

**CATATAN KULIAH
(*CLASSNOTES*)**

**PERANCANGAN SISTEM
KENDALI
(*Control Systems Design*)**

Rhiza S. Sadjad

2016

RENCANA PEMBELAJARAN

NAMA MATAKULIAH : **PERANCANGAN SISTEM KENDALI**
KODE MATAKULIAH : **402D432 (Tahun IV, Semester Awal, 2 SKS, TK)**
DOSEN-DOSEN : 1. Prof.Dr.Ir. H. Andani Ahmad, MT
2. Dr. Ir. H. Rhiza S. Sadjad, MSEE

1. DAFTAR PUSTAKA:

1. **Friedland**, Bernard, "*Control System Design*", McGraw-Hill Book Company, NY
2. **Ogata**, Katsuhiko, "*Modern Control Engineering*", Prentice Hall of India, New Delhi, atau terjemahannya (jilid 2) terbitan Penerbit Erlangga, Jakarta.

2. TUJUAN:

Penyajian matakuliah laboratorium (*project course*) ini bertujuan memberi kesempatan kepada mahasiswa Program Studi Teknik Elektro – khususnya yang berminat mengambil konsentrasi Teknik Komputer, Kendali dan Elektronika (TK) – untuk mempelajari kiat-kiat perancangan suatu sistem kendali dalam skala laboratorium.

3. SILABUS SINGKAT:

Konsep umum perancangan sistem kendali, pemodelan kendalian, verifikasi model kendalian, perancangan pengendali, Proyek 1: Rangkaian RLC (kendalian linier, stabil), Proyek 2: Pipa U (kendalian linier, tak stabil) Proyek 3: Sistem Suspensi (kendalian linier, tak stabil), Proyek 4: Sistem Pengatur Suhu Ruang (kendalian tak linier, *quasi-stable*), Proyek 5: Pendulum Terbalik (kendalian tak linier, tak stabil).

4. KOMPETENSI UTAMA:

1. Menguasai dasar-dasar teori kendali, baik yang klasik mau pun modern, serta aplikasinya dalam analisis dan perancangan sistem kendali
2. Mampu memakai paket-paket perangkat lunak komputer untuk pemodelan dan simulasi masalah-masalah Teknik Elektro khususnya dan masalah rekayasa pada umumnya

5. KOMPETENSI PENDUKUNG:

1. Mampu berwirausaha/bekerja sendiri/bekerja-sama dalam bidang Teknik Elektro.
2. Mampu menggunakan bahasa-bahasa pemrograman yang umum digunakan dalam dunia enjiniring

6. LAINNYA:

Memiliki jiwa kepemimpinan, peneliti dan entrepreneur serta mampu bersaing

7. PEKANAN:

Pembelajaran di Kelas dan Laboratorium

Pekan ke	Topik	Sub-topik
1	PENGANTAR	Penjelasan kegiatan pembelajaran
2	Langkah-langkah Desain Sistem Kendali	● Pemodelan Kendalian dan Verifikasi
3		● Stabilisasi dan Perbaikan Tanggapan
		● Perancangan Pengendali
4	PROYEK 1: Verifikasi Model Simulink	● Model Kendalian RLC dengan Simulink/MATLAB:
5		● Verifikasi Model
6	PROYEK 2: Pipa U	Model Kendalian Pipa U (linier, tak stabil):
7		- Pengendali Pegas
8		- Simulasi dengan Simulink
9	PROYEK 3: Sistem Suspensi Kendaraan	Model Kendalian Sistem Suspensi Kendaraan (linier, tak stabil), <i>Spring-Mass-Damper System</i>
10		- Pengendali <i>Shock Breaker</i>
11		- Simulasi dengan Simulink
	PROYEK 4: Pengaturan Suhu Ruang	Model Pengaturan Suhu Ruang (tak linier, quasi-stabil):
12		● Penurunan Model Matematik
13		● Pengukuran kendalian di laboratorium
		● Simulasi model kendalian
14		● Aplikasi pengendali PID
	PROYEK 5: Pendulum Terbalik	Model Pendulum Terbalik (tak linier, tak stabil):
15		● Penurunan Model Matematik
		● Pengukuran kendalian di laboratorium
		● Simulasi model kendalian
16		● Aplikasi pengendali dengan Umpan Balik Keadaan

Perancangan SISTEM KENDALI 2014

Project Course → TIRAK ADA UJIAN!

- * Cari partner!
- * Akses MATLAB minimal Matlab 7

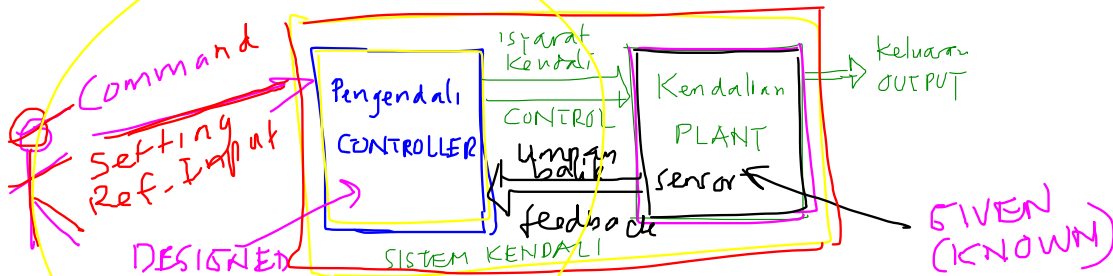
Setiap pekan mulai ba'da Asar hr SENIN

PBT301 atau 302 yang ada LED-nya, atau di LSKI.

Referensi Course Website:

<http://www.unhas.ac.id/rhiza/arsip/kuliah/>

Perancangan sistem Kendali



Merancang Sistem Kendali
(Control System Design)

- merancang CONTROLLER yang menghasilkan isyarat kendali (CONTROL) sehingga suatu Kendali (PLANT) yang diberikan menghasilkan keluaran (OUTPUT) yang diinginkan

- * Sistem Kendali OPTIMAL
- * Sistem Kendali ADAPTIF
- * Sistem Kendali CERDAS

* Sistem Kendali PROSES → Process Plant

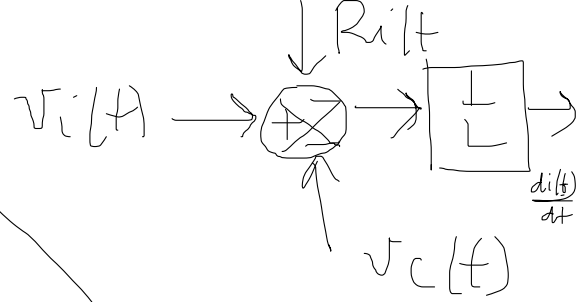
* Sistem Kendali KOKOH (Robust)

* dll.

next, VERIFIKASI SIMULINK
project 3

$$\frac{di(t)}{dt} = \frac{1}{L} (v_o(t) - v_c(t) - Ri(t))$$

$$\frac{dv_c(t)}{dt} = \frac{1}{C} i(t)$$



* SIMULINK

Hukum Ohm:

$$v_i(t) - v_c(t) = Ri(t) + L \frac{di(t)}{dt}$$

$$i(t) = \frac{1}{C} \frac{dv_c(t)}{dt}$$

$$\int \frac{di(t)}{dt} dt = \int di(t) = i(t)$$

$$\int \frac{dv_c(t)}{dt} dt = \int dv_c(t) = v_c(t)$$

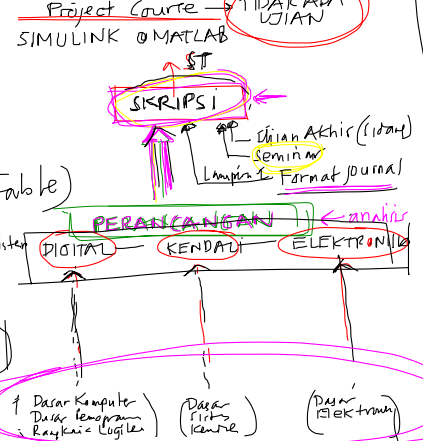
$$V_c(s) = \frac{V}{s(LCs^2 + RCs + 1)}$$

$$v_c(t) = \mathcal{L}^{-1} \left\{ \frac{V}{s(LCs^2 + RCs + 1)} \right\}$$

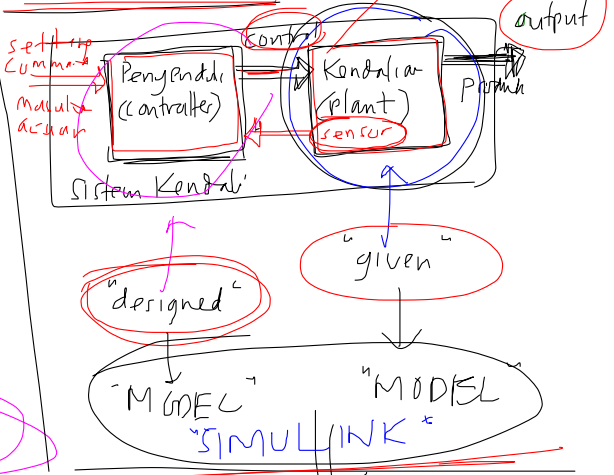
$$I_c(s) = \frac{V_c(s)}{Z_c} = \frac{V}{Ls^2 + RCs + 1}$$

$$i_c(t) = \mathcal{L}^{-1} \{ I_c(s) \}$$

PERANCANGAN SISTEM KENDALI



SISTEM KENDALI



- Persiapan:
- * Mencari MITRA (utk yang ingin bekerja bersama)
 - * Akses MATLAB -> Simulink

