UNIVERSITÄT DUISBURG-ESSEN
Fakultät für Ingenieurwissenschaften, Abt. Maschinenbau und Verfahrenstechnik
Lehrstuhl Steuerung, Regelung und Systemdynamik
(System Dynamics) July 19^{th}, 2013

Reading-up-time

For reviewing purposes of the problem statements, there is a "reading-up-time" of **10 minutes** prior to the official examination time. During this period it is **not** allowed to start solving the problems. This means explicitly that during the entire "reading-up-time" no writing utensils, e.g. pen, pencil, etc. at all are allowed to be kept on the table. Furthermore the use of carried documents, e.g. books, (electronic) translater, (electronic) dictionaries, etc. is strictly forbidden. When the supervisor refers to the end of the "reading-up-time" and thus the beginning of the official examination time, you are allowed to take your utensils and documents. Please **then**, begin with filling in the **complete** information on the titlepage and on page 3.

Good Luck!

LAST NAME	
FIRST NAME	
MATRIKEL-NO.	
TABLE-NO.	

Klausurunterlagen

Ich versichere hiermit, dass ich sämtliche für die Durchführung der Klausur vorgesehenen Unterlagen erhalten, und dass ich meine Arbeit ohne fremde Hilfe und ohne Verwendung unerlaubter Hilfsmittel und sonstiger unlauterer Mittel angefertigt habe. Ich weiß, dass ein Bekanntwerden solcher Umstände auch nachträglich zum Ausschluss von der Prüfung führt. Ich versichere weiter, dass ich sämtliche mir überlassenen Arbeitsunterlagen sowie meine Lösung vollständig zurück gegeben habe. Die Abgabe meiner Arbeit wurde in der Teilnehmerliste von Aufsichtsführenden schriftlich vermerkt.

THE ABOVE REQUIRED STATEMENTS AS WELL AS THE SIGNATURE ARE MANDATORY AT THE BEGINNING OF THE EXAM.

Duisburg, ______________ (Date)   ________________________________ (Student's signature)

Falls Klausurunterlagen vorzeitig abgegeben: ______________Uhr

Bewertungstabelle

Aufgabe 1	
Aufgabe 2	
Gesamtpunktzahl	
Angepasste Punktzahl	
%	
Bewertung gem. PO in Ziffern	

(Datum und Unterschrift 1. Prüfer, Univ.-Prof. Dr.-Ing. Dirk Söffker)

(Datum und Unterschrift 2. Prüfer, Dr.-Ing. Yan Liu)

(Datum und Unterschrift des für die Prüfung verantwortlichen Prüfers, Söffker)

Fachnote gemäß Prüfungsordnung:

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
1,0	1,3	1,7	2,0	2,3	2,7	3,0	3,3	3,7	4,0	5,0
sehr gut		gut			befriedigend			ausreichend		mangelhaft

Bemerkung: ______________________________

Attention: Give your answers to ALL problems directly below the questions in the exam question sheet.

You are NOT allowed to use a pencil and also NOT red color (red color is used for corrections).

This exam is taken by me as a
☐ mandatory (Pflichtfach)
☐ elective (Wahlfach)
☐ prerequsite (Auflage)
subject (cross ONE option according to your own situation).

Maximum achievable points:	**70**
Minimum points for the grade 1,0:	**95%**
Minimum points for the grade 4,0:	**50%**

General hints:

1) For the multiple-choice and multiple-choice-similar tasks the following rules are effective:
   i) For correct answers of exam task parts the desired number of points will be given.
   ii) For noncorrect answers of exam task parts the desired number of points will be counted negative.
   iii) No answering will neither lead to positive nor to negative points.
   iv) The points of the task will be summarized. The whole number can not be smaller than zero.

2) If in the exam tasks no information is given for the valid range of numbers for time constants or masses etc.: take for time constants (in sec.), for masses (in kg) positive numbers.

3) If in the exam tasks no information is given for applying negative or positive feedback: use the usual negative feedback.

Problem 1 (40 Points)

1a) (2 × 5 × 1 Point, 10 Points)
Which of the following statements are true and which are false?

