The Hong Kong Polytechnic University
Department of Electronic and Information Engineering
EIE3123 Dynamic Electronic Systems / EIE3105 Integrated Project
Joint Laboratory Exercise (Lab 6) Report: The Dynamic Control of a Robot Car
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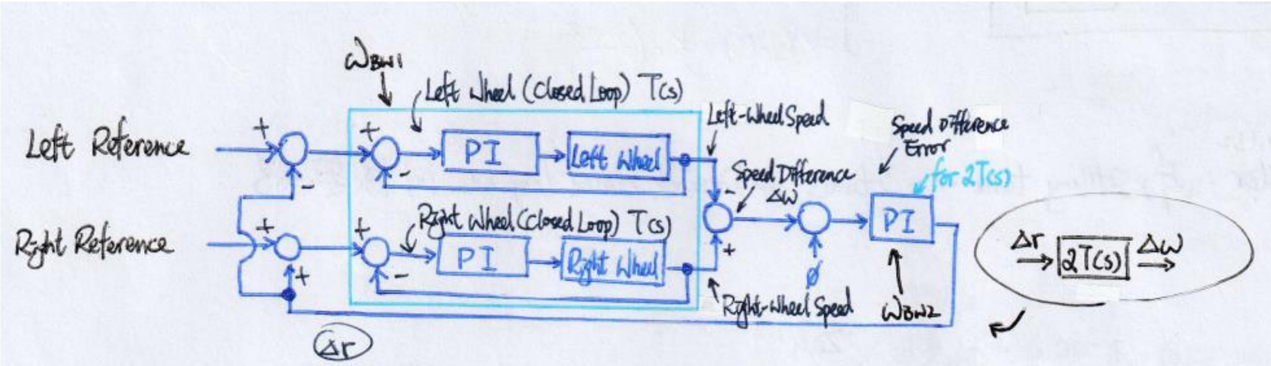
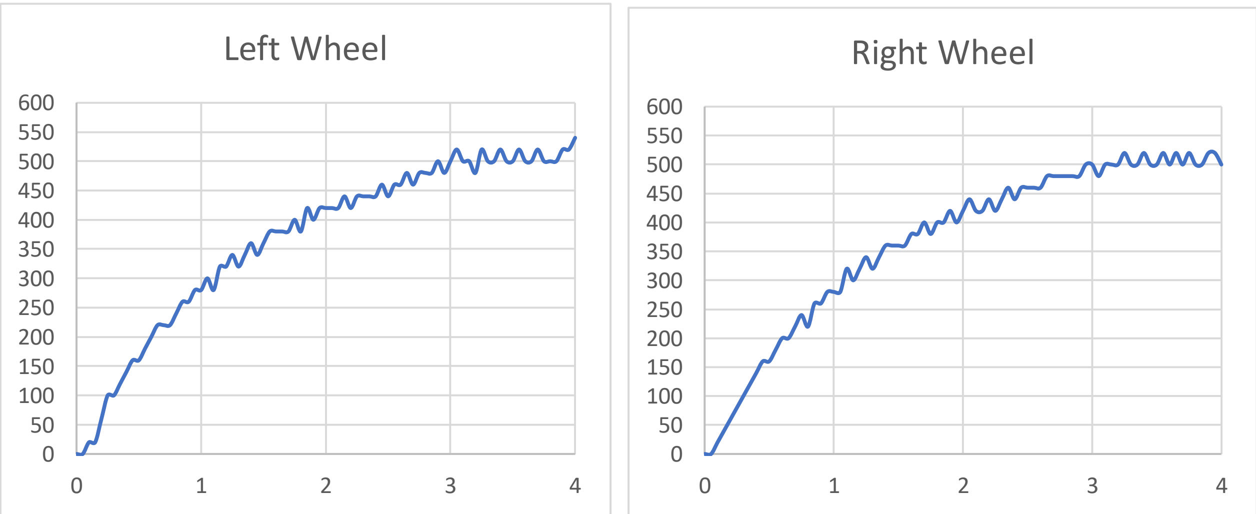
In this joint lab exercise, it is required to design a dynamic control system for controlling the robot car moving in a straight line.