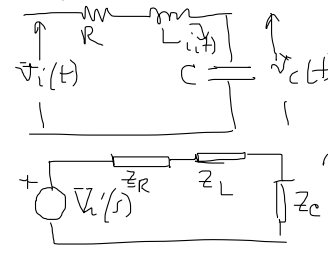
Nanti VERIFIKASI SIMULINK

Project 1 Verifikasi Simulink

toleransi

* ANALITIK

Menggunakan Konsep Impedansi



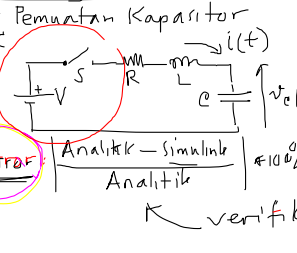
$$I(s) = \frac{V_c(s)}{Z_c} = \frac{V}{Z_R + Z_L + Z_C}$$

$$V_c(s) = \frac{Z_C V(s)}{Z_R + Z_L + Z_C}$$

$$= \frac{V}{R + Ls + \frac{1}{Cs}}$$

$$= \frac{V}{s(LCs^2 + RCs + 1)}$$

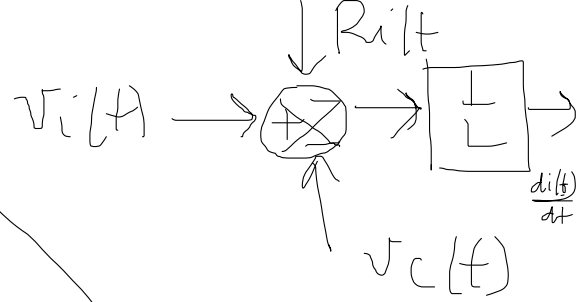
* Rangkaian RLC seri



Saklar S ditutup pada $t=0$, $v_c(0) = 0$. Tentukan $v_c(t)$ dan $i(t)$.
 * ANALITIK -> exact
 * SIMULINK
 Error Analitik - Simulink 100%
 verifikasi

$$\frac{di(t)}{dt} = \frac{1}{L} (v_o(t) - v_c(t) - Ri(t))$$

$$\frac{dv_c(t)}{dt} = \frac{1}{C} i(t)$$



* SIMULINK

Hukum Ohm:

$$v_i(t) - v_c(t) = Ri(t) + L \frac{di(t)}{dt}$$

$$i(t) = \frac{1}{C} \frac{dv_c(t)}{dt}$$

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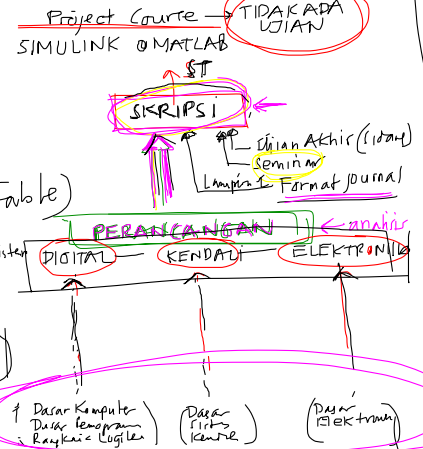
$$V_c(s) = \frac{V}{s(LCs^2 + RCs + 1)}$$

$$v_c(t) = \mathcal{L}^{-1} \left\{ \frac{V}{s(LCs^2 + RCs + 1)} \right\}$$

$$I_c(s) = \frac{V_c(s)}{Z_c} = \frac{V}{Ls^2 + RCs + 1}$$

$$i_c(t) = \mathcal{L}^{-1} \{ I_c(s) \}$$

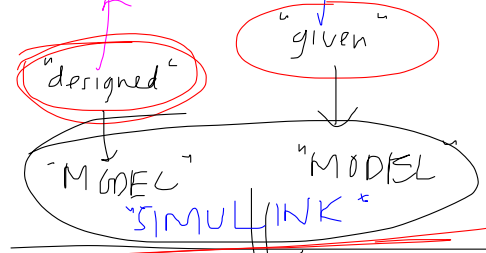
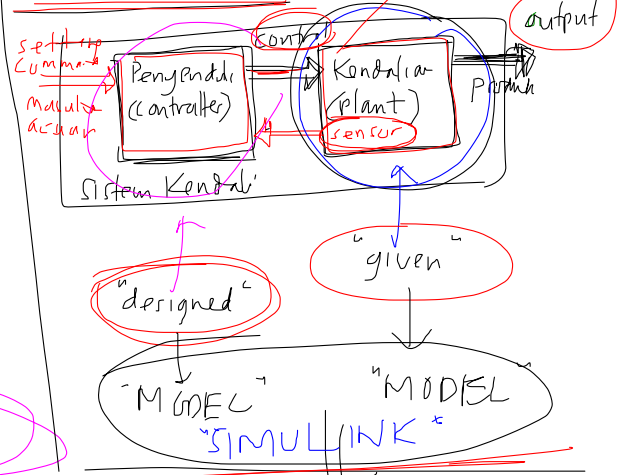
PERANCANGAN SISTEM KENDALI



Periapan: * Mencari MITRA (utk yang ingin bekerja bersama)
* Akses MATLAB → Simulink

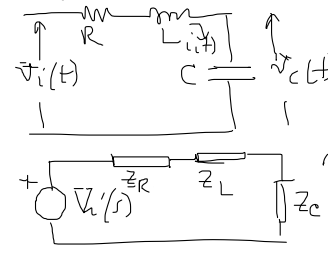
Nerak VERIFIKASI SIMULINK

SISTEM KENDALI



* ANALITIK

Menggunakan Konsep Impedansi



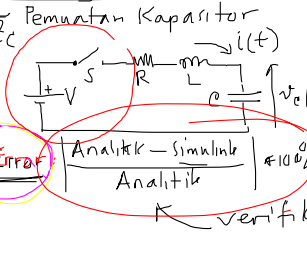
$$Z(s) = \frac{V_c(s)}{I(s)} = \frac{Z_c}{Z_R + Z_L + Z_C}$$