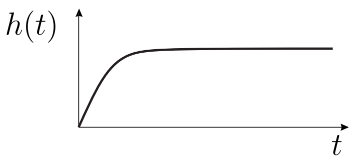
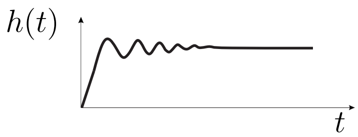
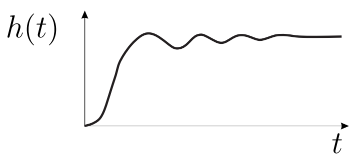
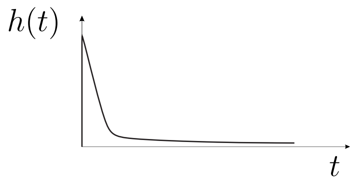
No.	Task/Question/Judgment	True	False
A1)	In linear control technique, SISO-systems have linear transfer behavior. A typical I/O-description is given by the following equation $$y^{(n)} + a_{\text{n-1}}y^{(n-1)} + ... + a_1 y + a_0 = K[u(t) + \frac{1}{T}\int u\, dt + T_{\text{D}}\dot{u}],$$ with dim $y^{(i)} = [n, 1]$.	○	○
A2)	A closed-loop control is capable to manipulate the influence of disturbances. (Note: The output-side disturbances also affects the measurement.)	○	○
A3)	An open loop control can be realized without actuators, a closed loop control must be implemented with actuators.	○	○
A4)	A simple test of the linearity involves a change of an input variable of the system. At a linear system behavior also the output of the system is changing.	○	○
A5)	At the input side of a system, the input variable is $u(t) = a\sin(\omega_o t)$. At the output side $y(t) = b(\sin(\omega_o t + \pi)$ is measured. With a change to $u_2(t) = a^2\sin(\omega_o t)$ on the output side $y_2(t) = ab(\sin(\omega_o t + \frac{\pi}{2}))$ is obtained. The system is linear.	○	○

| □

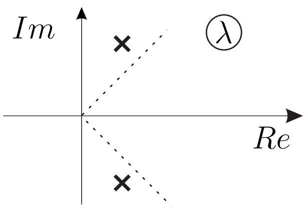
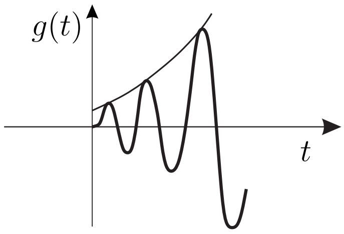
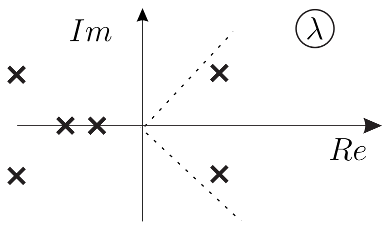
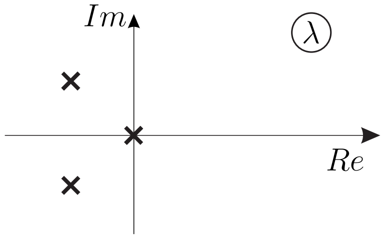
B1)	The control elements described generally by systems of second order $$\frac{1}{\omega_0^2}\ddot{y} + \frac{2D}{\omega_0}\dot{y} + y = K[u + \frac{1}{T_{\text{I}}}\int u\, dt + T_{\text{D}}\dot{u}],$$ have a double real eigenvalue for D = 1.	○	○
B2)	For $D > 1$ in the above described I/O-relationship (1a)B1), visible oscillation are not present.	○	○
B3)	For $D > 1$ the system described in 1a)B1 has two different eigenvalues without imaginary part.	○	○
B4)	For $D > -\frac{\sqrt{2}}{2}$ the system described in 1a)B1 can has unstable behavior.	○	○

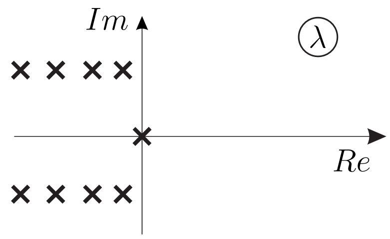
No.	Task/Question/Judgment	True	False
B5)	A system described by $$\frac{1}{\omega_0^2}\ddot{y} + y = KT_D\dot{u}$$ shows for $u(t) = \delta(t)$ the behavior of $y(t) = g(t) = sin(\omega_o t + \varphi)$.	○	○

1b) (4 × 0.5 Points, 2 Points)

No.	Task/Question/Judgment	True	False
	The following step responses are belonging to linear systems of first order.		
1)		○	○
2)		○	○
3)		○	○
4)		○	○

1c) (6 × 0.5 Points, 3 Points)

No.	Task/Question/Judgment	True	False
1)	A system with the eigenvalue distribution  can show the following behavior. 	○	○
2)	The SISO-system with the eigenvalue distribution  has 2 conjugate complex eigenvalues.	○	○
3)	The system with the eigenvalue distribution  is boundary stable.	○	○

