ASE3093 Automatic Control: Midterm exam (1 big problem, 90 minutes)

Before the exam begins, write the following 'Student Honor Code' at the top of your answer sheet and sign it: **"By signing this pledge, I promise to adhere to exam requirements and maintain the highest level of ethical principles during the exam period."**
시험 시작 전, 다음의 '학생 명예선서(Honor Code)'를 답지 맨 위에 적고 서명하시오:
"나는 정직하게 시험에 응할 것을 서약합니다."

1) *Mars rover position control (30pts).* The ACSL team at Inha university is developing a new *Mars exploration rover*, called *Silver Star*, whose mission is to autonomously travel across wide Martian plains and rocky terrains.

The simplified longitudinal dynamics of the rover are:

$$m\dot{v}(t) + bv(t) = u(t),$$
$$\dot{x}(t) = v(t) + d(t),$$

where:

- $x(t)$ is the rover's position,
- $v(t)$ is its velocity,
- $u(t)$ is the motor force command,
- $d(t)$ is an unknown external disturbance (from terrain irregularities),
- m and b are positive known constants (mass and damping coefficient).

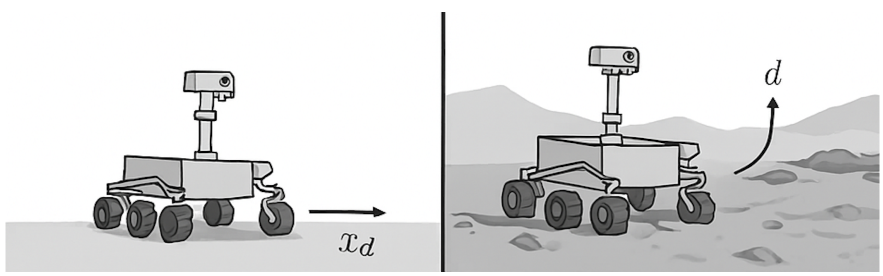

Figure 1: (Left) Lab testing on clean terrain, with $d(t) = 0$.
(Right) Rough Mars terrain, with $d(t) \neq 0$.

Lab Phase: Ideal Condition

During initial tests on clean indoor terrain, the engineers propose a simple Proportional (P) controller based on position tracking error:

$$u(t) = K_p\left(x_d(t) - x(t)\right).$$

a) Present the appropriate block diagram describing your controller, the rover dynamics, the reference command $x_d(t)$, output $x(t)$, and the disturbance $d(t)$ (5pts).

b) Assuming $d(t) = 0$, derive the closed-loop transfer function from $x_d(t)$ to $x(t)$. Determine whether the rover achieves *zero* steady-state error for a *step* reference input $x_d(t)$ (5pts).

Mars Mission Phase: Realistic Disturbances

After a long interplanetary voyage, *Silver Star* successfully lands on Mars. However the engineers notices that her steady-state tracking performance is seriously degraded. One hypothesis is this. "Martian surface is *not clean*: rough rocks and dust layers cause a *constant external disturbance* $d(t)$; a nonzero *step disturbance* affecting rover velocity."

c) Assuming that $d(t)$ is a nonzero unknown constant, analyze whether the simple P controller still ensures zero steady-state error in tracking $x_d(t)$. Check whether the hypothesis makes sense (5pts).

Adding Integral Action

Realizing the steady-state tracking error problem, the engineering team decides to upload the modified control algorithm to include *integral action*:

$$u(t) = K_p\left(x_d(t) - x(t)\right) + K_i\epsilon(t),$$
$$\dot{\epsilon}(t) = x_d(t) - x(t).$$

d) Present the appropriate block diagram describing your controller, the rover dynamics, the reference command $x_d(t)$, output $x(t)$, and the disturbance $d(t)$ (5pts).

e) Derive the new closed-loop transfer function and confirm that *zero steady-state error* is achieved for a step reference $x_d(t)$ and step disturbance $d(t)$ (5pts).

Teleoperation Phase: Communication Delay

After initial autonomous driving tests, the ACSL team realizes that certain critical maneuvers (e.g., docking, obstacle avoidance) must be remotely controlled from Earth.

However, communication delay between Earth and Mars is significant — approximately 5 to 20 minutes one way depending on planetary positions.

Thus, the rover's motor command $u(t)$ is no longer generated instantly from the local on-board controller. Instead, it comes from a teleoperated command sent from Earth, which experiences a pure delay τ.

The modified input to the rover is:

$$u(t) = u_c(t - \tau),$$

where:

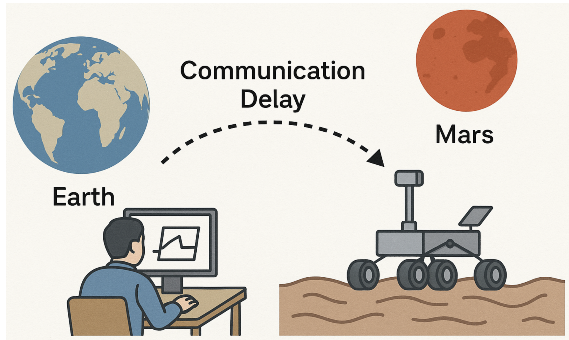

Figure 2: Teleoperation between Earth and Mars.

- $u_c(t)$ is the commanded control input sent from the Earth,
- $\tau > 0$ is the one-way communication delay from Earth to Mars (assumed constant during a maneuver).

The rover dynamics are still:

$$\begin{aligned} m\dot{v}(t) + bv(t) &= u(t) \\ \dot{x}(t) &= v(t) + d(t), \end{aligned}$$

and the controller we use is the one with the integral action:

$$\begin{aligned} u_c(t) &= K_p\left(x_d(t) - x(t)\right) + K_i \epsilon(t), \\ \dot{\epsilon}(t) &= x_d(t) - x(t). \end{aligned}$$

Note that we now have $u_c(t)$ instead of $u(t)$:

f) Express the closed-loop system transfer function from $x_d(t)$ to $x(t)$ including the delay. In your solution, clearly present the appropriate block diagram describing your controller, the rover dynamics, the reference command $x_d(t)$, output $x(t)$, disturbance $d(t)$, and the communication delays (5pts).

How well the proposed controller manages the communication delay challenge will be an exciting topic we'll dive into together after the midterm exam. Stay tuned!