$$V_c(s) = \frac{Z_c V_i(s)}{Z_R + Z_L + Z_C}$$

$$= \frac{Z_c V_i(s)}{R + Ls + \frac{1}{Cs}}$$

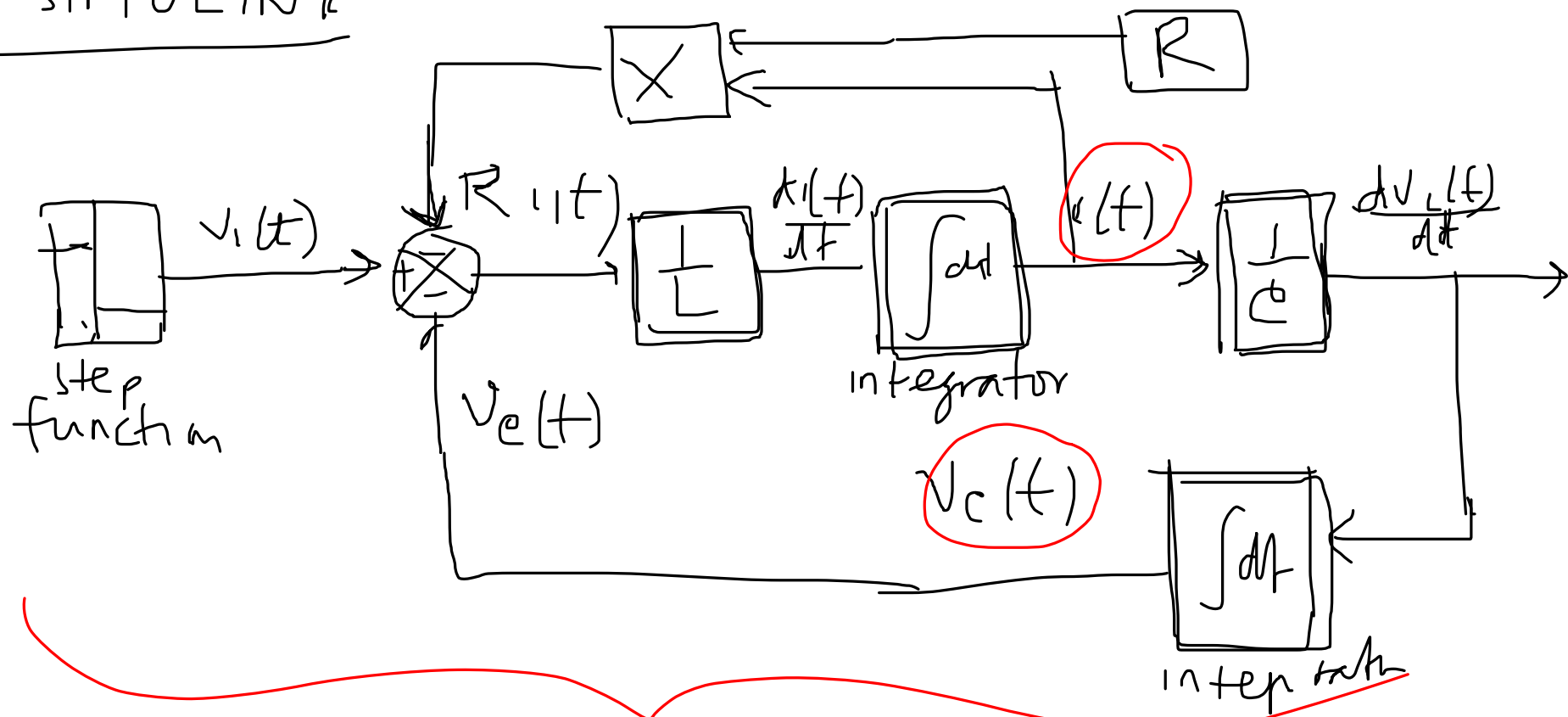
$$= \frac{V_i(s)}{s(LCs^2 + RCs + 1)}$$

* Rangkaian RLC seri

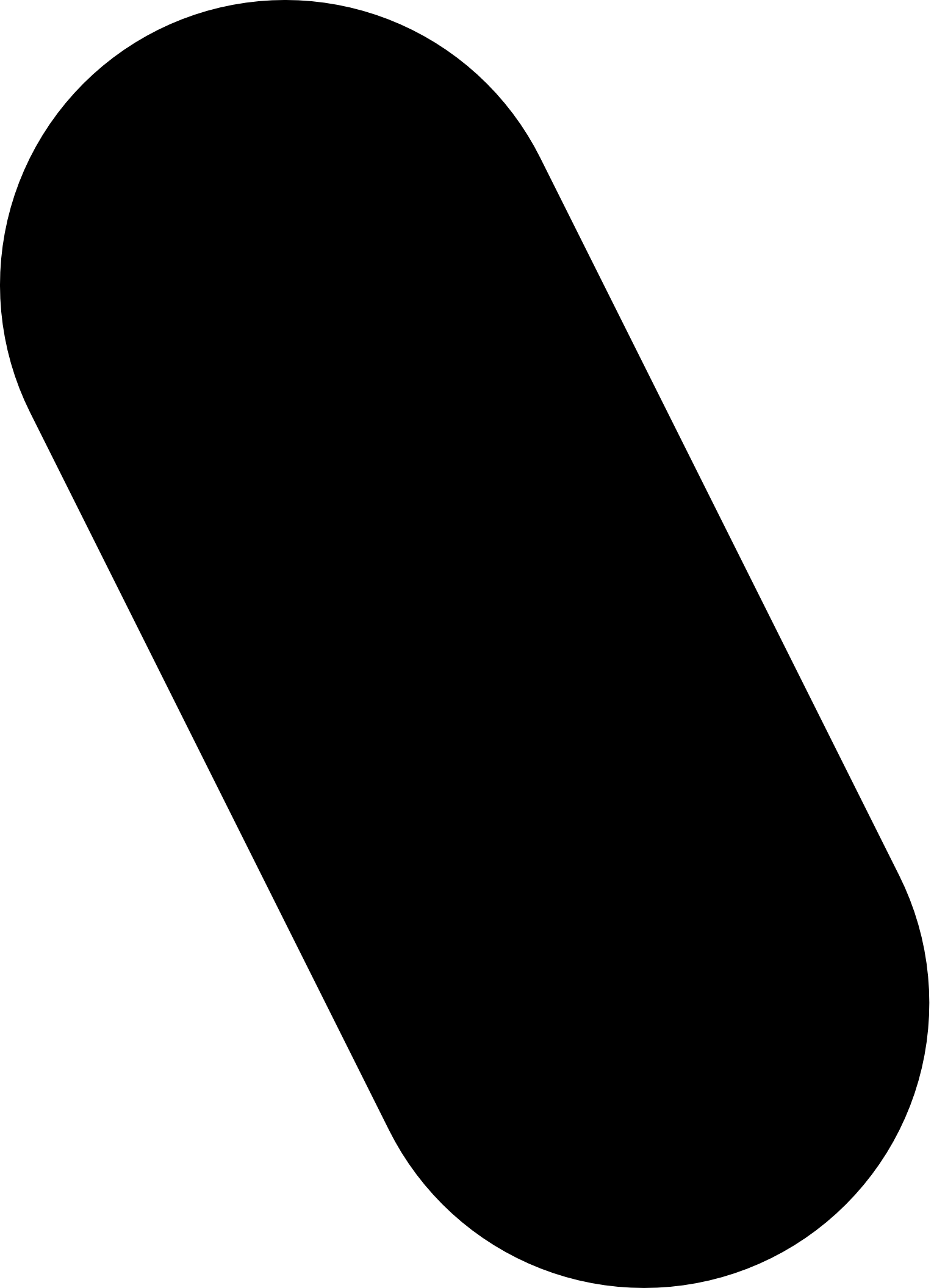


Saklar S ditutup pada $t=0$, $v_c(0) = 0$
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* ANALITIK → exact
* SIMULINK
→ verifikasi

Model SIMULINK

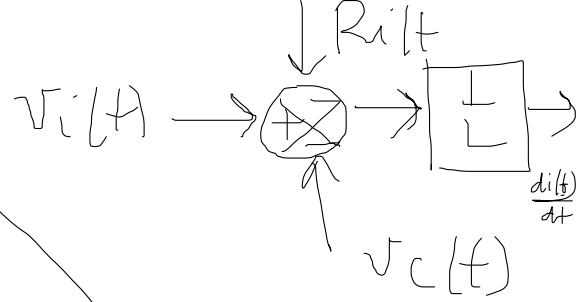


SIMULINK @ MATLAB



$$\frac{di(t)}{dt} = \frac{1}{L} (v_o(t) - v_c(t) - Ri(t))$$

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* SIMULINK

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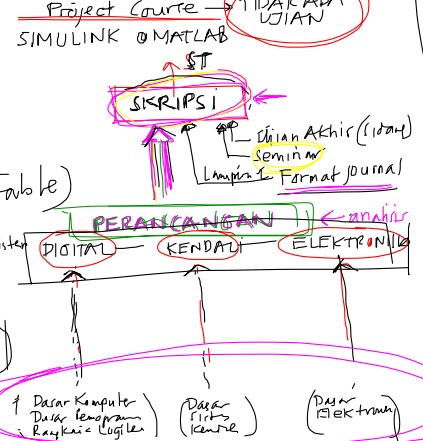
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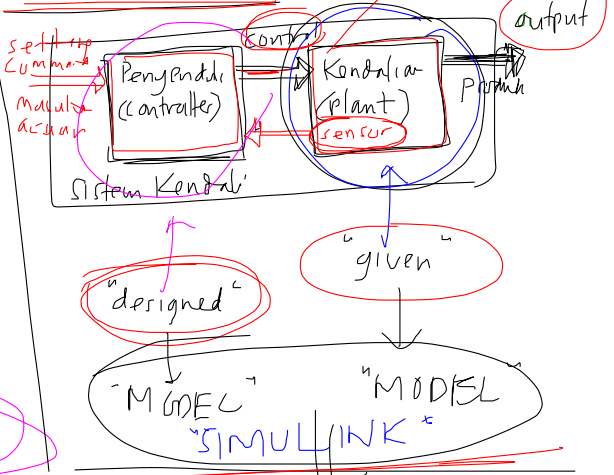
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PERANCANGAN SISTEM KENDALI



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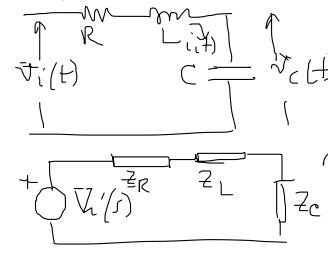
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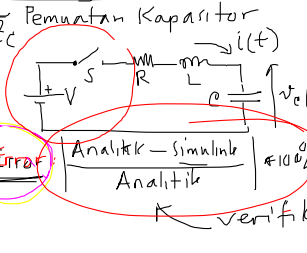


$$I(s) = \frac{V_i(s)}{Z_R + Z_L + Z_C}$$

$$V_c(s) = I(s) \cdot Z_C = \frac{Z_C V_i(s)}{Z_R + Z_L + Z_C}$$

$$= \frac{V}{s(LCs^2 + RCs + 1)}$$

* Rangkaian RLC seri



Saklar S ditutup pada $t=0$, $v_c(0) = 0$. Tentukan $v_c(t)$ dan $i(t)$.