For designing the plant in the system, the PWM values of two wheels are set to be 20500 at first. Getting the counting values of two wheels and plotting the graph (Figure 2), it is found that in steady state, the final value (c_{final}) of function c(t) is 510 counts per second. As 63% of final value at t is equal to one time constant, t = 1.2s when it reaches 320 counts per second (510 × 0.63 = 321.3 counts). Exponential frequency = $a = \frac{1}{\tau} = \frac{1}{1.5} = 0.8333$ rad/s. It is given that the maximum PWM values of two wheels are 44999. The first-order transfer function can be derived: $G(s) = c_{final} \times \frac{a}{s+a} \times \frac{1}{44999} = 510(\frac{0.8333}{s+0.8333})(\frac{1}{44999})$.

Figure 2. Two wheels' counts (each 50ms) per minute – time graph with PWM value 20500. They have the same c_{final}, the transfer function for left and right wheels are the same.



There is enough phase margin. However, DC gain is not infinite without an integrator in the system. In order to increase low-frequency gain, adding a prior integrator to have nearly zero static state error. From figure 3, with -20dB/decade, it reaches -58.913dB at 8.2913 rad/s (set to be the desired 0-dB frequency).

Set 8.2913 rad/s to be the desired 0-dB frequency. High frequency gain = $58.913\ dB = 20\,log_{10} K_P$. Therefore, $K_P = 882.3685$.
$K_I/K_P = z = 0.8333$. Therefore, $K_I = 735.3071$.

PI controller: $G_c(s) = K_P + \frac{K_I}{s} = K_P\left(\frac{S+K_I/K_P}{s}\right) = 882.3685\left(\frac{S+0.8333}{s}\right)$

Given that sampling time should be 0.0025s. $G_c(z) = \frac{900.8z-864}{z-1} = \frac{D(z)}{E(z)}$.

$$D(z)(z-1) = 900.8z \times E(z) - 864E(z) \rightarrow D(z)\left(1-\frac{1}{z}\right) = 900.8E(z) - \frac{864}{z}E(z)$$

$$D[k] = D[k-1] + 729.2\ \ e[k] - 728\ \ e[k-1]$$

Figure 3. Bode plot for G(s) and G(s)×G_c(s). The blue line represents G(s) – the uncompensated system; orange line represents the compensated system, which has infinite DC gain with 0-dB frequency 6.6667 rad/s.