No.	Task/Question/Judgment	True	False
4)	The system with the eigenvalue distribution  is asymptotically stable.	○	○
5)	The step response behavior of linear systems can practically be calculated using a measured weighting function.	○	○
6)	MIMO-systems are always stable.	○	○

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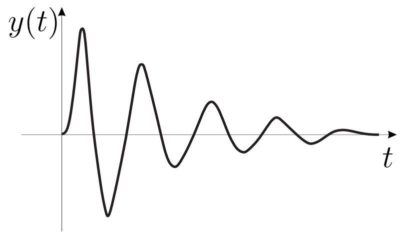
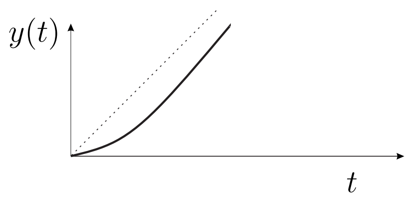
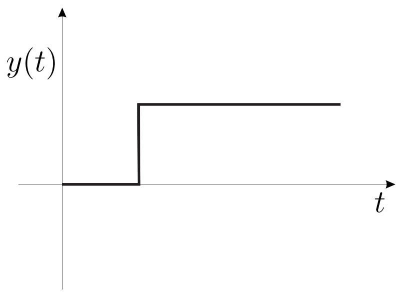
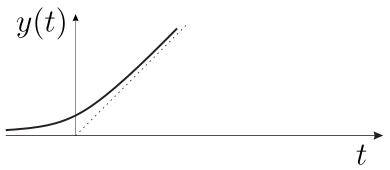
1d) (4 × 0.5 Points, 2 Points)

No.	Task/Question/Judgment	True	False
	Depending on the parameters K, T_I, and T_t the transfer system described by $$y = K[u(t - T_\mathrm{t}) + \frac{1}{T_\mathrm{I}} \int u(t - T_\mathrm{t})\, dt] \qquad \text{with } K,\ T_\mathrm{I}, \text{ and } T_\mathrm{t} > 0$$ can show the following output behaviors.		
1)		○	○
2)		○	○
3)		○	○
4)		○	○

1e) (4 × 1 Point, 4 Points)

No.	Task/Question/Judgment	True	False
1)	The transfer behavior of a transfer element is $$P\dddot{y} + D\ddot{y} + T_3\dot{y} = u(t).$$ It describes a PDT_3-System.	○	○
2)	The differential equation $$a_1 x_\mathrm{a}(t) + a_2 \int x_\mathrm{a}(t)dt = b_1 \int\int x_\mathrm{e}(t)dtdt + b_2 \int x_\mathrm{e}(t)dt$$ with $x_\mathrm{a}(t=0) = 0$, $x_\mathrm{e}(t=0) = 0$ describes the dynamic behavior of an analyzed system with output value $x_\mathrm{a}(t)$ and input value $x_\mathrm{e}(t)$. It is a PIT_1-System.	○	○
3)	The considered system is described by $$\begin{bmatrix}\dot{x_1}\\ \dot{x_2}\end{bmatrix} = \begin{bmatrix}0 & 1\\ a & b\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}0\\ 1\end{bmatrix}u.$$ It is a PT_2-System.	○	○
4)	A controller $u = -Kx_1$ is used for feedback of the system in the task 1e)3). Is the controlled system behavior with $K > 4$ and $a = 4$, $b = -3$ asymptotically stable?	○	○

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1f) (3 × 5 × 1 Point, 15 Points)
The eigenvalues of the I/O-behavior from four different linear systems without time delay are illustrated in figure 1.1. The measured step response functions $h(t)$ of the systems are shown in figure 1.2. Evaluate the statements in the following tables.