* ANALITIK → exact

* SIMULINK

verifikasi

* Dengan menggunakan spread-sheet,
 * can error untuk 3 (tiga) nilai
 toleransi yang berbeda, 10^{-3} , 10^{-4} , 10^{-5} , ...
 pada simulink

* Carilah solusi
 ANALITIK untuk
 $v_c(t)$ dan $i(t)$

* Perbesar dan
 perkecil nilai

R sehingga
 ada ketiga
 kasus nilai ξ

* $\xi > 1$
 * $\xi = 1$
 * $0 < \xi < 1$

TABEL
 TIDAK
 DIKUMPUL

9 tabel
 PENYAMPAIAN

Tabel Laplace:

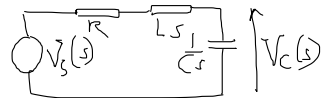
$$v_c(t) \rightarrow \begin{cases} * \xi > 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s(s+a)(s+b)} \\ * \xi = 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s(s+\omega_n)^2} \rightarrow \mathcal{L}^{-1} \frac{K}{s(s+a)^2} \\ * 0 < \xi < 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s(s^2 + 2\xi\omega_n s + \omega_n^2)} \end{cases}$$

Tugas 1 Verifikasi SIMULINK
 * Ambil tgl lahir dan salah seorang
 TT-BB-IGHH $V = 12$ Volt
 $C = 10$ HH $RF = 10$ HH $\times 10^{-6}$ F
 $L = 88$ Henry
 $R = TT$ Ohm

$$i(t) = \mathcal{L}^{-1} I(s) = \mathcal{L}^{-1} \frac{V_c(s)}{Z_c} = \mathcal{L}^{-1} \frac{V/L}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})}$$

$$= \mathcal{L}^{-1} \frac{VL}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \mathcal{L}^{-1} \frac{K}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

$$\begin{cases} \xi > 1 \rightarrow \mathcal{L}^{-1} \frac{K}{(s+a)(s+b)} \\ \xi = 1 \rightarrow \mathcal{L}^{-1} \frac{K}{(s+a)^2} \\ 0 < \xi < 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s^2 + 2\xi\omega_n s + \omega_n^2} \end{cases}$$



$$V_s(s) = \mathcal{L}\{V_u(t)\} = \frac{V}{s}$$

$$V_c(s) = \frac{Z_c}{Z_R + Z_L + Z_C} \cdot V_s(s)$$

$$= \frac{\frac{1}{Cs}}{R + Ls + \frac{1}{Cs}} \cdot \frac{V}{s}$$

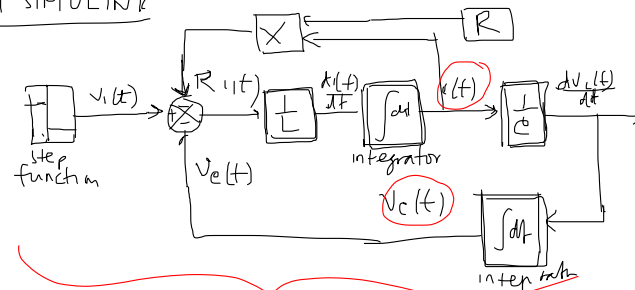
$$= \frac{V}{s(LCs^2 + RCs + 1)}$$

$$= \frac{V/LC}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})}$$

$$v_c(t) \text{ ANALITIK } \begin{cases} = \mathcal{L}^{-1} \frac{V/LC}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})} \\ = \mathcal{L}^{-1} \frac{K}{s(s^2 + 2\xi\omega_n s + \omega_n^2)} \end{cases}$$

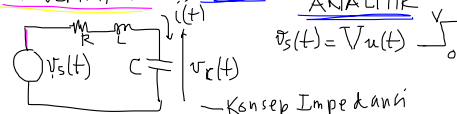
$$\begin{aligned} \omega_n^2 &= \frac{1}{LC} \\ \omega_n &= \frac{1}{\sqrt{LC}} \\ 2\xi\omega_n &= \frac{R}{L} \rightarrow \xi \end{aligned}$$

Model SIMULINK

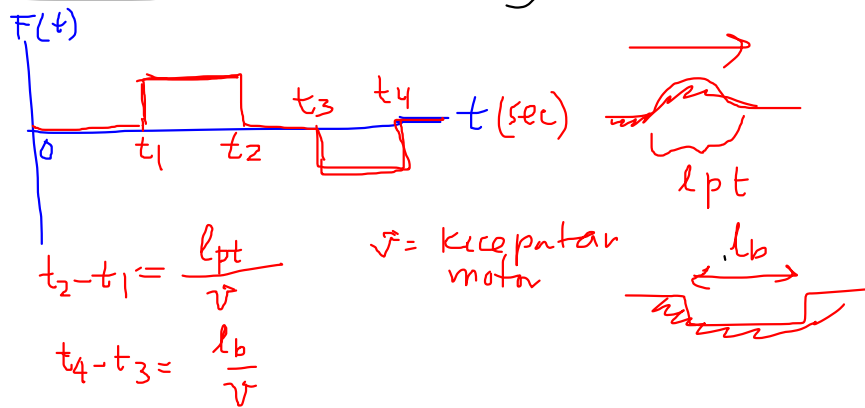


* VALIDASI $\rightarrow$ di LAB

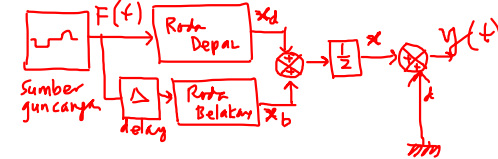
* VERIFIKASI $\rightarrow$ referensi: Hasil perhitungan ANALITIK



Simulasi Gaya guncanya



SISTEM SUSPENSII SEPEDA MOTOR



tanah = permukaan jalan
 $F(t)$ gaya guncanya
 $y(t)$ posisi pengendara terhadap tanah
 d = jarak antara sadel dengan tanah

Δ = delay antara roda depan dan roda belakang

$$\Delta = \frac{l}{v} \text{ [second]}$$



$$v = 5 \text{ km/jam}$$

$$l = 1,2 \text{ m}$$

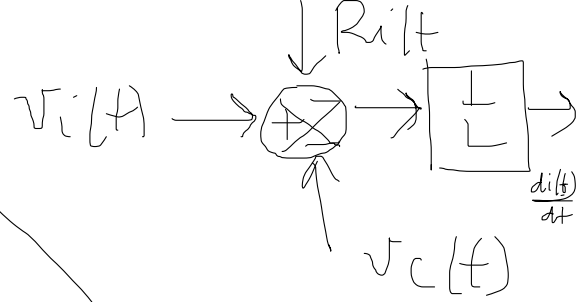
$$\text{Jadi } \Delta = \frac{1,2 \text{ m}}{5000 \text{ m} / 3600 \text{ se}}$$

$$= \frac{4,2 \times 3600}{5000} \text{ se}$$

$$= 0,864 \text{ se}$$

$$\frac{di(t)}{dt} = \frac{1}{L} (v_o(t) - v_c(t) - Ri(t))$$

$$\frac{dv_c(t)}{dt} = \frac{1}{C} i(t)$$



* SIMULINK

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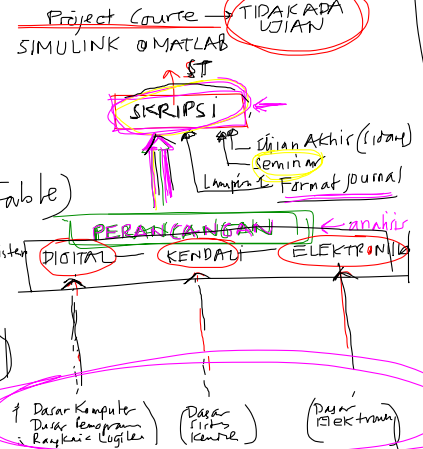
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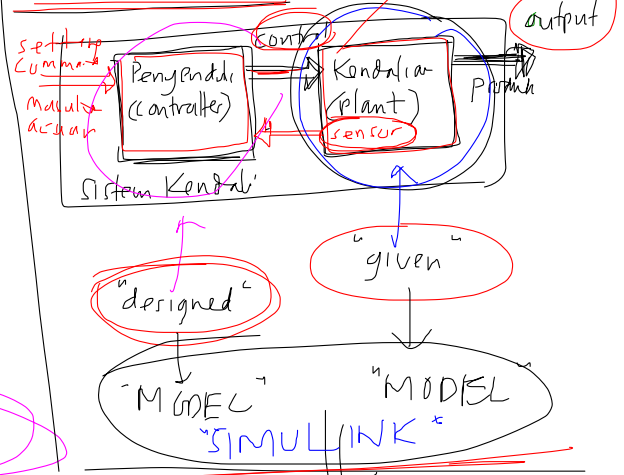
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PERANCANGAN SISTEM KENDALI



