1. (a)

(b) Since the robot is modeled as a linear system, and the controller is also linear, the system from reference position to control input is linear. Hence, a 5 times larger reference step will yield a 5 times larger control input. According to figure 1b, the maximum control was 0.1 for a reference step of magnitude 1 cm, so now the maximum will be 0.5.

3. The relation between the poles of the continuous time system and the discretized system is given by the map \( \lambda \mapsto e^{T_s \lambda} \), where \( \lambda \) a pole of the continuous time system. Hence, if we assume that the continuous time poles satisfy \( \text{Im}(T_s \lambda) < \pi \), the relation can be reversed. Here, the discrete time poles are the roots of the denominator polynomial \( z^2 - 1.98 z + 0.98 \), that is \( \{1.0, 0.98\} \), which corresponds to continuous time poles in \( \left\{ \frac{1}{T_s} \ln(1.0), \frac{1}{T_s} \ln(0.98) \right\} = \{0.0, -0.22\} \).

4. (a) The closed loop discrete time system has the transfer function

\[
H_c(z) = \frac{0.00993 z + 0.00987}{z^2 - 1.98 z + 0.98 + K (0.00993 z + 0.00987)} = \frac{0.00993 z + 0.00987}{z^2 + (0.00993 K - 1.98) z + 0.00987 K + 0.98}
\]

The poles of this system are \(-\frac{1}{2}(0.00993 K - 1.98) \pm \sqrt{\frac{1}{4}(0.00993 K - 1.98)^2 - (0.00987 K + 0.98)}\). For \( K = 100 \), this evaluates to 0.494 ± 1.31i, clearly outside the unit circle. That is, the closed loop system is not stable for \( K = 100 \).

(b)


6. The main advantage is that stationary errors can be eliminated, but the drawback is that the closed loop system may become more oscillatory, and possibly also unstable.

7.

8. (a) The closed loop system is given by \( G_c(s) = \frac{K}{s+1+K} \). Thus the pole is \( s = -1 - K < 0 \) for all \( K > 0 \), and hence the closed loop system is stable for all \( K > 0 \).

(b) The sampled system is \( H(z) = \frac{0.3935}{z-0.6065} \). The closed loop discrete system is \( H_c(z) = \frac{0.3935K}{z-0.6065+0.3935K} \). The pole is \( z = 0.6065 - 0.3935K \) and \( |0.6065 - 0.3935K| < 1 \Rightarrow K < 4.08 \).

9. Transfer function \( G_1 \) is the only with an integration, and only one of the step responses match this; \( G_1 \)–A. All remaining transfer functions but \( G_4 \) has static gain 1, hence \( G_4 \)–B. The transfer functions \( G_2 \) and \( G_3 \) have two coinciding real poles, and will hence have step responses without overshoot. By relating the speed of the step responses to the magnitude of the poles, it is found that \( G_2 \)–C and \( G_3 \)–D. The remaining pair is \( G_5 \)–E, which is reasonable since the pair of complex conjugated poles in \( G_5 \) explains the oscillations in the step response. In summary: \( G_1 \)–A, \( G_2 \)–C, \( G_3 \)–D, \( G_4 \)–B, \( G_5 \)–E.