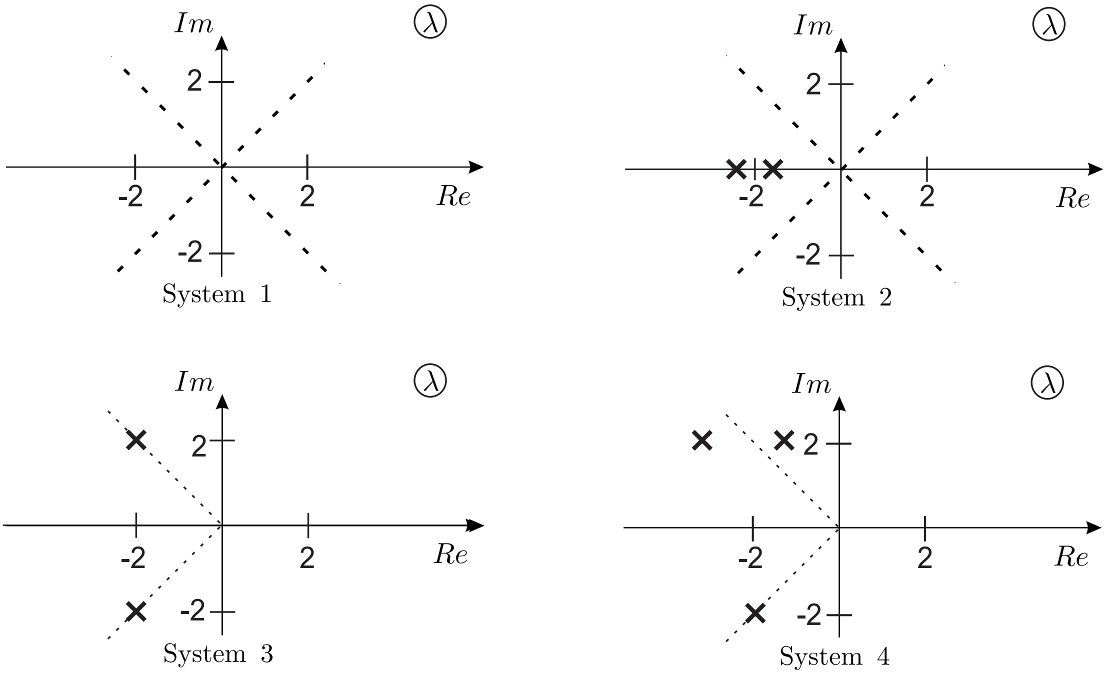

Figure 1.1: Eigenvalue distribution of four different systems

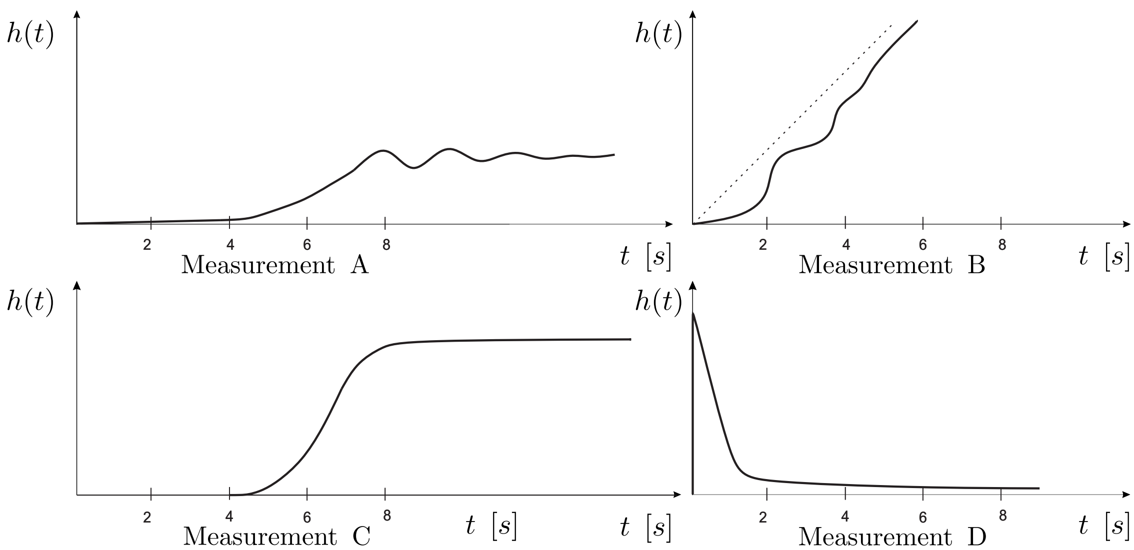

Figure 1.2: Step response functions

No.	Task/Question/Judgment	True	False
A1)	Measurement B shows a damping behavior with $D > 1$.	◯	◯
A2)	Measurement A shows time delay behavior.	◯	◯
A3)	Measurement C shows time delay behavior.	◯	◯
A4)	Measurement D shows, that the corresponding system has no dynamics (in terms of delays, inertia).	◯	◯
A5)	Measurement B could correspond to the behavior of a $\mathrm{PIT_2T_t}$-System with $\mathrm{T_t} > 0$.	◯	◯

| ☐

B1)	System 1 can be described by $y = Ku.$	◯	◯
B2)	System 4 can not be described with an equation expressing useful technical relations.	◯	◯
B3)	System 3 corresponds to a system with a damping $D < 1$.	◯	◯
B4)	Systems 2 and 3 obviously show an identical damping.	◯	◯
B5)	System 1 is stable in the sense of Ljapunov.	◯	◯

| ☐

C1)	Measurement D corresponds to system 4.	◯	◯
C2)	Measurement B corresponds to system 3.	◯	◯
C3)	Measurement A corresponds to system 3.	◯	◯
C4)	Connecting a time delay system in series before system 2, measurement C can be obtained.	◯	◯
C5)	Connecting a time delay system in series after system 2, measurement C can be obtained.	◯	◯

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1c) (4 Points)

The following step response function is given.