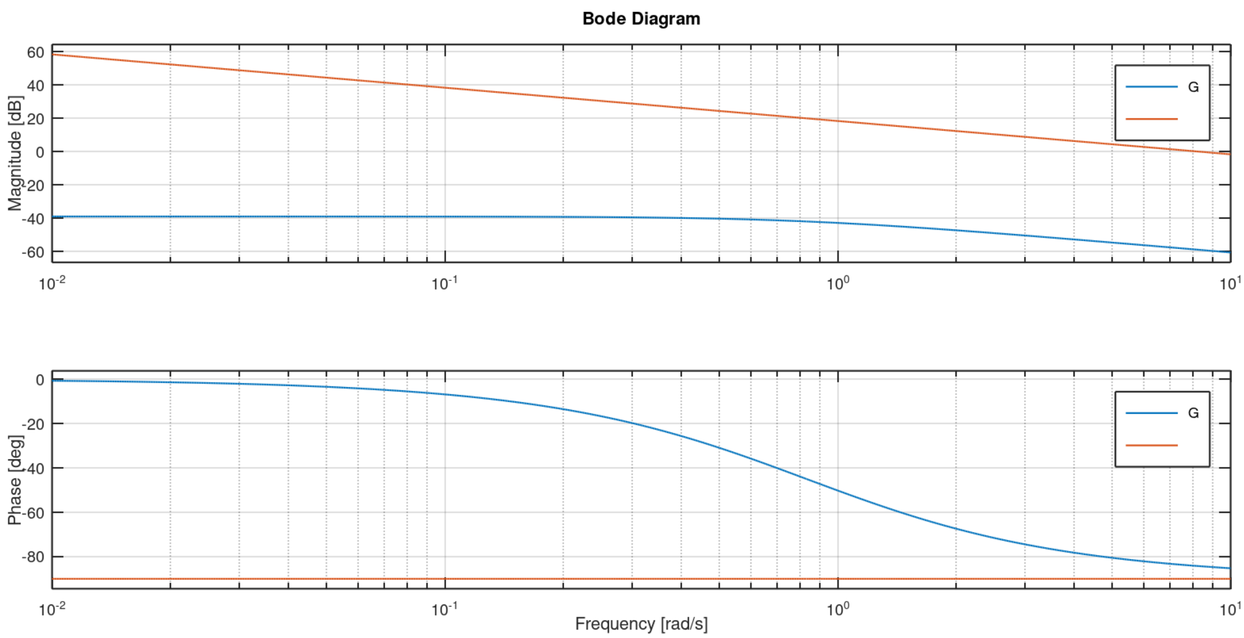
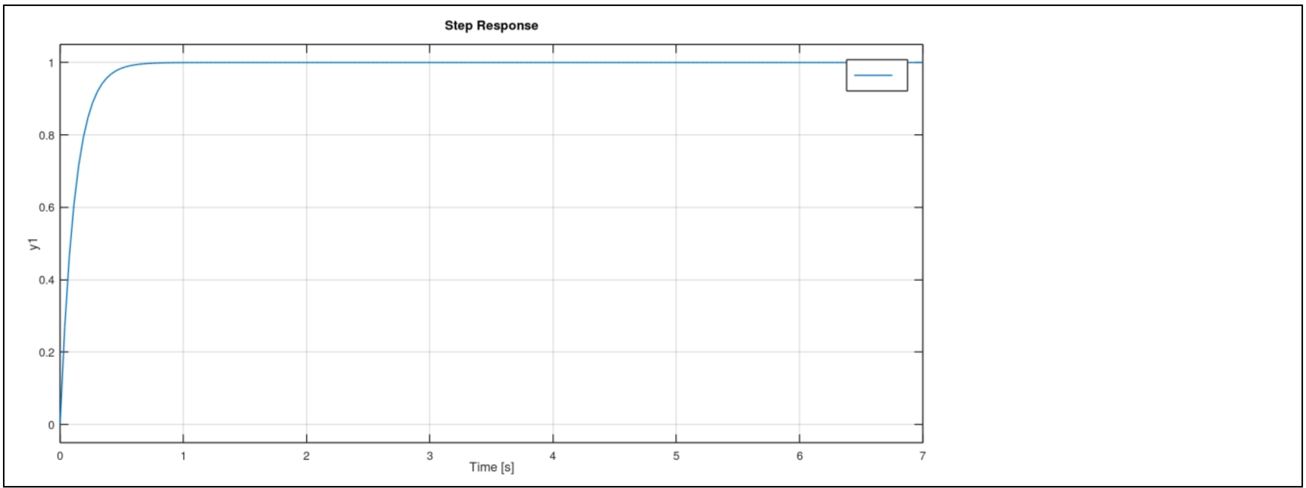


Figure 4. The graph which is showing the step response of T(s). It is critically damped and without overshoot. >> step (feedback(G*Gc,1)); grid on;



It comes to the part of dealing with the speed difference between left and right wheels. One more PI controller is needed for the system, to modify the reference speed of two wheels.

Left wheel: $\Delta\omega_{LEFT} = -\Delta r T(s)$; right wheel: $\Delta\omega_{RIGHT} = \Delta r T(s)$

$\Delta\omega = \Delta\omega_{RIGHT} - \Delta\omega_{LEFT} = 2\Delta r T(s) \rightarrow \frac{\Delta\omega}{\Delta r} = 2T(s)$

From figure 5, it is found that the 0-dB frequency (ω_{BW1}) for 2×T(s) is 14.434 rad/s. As $\omega_{BW1} >> \omega_{BW2}$ (0-dB frequency of PI controller in outer loop), assume ω_{BW2} is smaller than ω_{BW1} around 10 times. When frequency is equal to 1.4434 rad/s, the gain is 5.8922 dB.

