**Academic Year 2023-2024**

**Exam 2 – Part II - Maximum duration: 3 hours**

**Problem 1 [5 points]**

A dynamic system is described by the following transfer function:

1. Calculate an internal description (state space) of the system represented by . Assuming that no sensors are available to measure the states (only the values of the system input and output are known), design a control system that allows the states to be regulated to the origin (reference equal to zero and without disturbances) by imposing a closed-loop dynamics characterised by two equal real poles at and an observation error dynamics characterised by two equal real poles at . Verify that the system is controllable and observable and draw the complete block diagram including the control and state observer with the highest possible degree of definition (using integrator blocks to represent the relationship between the states and their derivatives). You must also indicate the equations that provide the evolution of the estimated states and the control signal (write the equation for each estimated state). **[1.5 points]**
2. Using root locus analysis and analytical methods, propose the simplest possible controller (with the fewest parameters) that stabilises the closed-loop system from a certain value of and:
   1. The closed loop has two real poles equal to . **[0.5 points]**
   2. Setting the zero(s) and/or pole(s) of the controller proposed in the previous section, indicate the value of the controller gain at which the closed loop is stabilised, as well as the natural oscillation frequency. **[0.5 points]**
   3. Using the same control structure as in the previous sections, calculate the controller parameters that provide a closed-loop system with two complex conjugate poles with an undamped natural frequency of 10 rad/s and whose real part is halfway between the origin of the s-plane and the most dominant zero/pole of the proposed controller. Indicate the expected overshoot value and peak time and whether any additional elements need to be added to the control loop. At what frequency does the sensitivity function of the closed-loop system become greater than or equal to 1? Draw the approximate modulus of the sensitivity function on the attached semi-logarithmic paper. What implications does this have for the rejection of disturbances at the plant input? **[1 point]**

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1. Analyse the stability of the closed-loop system in section 2.b (including the controller and leaving free) using Nyquist's stability criterion and indicating the values of with which a stable, marginally stable and unstable closed loop is achieved. **[0.75 points]**
2. Perform the calculations analytically or using semi-logarithmic diagrams. For the system equivalent to the previous one but with minimum phase given by design:
   1. A proportional controller that achieves a steady-state error at a parabolic reference of 0.1. What are the phase margin and gain margin of the system? **[0.35 points]**
   2. A controller that achieves a steady-state error to reference ramp of 0.1, a phase margin of 60º (and a gain cutoff frequency greater than 5 rad/s). What overshoot is expected with this controller? **[0.4 points]**

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**Formulas of interest:**