_{P_0} = \theta_0$ for speed ratios $\nu = 0.8, 1$, and 1.2. (Computer assignment)

2) NPTEL lecture series Question 3 on Page 108-109 for speed ratios $\nu = \frac{V_P}{V_T} = 0.8$, 1 and 1.5. (It's mainly **Computer assignment.** However, you should practice computations as much as possible in hand.)

3) Consider a Pure Pursuit (PP)-guided pursuer with speed V_P against a maneuvering target with speed V_T and constant turn rate $\dot{\alpha}_T$. Analyze the PP trajectory on (V_θ, V_r)-space and find the conditions of successful capture. Identify the capture region in terms of V_{θ_0}, V_{r_0}.

4) NPTEL lecture series Question 3 on Page 108-109 for speed ratios $\nu = \frac{V_P}{V_T} = 0.8$, 1 and 1.5 and constant target maneuver $\dot{\alpha}_T = \pm\pi/6$ rad/sec. (It's mainly **Computer assignment.** However, you should practice computations as much as possible in hand.)

5) Consider a Pure Pursuit (PP)-guided pursuer with speed V_P against a maneuvering target with speed V_T and turn rate $\dot{\alpha}_T = c_T\dot{\theta}$. Consider three cases of $\nu = V_P/V_T \lesseqgtr 1$. For each of these three cases consider $c_T \lesseqgtr 1$. For each of these 9 cases:

   i. Obtain the trajectory on the (V_R, V_θ)-space.

   ii. In cases of successful capture:

      i. What are the conditions of successful capture?

      ii. Identify the capture region in terms of V_{R_0} and V_{θ_0}.

      iii. Derive the expression of t_f.

   iii. In other cases (no capture):

      i. Derive the expressions of t_{miss} and R_{miss}.

   iv. Derive expressions of $R(\psi)$ and $a_P(\psi)$. Obtain final values of R and a_P for $\nu \geq 1$.

   v. Obtain the value of $a_{P_{max}}$, and find at which value of ψ, $a_P(\psi) = a_{P_{max}}$.

6) Consider the initial engagement geometry in Question 3 on Page 108-109 of NPTEL lecture series. Consider speed ratios $\nu = 0.8, 1, 1.5$. For each of these three cases consider $c_T = 0.8, 1, 1.5$, where $\dot{\alpha}_T = c_T\dot{\theta}$. Solve Question 3 with all these set-ups.

(Part A: A1, A2, A5 – **Computer assignment**; Part B: C1 – **Computer assignment**)