SISTEM KENDALI



- Persiapan:
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 - * Akses MATLAB → Simulink

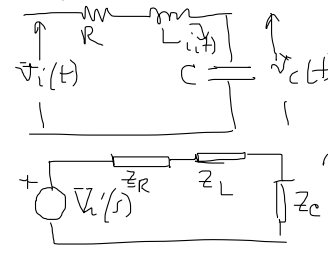
Nanti VERIFIKASI SIMULINK

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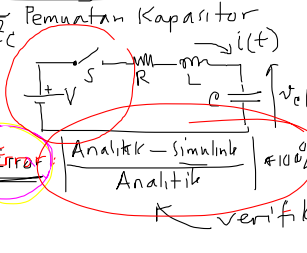
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Saklar S ditutup pada $t=0$, $v_c(0) = 0$. Tentukan $v_c(t)$ dan $i(t)$.

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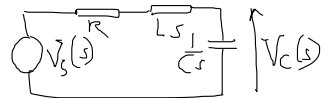
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Tugas 1 Verifikasi SIMULINK
 * Ambil tgl lahir dan salah seorang
 TT-BB-IGHH $V = 12 \text{ Volt}$
 $C = 10 \text{ HH}$ $RF = 10 \text{ HH} \times 10^{-6} \text{ F}$
 $L = 88 \text{ Henry}$
 $R = \text{TT Ohm}$

$$i(t) = \mathcal{L}^{-1} I(s) = \mathcal{L}^{-1} \frac{V_c(s)}{Z_c} = \mathcal{L}^{-1} \frac{V/L}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})}$$

$$= \mathcal{L}^{-1} \frac{VL}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \mathcal{L}^{-1} \frac{K}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

$$\begin{cases} \xi > 1 \rightarrow \mathcal{L}^{-1} \frac{K}{(s+a)(s+b)} \\ \xi = 1 \rightarrow \mathcal{L}^{-1} \frac{K}{(s+a)^2} \\ 0 < \xi < 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s^2 + 2\xi\omega_n s + \omega_n^2} \end{cases}$$



$$V_s(s) = \mathcal{L}\{V_u(t)\} = \frac{V}{s}$$

$$V_c(s) = \frac{Z_c}{Z_R + Z_L + Z_C} \cdot V_s(s)$$

$$= \frac{\frac{1}{Cs}}{R + Ls + \frac{1}{Cs}} \cdot \frac{V}{s}$$

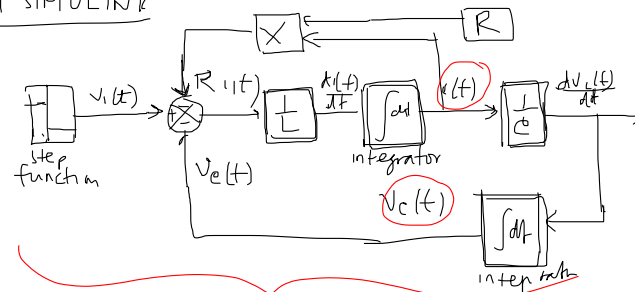
$$= \frac{V}{s(LCs^2 + RCs + 1)}$$

$$= \frac{V/LC}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})}$$

$$V_c(t) \text{ ANALITIK } \begin{cases} = \mathcal{L}^{-1} \frac{V/LC}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})} \\ = \mathcal{L}^{-1} \frac{K}{s(s^2 + 2\xi\omega_n s + \omega_n^2)} \end{cases}$$

$$\begin{aligned} \omega_n^2 &= \frac{1}{LC} \\ \omega_n &= \frac{1}{\sqrt{LC}} \\ 2\xi\omega_n &= \frac{R}{L} \rightarrow \xi \end{aligned}$$

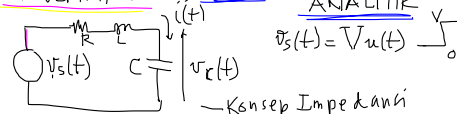
Model SIMULINK



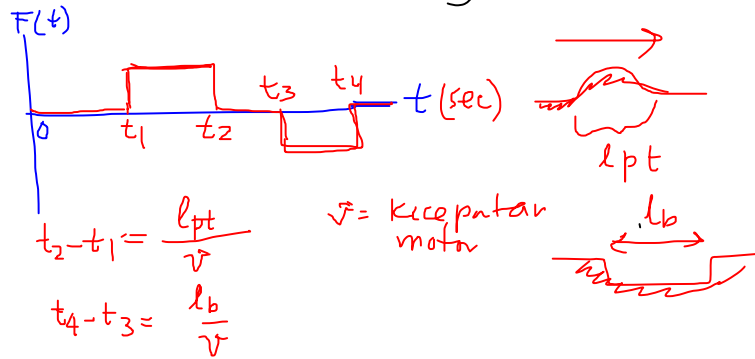
SIMULINK @ MATLAB

* VALIDASI $\rightarrow$ di LAB

* VERIFIKASI $\rightarrow$ referensi: Hasil perhitungan ANALITIK



Simulasi Gaya guncangan

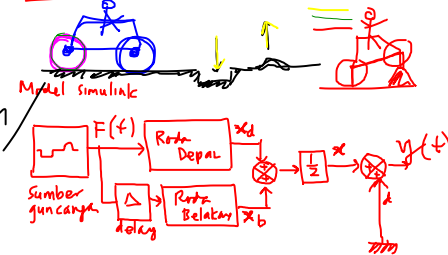


Diunduh dari:

<http://www.unha.ac.id/rhiza/arsip/kuliah/>

cari Perancangan - Sistem - Kontrol

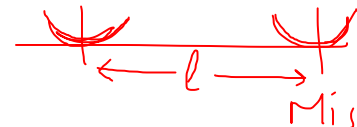
SISTEM SUSPENSI SEPEDA MOTOR



tanah = permukaan jalan
 $F(t)$ gaya guncangan
 $y(t)$ posisi pengendara terhadap tanah
 d = jarak antara sadel dengan tanah

Δ = delay antara roda depan dan roda belakang

$$\Delta = \frac{l}{v} \text{ [second]}$$



Mis, $v = 5 \text{ km/jam}$
 $l = 1,2 \text{ m}$

$$\begin{aligned}
 \text{Jadi } \Delta &= \frac{1,2 \text{ m}}{5000 \text{ m} / 3600 \text{ se}} \\
 &= \frac{1,2 \times 3600}{5000} \text{ se} \\
 &= 0,864 \text{ se}
 \end{aligned}$$

* Project 3 MENARA AIR

Katup + Pelampung (otomatis)