Again, DC gain is not infinite without an integrator in the system. This time, it is going to set 1.4434 rad/s as the new 0-dB frequency.

$-5.8922\ dB = 20\,log_{10} K_P$. Therefore, $K_P = 0.5074$.

$K_I/K_P = 1.4434$. Therefore, $K_I = 0.7324$.

PI controller: $G_{c\_out}(s) = K_P + \frac{K_I}{s} = K_P\left(\frac{S+K_I/K_P}{s}\right) = 0.5882\left(\frac{S+1.4434}{s}\right)$

Given that sampling time should be 0.0025s. $G_{c\_out}(z) = \frac{0.5257z - 0.4891}{z-1} = \frac{D(z)}{E(z)}$.

$D[k] = D[k-1] + 0.5257\ e[k] - 0.4891\ e[k-1]$.

Figure 5. Bode plot for 2×T(s) and 2×T(s)×$G_{c\_out}(s)$. The blue line represents 2×T(s) – the uncompensated system; orange line represents the compensated system, which has infinite DC gain with 0-dB frequency 1.4434 rad/s.

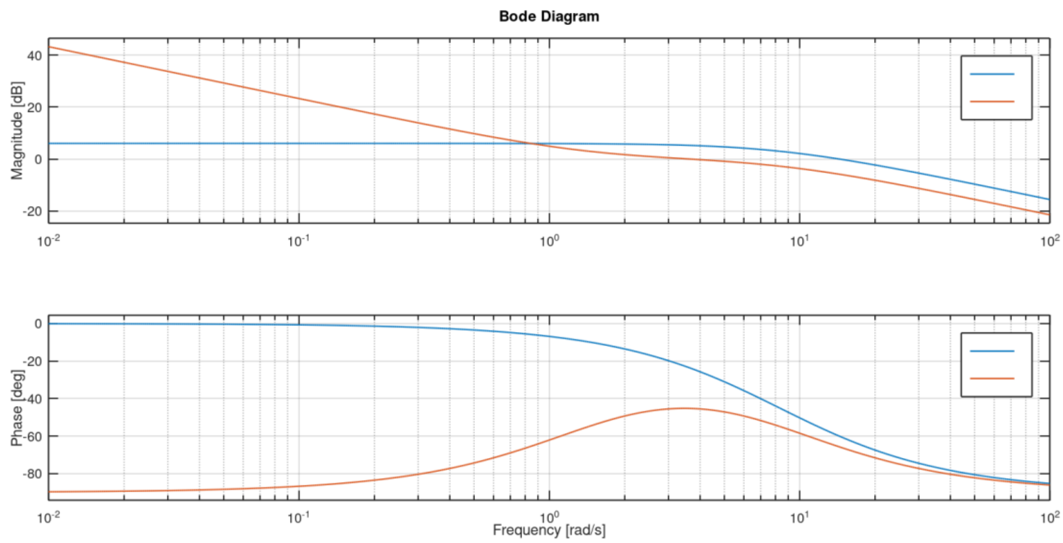


Figure 6. The graph which is showing the step response of 2×T(s)×G_{c_out}(s). It is critically damped and without overshoot.