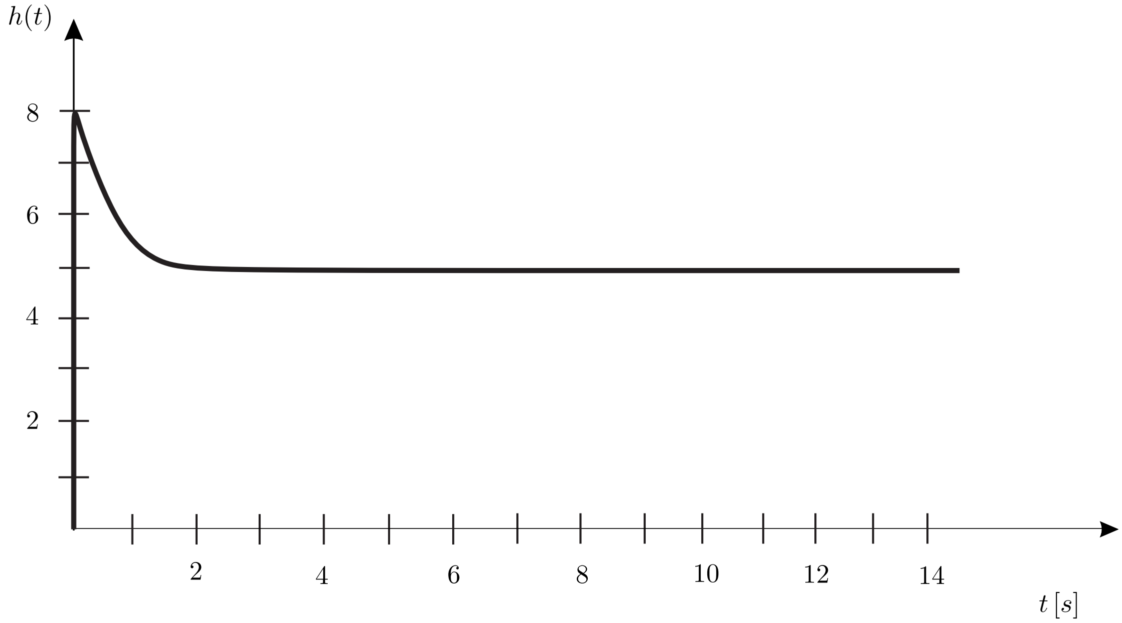


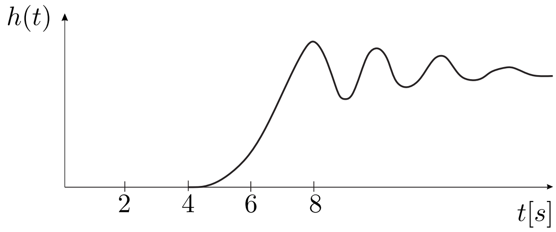
Figure 1.3: Step response behavior

- Give the system behavior of the system by setting the corresponding equation.
- Classify the behavior.

$\sum$

Problem 2 (30 Points)

2a) (3 × 1 Point, 3 Points)
Which of the following statements are true and which are false?

No.	Task/Question/Judgment	True	False
1)	From the description of the state behavior given by $$x(t) = \phi(t)x_0(t=0) + \int_{t=0}^{t} \phi(t-\tau)bu(\tau)d\tau,$$ the time response of the output $y(t)$ can be determined exactly as $y(t) = Cx(t)$ with known C.	○	○
2)	The system described by $$A = \begin{bmatrix} 0 & 1 \\ -k & -d \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}, \quad C = \begin{bmatrix} 0 & 1 \end{bmatrix}, \quad \text{and} \quad D = 0$$ is identical to the I/O-description $$\ddot{y} + d\dot{y} + ky = u,$$ where $\dot{y}$ is measured.	○	○
3)	The system with  can be classified as PT_2-system.	○	○