TANGKI

SIMULINK

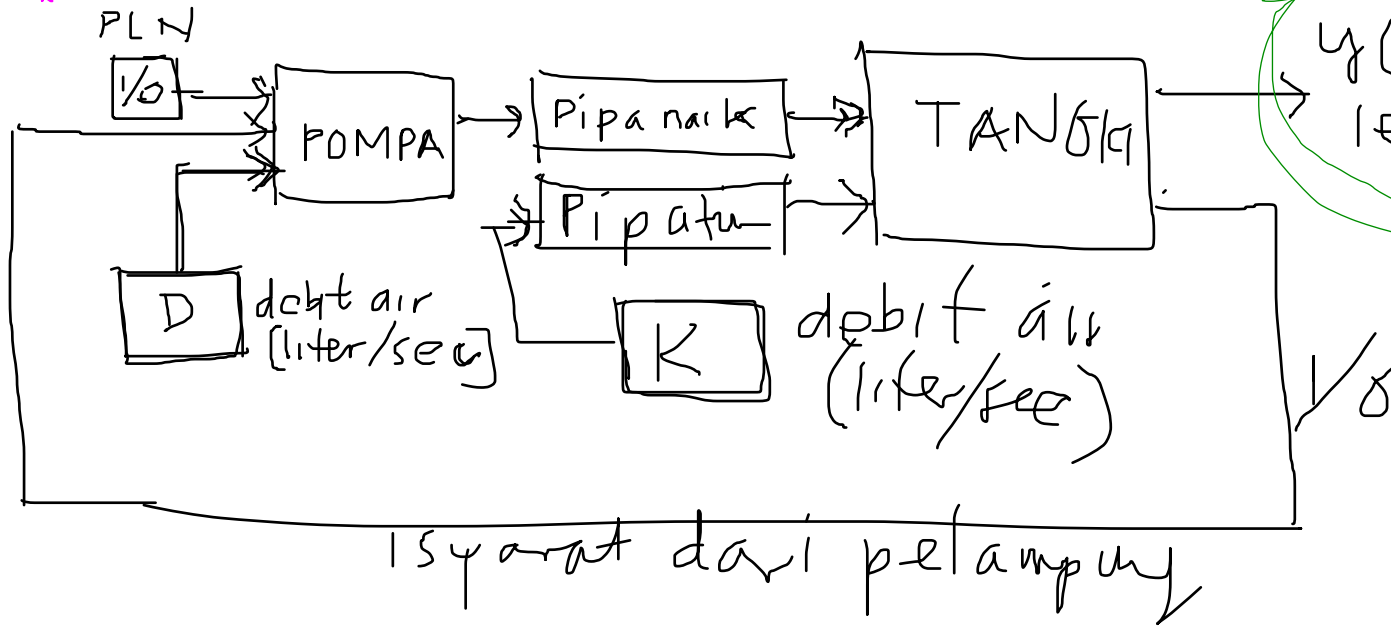
KERAN

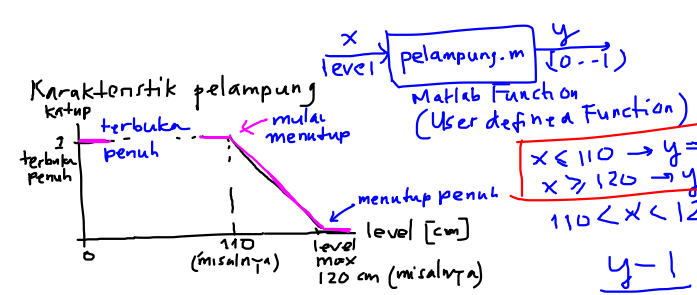
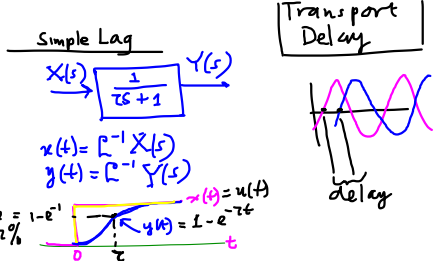
Subsistem

Jika keran dibuka maka air mengalir ke luar dengan debit $K \text{ liter/sec}$

$K \text{ liter/sec}$

$y(t)$
level air





$x \leq 110 \rightarrow y = 1$ terbuka penuh
 $x \geq 120 \rightarrow y = 0$ tertutup penuh
 $110 < x < 120$

$$\frac{y-1}{0-1} = \frac{x-110}{120-110}$$

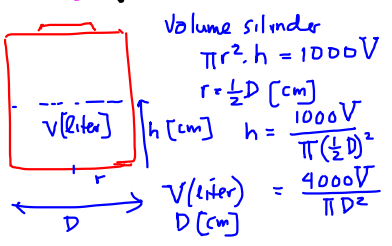
$$10(y-1) = -x + 110$$

$$y-1 = -0.1x + 11$$

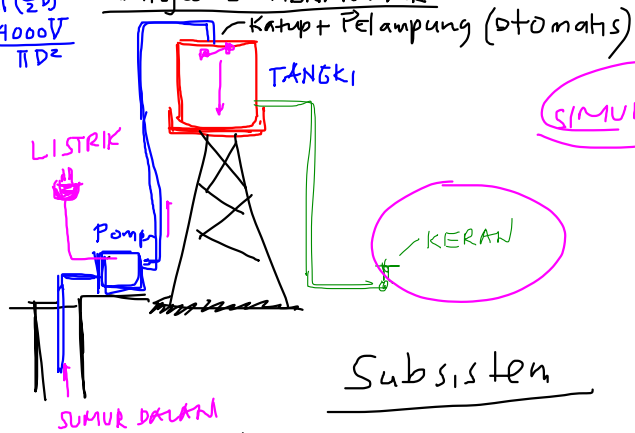
$$y = -0.1x + 12$$

$\rightarrow$ masuk ke pelampung.m

$\rightarrow$ check $(0 < x)$
 $x = 110 \rightarrow y = -11 + 12 = 1$
 $x = 120 \rightarrow y = -12 + 12 = 0$