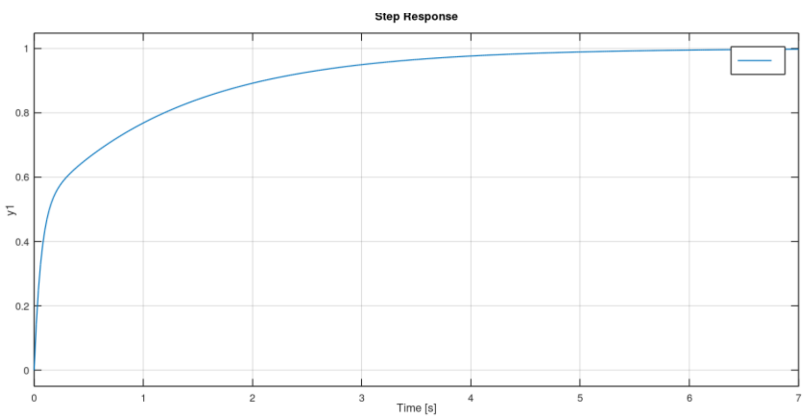
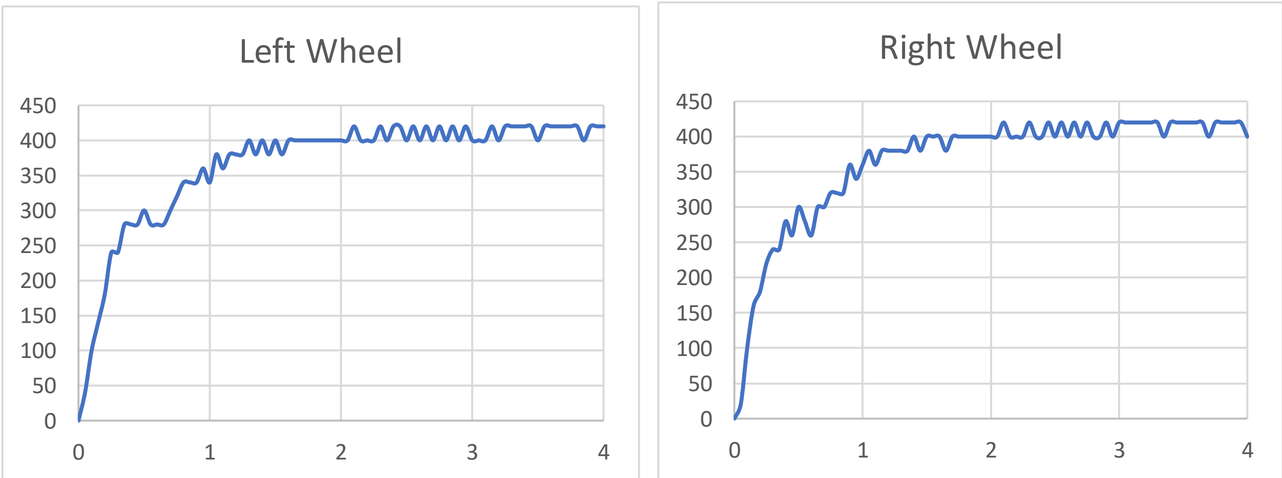


Figure 7. Two wheels' counts (each 50ms) per minute – time graph after designed the dynamic system. Total counts in 4 seconds: 1478 (left wheel) and 1473 (right wheel). Therefore, they traveled a same distance approximately.



The designed dynamic control system has proportional control and integral control.
Proportional control is mainly used for minimizing the effect of overshooting and inconsistent angular velocity of two wheels. Applying the correction (proportional gain kp) to the plant in the system, the angular velocity will tend to be corrected to the desired value.

With proportional control: Error = target value – encoder reading PWM = kp × Error

There are still some errors after having proportional control. From lecture notes, integral control is to minimize the steady-state tracking error and the steady-state output response to disturbances. Integral is the sum of all previous errors.

With integral control: Error = target value – encoder reading Integral = Integral + Error PWM = ki × Integral + kp × Error

Based on these concepts to finish the software part, after designing the dynamic control system. It is required to alter the codes in control.cpp. The robot car is set to move more than 2 meters in straight line and stop after 4 second. The real-time speed of the car is used for calculating the actual differences in speed of those two wheels. In last procedure, proportional gain (kp) and integral gain (ki) in three PI controllers based on experimental observations has been derived: kp and ki for left and right wheel are 900.8 and 864, for speed difference are 0.5257 and 0.4891, respectively.

The robot car can successfully accomplish the goal. There are some difficulties in the implementation. First one is related to the hardware problems. When the system was still uncompensated, it was difficult to observe the steady state and sometimes extreme data may exist (>5 counts per 2.5ms). Therefore, the gearbox and motor has replaced by new one.

Second is about the sampling, if the ground is not flat enough or with different frictional force, this may affect the performance of robot and the calculation process later. I have prevented these undesirable situations and tested few more times.