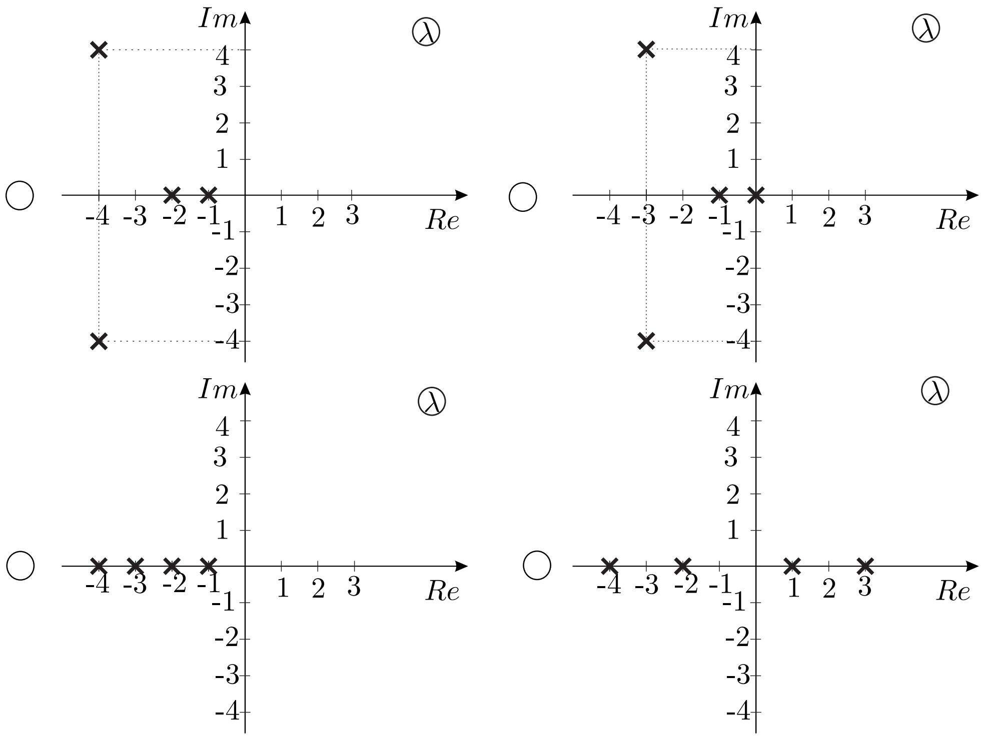
|☐

2b) (2 Points)

The I/O-transmittance behavior

$$\ddddot{y} + 2\dddot{y} - 13\ddot{y} - 14\dot{y} + 24y = u$$

has the following eigenvalue distribution.



Shows the system oscillations? State reason(s) for your answer.

2c) (5 × 1 Point, 5 Points)

The measurement of the step response behavior of a novel actuator is given in the figure below.

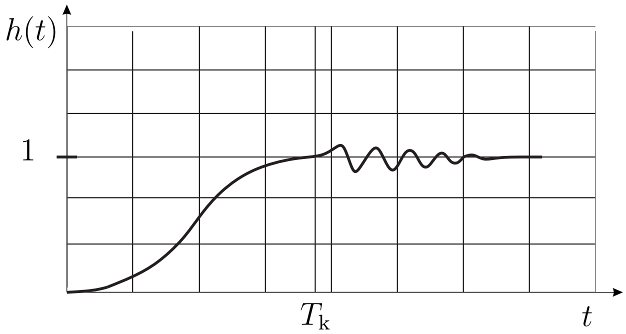


Figure 2.1: Step response behavior

What can be concluded from the figure or gives the background, respectively?

No.	Task/Question/Judgment	True	False
A1)	It is definitively a nonlinear system.	○	○
A2)	It is a stable system behavior (BIBO = Bounded-Input Bounded-Output).	○	○
A3)	Until the point in time $t = T_k$, the behavior can be classified as a PT_2-system behavior.	○	○
A4)	There is a time delay in the system response.	○	○
A5)	From measured transition behaviors of linear systems the linearity can easily be derived in practice.	○	○

| ☐

2d) (7 Points)

An inventor presents the block diagram of a novel controller with four transfer elements, given in Figure 2.2. The input is denoted as y and the output as u.