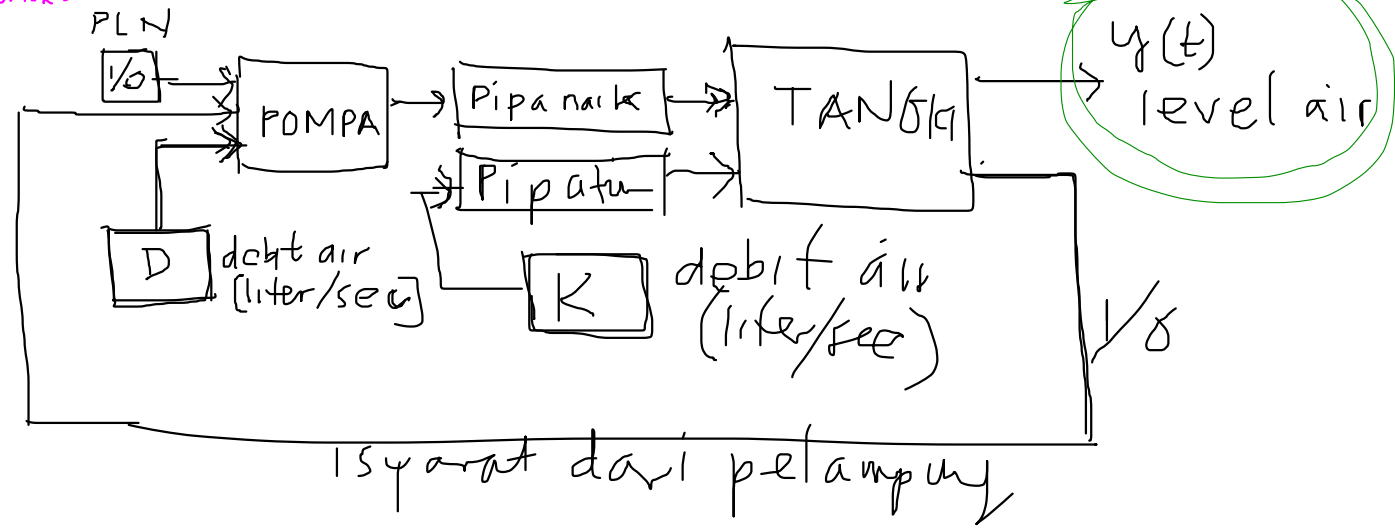
*** Project 3 MENARA AIR**



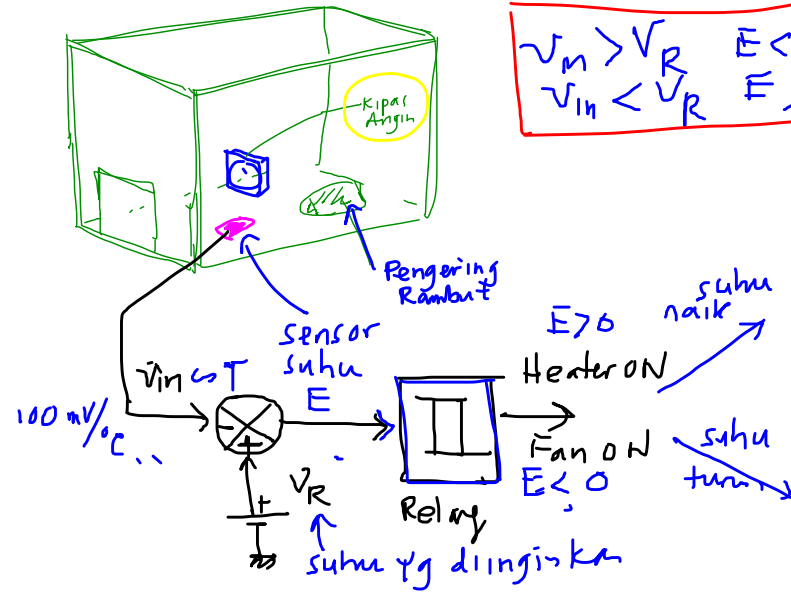
SIMULINK

KERAN

Jika keran dibuka maka air mengalir ke luar dengan debit K liter/sec

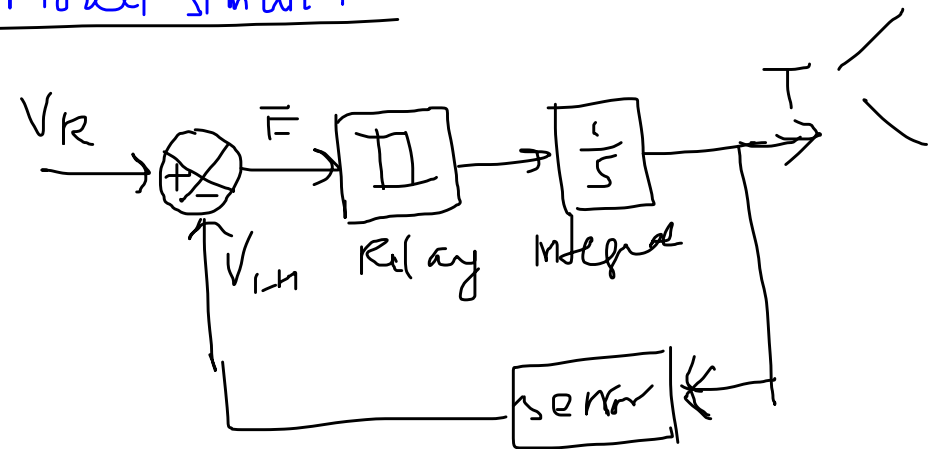


Project 4 PEMANAS RUANG

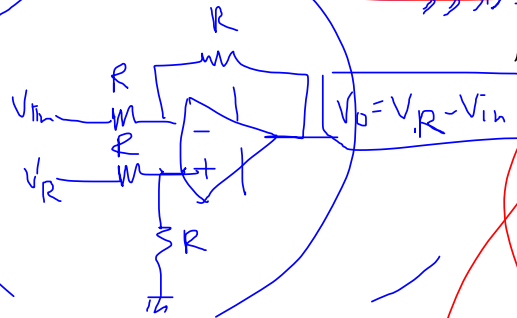
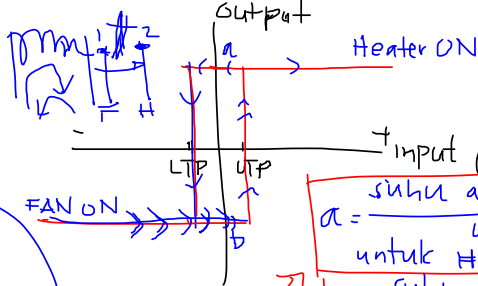


$V_{in} > V_R \quad E < 0 \quad \text{FAN ON}$
 $V_{in} < V_R \quad E > 0 \quad \text{Heater ON}$

Model Simulink:



Karakteristik RELAY



$$\alpha = \frac{\text{suatu akhir} - \text{suatu awal}}{\text{waktu}} \text{ untuk HEATER}$$

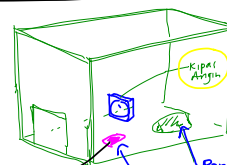
$$b = \frac{\text{suatu akhir} - \text{suatu awal}}{\text{waktu}} \text{ untuk FAN}$$

Tugas di lab:

* Menyalakan heater.
ukur. suhu awal
suhu akhir
waktu

* Menyalakan fan:
ukur. suhu awal
suhu akhir
waktu

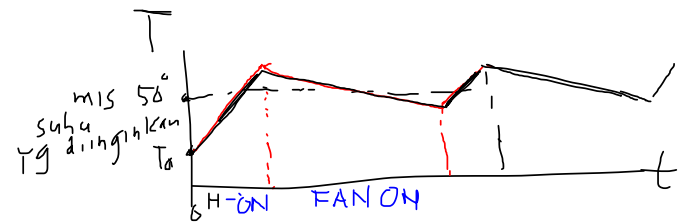
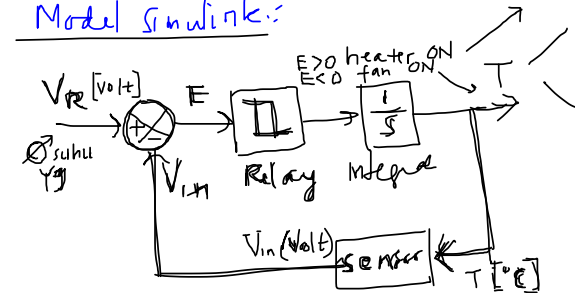
Project 4. TERMINAS RUANGNYA



$$V_m > V_R \quad E < 0 \quad \text{FAN ON}$$

$$V_m < V_R \quad E > 0 \quad \text{Heater ON}$$

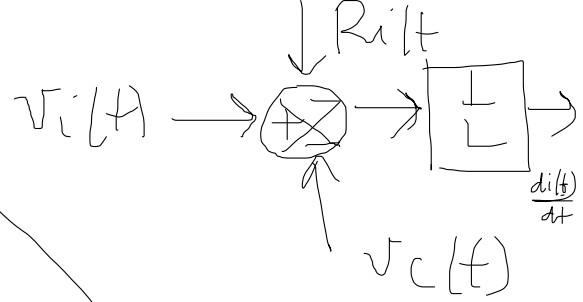
Model Simulink:



$T_0 = \text{suhu ruang}$

$$\frac{di(t)}{dt} = \frac{1}{L} (v_o(t) - v_c(t) - Ri(t))$$

$$\frac{dv_c(t)}{dt} = \frac{1}{C} i(t)$$



* SIMULINK

Hukum Ohm:

$$v_i(t) - v_c(t) = Ri(t) + L \frac{di(t)}{dt}$$

$$i(t) = \frac{1}{C} \frac{dv_c(t)}{dt}$$

$$\int \frac{di(t)}{dt} dt = \int di(t) = i(t)$$

$$\int \frac{dv_c(t)}{dt} dt = \int dv_c(t) = v_c(t)$$

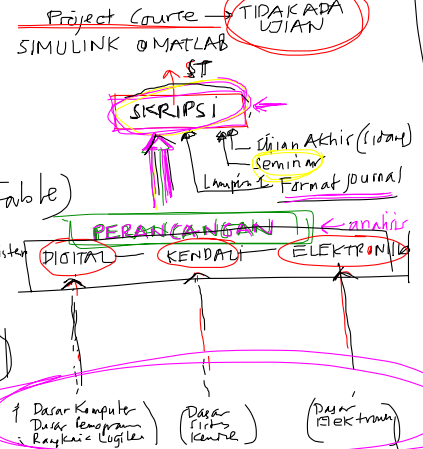
$$V_c(s) = \frac{V}{s(LCs^2 + RCs + 1)}$$

$$v_c(t) = \mathcal{L}^{-1} \left\{ \frac{V}{s(LCs^2 + RCs + 1)} \right\}$$

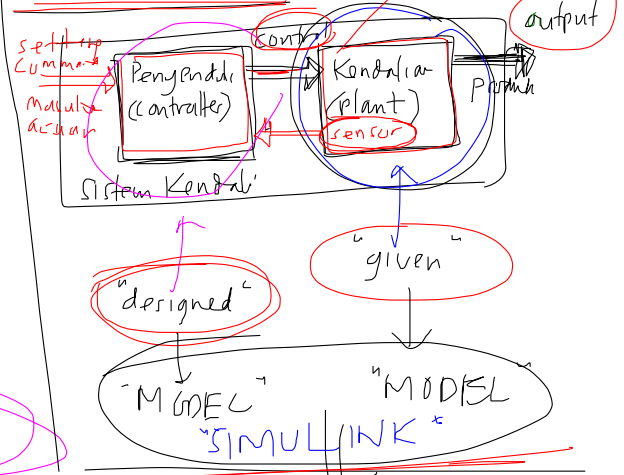
$$I_c(s) = \frac{V_c(s)}{Z_c} = \frac{V}{Ls^2 + RCs + 1}$$

$$i_c(t) = \mathcal{L}^{-1} \{ I_c(s) \}$$

PERANCANGAN SISTEM KENDALI



SISTEM KENDALI



Persiapan:

- * Mencari MITRA (utk yang ingin bekerja bersama)
- * Akses MATLAB → Simulink

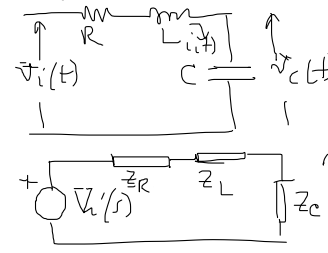
Nanti VERIFIKASI SIMULINK

Project 1 Verifikasi Simulink

toleransi

* ANALITIK

Menggunakan Konsep Impedansi



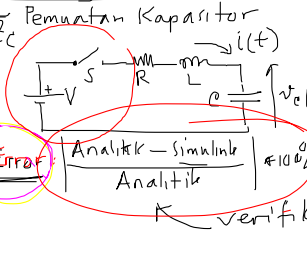
$$I(s) = \frac{V_i(s)}{Z_R + Z_L + Z_C}$$

$$V_c(s) = I(s) \cdot Z_C = \frac{Z_C V_i(s)}{Z_R + Z_L + Z_C}$$

$$= \frac{V}{R + Ls + \frac{1}{Cs}}$$

$$= \frac{V}{s(LCs^2 + RCs + 1)}$$

* Rangkaian RLC seri



Saklar S ditutup pada $t=0$, $v_c(0) = 0$. Tentukan $v_c(t)$ dan $i(t)$.