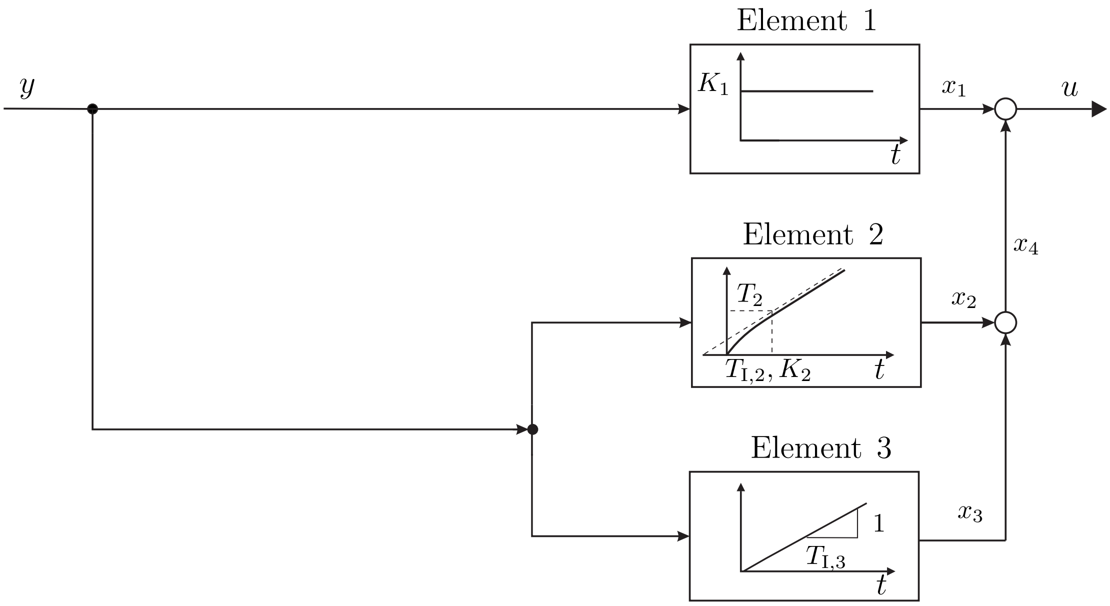


Figure 2.2: Block diagram of a novel controller type

i) (5 Points)
Give the type of the individual transfer behavior for element 1 to 3 and the corresponding differential equation in the given variables. Determine the whole transmittance behavior from $y \rightarrow u$. If a classification is possible, classify the resulting behavior with respect to the usual type of $\mathrm{PIDT_nT_t}$-behavior. Is it a novel controller?

ii) (2 Points)

The system shown in figure 2.2 describes in terms of its behavior a specific behavior. Assume $T_2 = 0$.

Assuming you want to improve the dynamics of the system for small values. Which addition of the controller do you suggest in case of a parallel or serial transmittance behavior?

Draw the improved block diagram for the new transfer element.

2e) (3 Points)
During a control loop measurement at the stability bound, the following values, shown in figure 2.3, are measured. The gain of the controller was observed as $K = 1.2$.

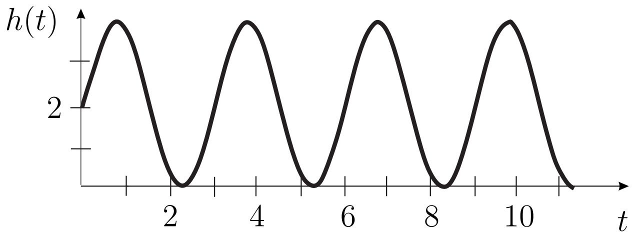


Figure 2.3: Measurement

Calculate the parameters K, T_I, and T_D of a PID-controller, similar to the ITAE-optimization.

2f) (9 × 1 Point, 9 Points)
The block diagram of a system of transfer elements is given (see Figure 2.4). Answer the following questions related to the mentioned system:

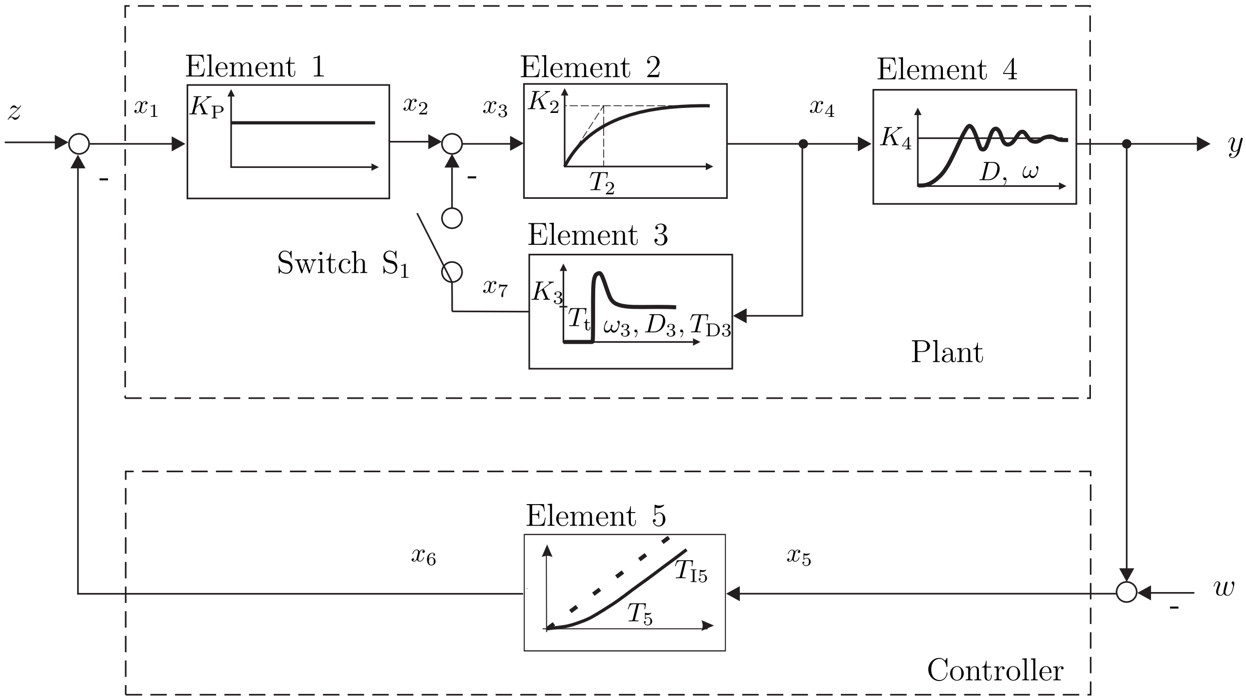


Figure 2.4: Block diagram

No.	Task/Question/Judgment	True	False
1)	Element 5 is a system with proportional behavior.	○	○
2)	Element 3 is a PDT_1T_t-System.	○	○
3)	The system behavior from x_2 to x_4 contains at closed switch S_1 no time delay.	○	○
4)	Assuming the switch S_1 is open: In the stationary state the gain of the transmittance behavior of x_1 to y is $\tilde{K} = K_P \cdot K_2 \cdot K_4$.	○	○
5)	Element 5 shows for $t \to \infty$ the behavior of $x_6 \to \infty$.	○	○
6)	Depending on the parameters (K_2, T_2), element 2 can show unstable behavior $(K_2, T_2 > 0)$.	○	○
7)	Assuming the system behavior from $x_1 \to y$ can be described by a proportional behavior: The given choice of the element 5 is suitable for stationary precise control of the system.	○	○
8)	Element 4 shows a behavior that is not corresponding to the linear theory due to its transfer behavior.	○	○
9)	The Ziegler-Nichols approach can be applied for a setting of the controller (element 5).	○	○

| ☐

2g) (1 Point)

For precise and safe landing of aircrafts, pilots can be supported by assistance systems. The system shown in figure 2.5 helps by displaying a so-called "tunnel in the sky" into the field of view of the pilot, to achieve the ideal flight path for the landing. The optimal (and required) manually performed landing can be achieved when the aircraft is within this tunnel during the final landing approach.

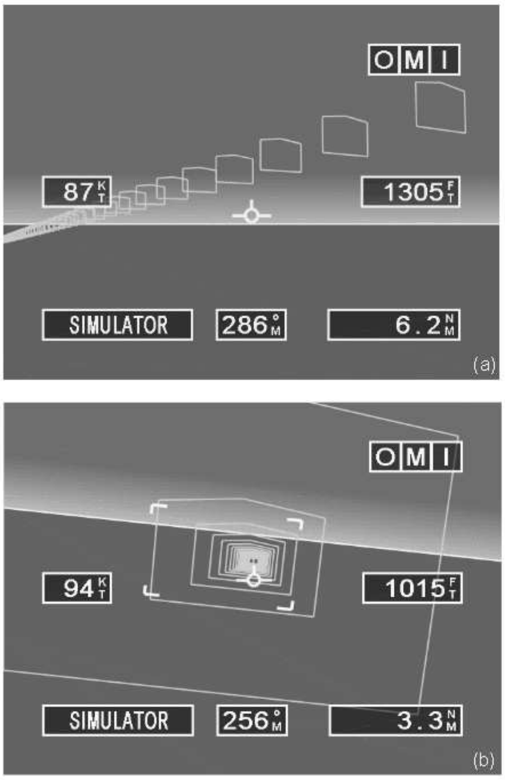


Figure 2.5: Top: Airplane on intercept to final landing approach, Bottom: Airplane on final approach inside tunnel (Reference: Operational Experience with and Improvements to a Tunnel-in-the-Sky Display for Light Aircraft (Barrows, Alter, Enge, Parkinson and Powell), Department of Aeronautics and Astronautics Stanford University (1997))

No.	Task/Question/Judgment	True	False
A1)	The human-machine system shown in figure 2.5 defines a closed loop control system.	○	○

□

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