* ANALITIK → exact

* SIMULINK

verifikasi

* Dengan menggunakan spread-sheet,
 * can error untuk 3 (tiga) nilai
 toleransi yang berbeda, 10^{-3} , 10^{-4} , 10^{-5} , ...
 pada simulink

* Carilah solusi
 ANALITIK untuk
 $v_c(t)$ dan $i(t)$

* Perbesar dan
 perkecil nilai

R sehingga
 ada ketiga
 kasus nilai ξ

* $\xi > 1$
 * $\xi = 1$
 * $0 < \xi < 1$

TABEL
 TIDAK
 DIKUMPUL

9 tabel
 PENYAMPAIAN

Tabel Laplace:

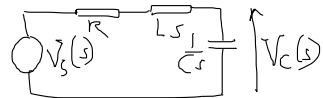
$$v_c(t) \rightarrow \begin{cases} * \xi > 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s(s+a)(s+b)} \\ * \xi = 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s(s+\omega_n)^2} \rightarrow \mathcal{L}^{-1} \frac{K}{s(s+a)^2} \\ * 0 < \xi < 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s(s^2 + 2\xi\omega_n s + \omega_n^2)} \end{cases}$$

Tugas 1 Verifikasi SIMULINK
 * Ambil tgl lahir dan salah seorang
 TT-BB-IGHH $V = 12$ Volt
 $C = 10$ HH $RF = 10$ HH $\times 10^{-6}$ F
 $L = 88$ Henry
 $R = TT$ Ohm

$$i(t) = \mathcal{L}^{-1} I(s) = \mathcal{L}^{-1} \frac{V_c(s)}{Z_c} = \mathcal{L}^{-1} \frac{V/L}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})}$$

$$= \mathcal{L}^{-1} \frac{VL}{s^2 + \frac{R}{L}s + \frac{1}{LC}} = \mathcal{L}^{-1} \frac{K}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

$$\begin{cases} \xi > 1 \rightarrow \mathcal{L}^{-1} \frac{K}{(s+a)(s+b)} \\ \xi = 1 \rightarrow \mathcal{L}^{-1} \frac{K}{(s+a)^2} \\ 0 < \xi < 1 \rightarrow \mathcal{L}^{-1} \frac{K}{s^2 + 2\xi\omega_n s + \omega_n^2} \end{cases}$$



$$V_s(s) = \mathcal{L}\{V_u(t)\} = \frac{V}{s}$$

$$V_c(s) = \frac{Z_c}{Z_R + Z_L + Z_C} \cdot V_s(s)$$

$$= \frac{\frac{1}{Cs}}{R + Ls + \frac{1}{Cs}} \cdot \frac{V}{s}$$

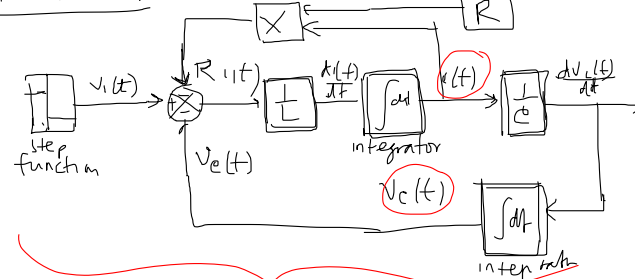
$$= \frac{V}{s(LCs^2 + RCs + 1)}$$

$$= \frac{V/LC}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})}$$

$$v_c(t) \text{ ANALITIK } \begin{cases} = \mathcal{L}^{-1} \frac{V/LC}{s(s^2 + \frac{R}{L}s + \frac{1}{LC})} \\ = \mathcal{L}^{-1} \frac{K}{s(s^2 + 2\xi\omega_n s + \omega_n^2)} \end{cases}$$

$$\begin{aligned} \omega_n^2 &= 1/LC \\ \omega_n &= 1/\sqrt{LC} \\ 2\xi\omega_n &= R/L \rightarrow \xi \end{aligned}$$

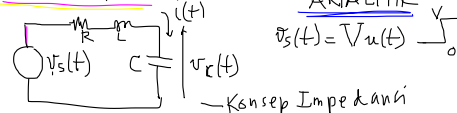
Model SIMULINK



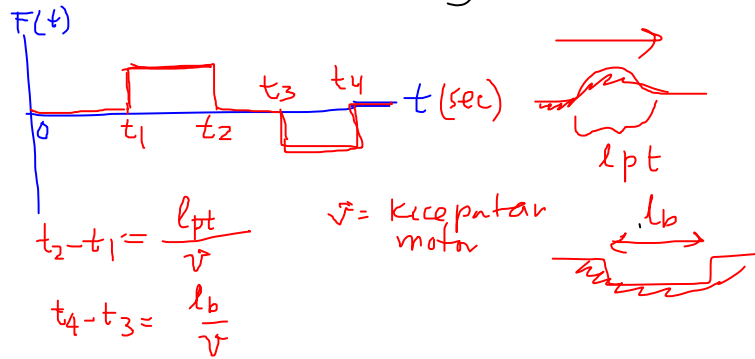
SIMULINK & MATLAB

* VALIDASI $\rightarrow$ di LAB

* VERIFIKASI $\rightarrow$ referensi: Hasil perhitungan ANALITIK



Simulasi Gaya guncangan

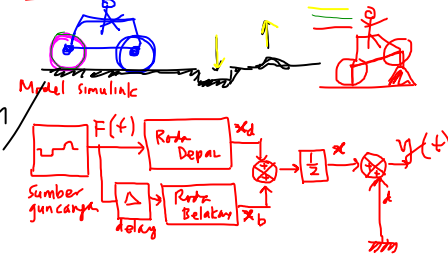


Diunduh dari:

<http://www.unha.ac.id/rhiza/arsip/kuliah/>

cari Perancangan - Sistem - Kontrol

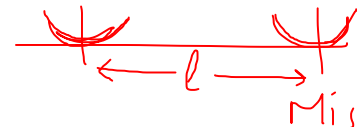
SISTEM SUSPENSI SEPEDA MOTOR



tanah = permukaan jalan
 $F(t)$ gaya guncangan
 $y(t)$ posisi pengendara terhadap tanah
 d = jarak antara sadel dengan tanah

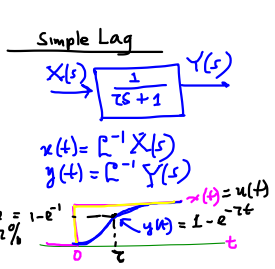
Δ = delay antara roda depan dan roda belakang

$$\Delta = \frac{l}{v} \text{ [second]}$$

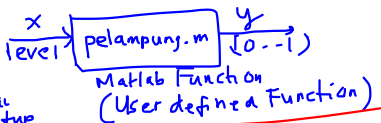
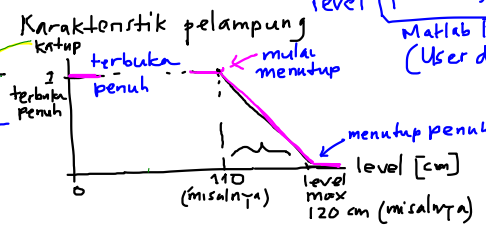
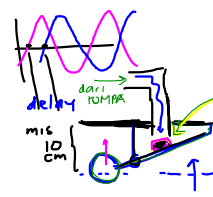


Mis, $v = 5 \text{ km/jam}$
 $l = 1,2 \text{ m}$

$$\begin{aligned}
 \text{Jadi } \Delta &= \frac{1,2 \text{ m}}{5000 \text{ m} / 3600 \text{ se}} \\
 &= \frac{1,2 \times 3600}{5000} \text{ se} \\
 &= 0,864 \text{ se}
 \end{aligned}$$



Transport Delay



$x \leq 110 \rightarrow y = 1$ terbuka penuh
 $x \geq 120 \rightarrow y = 0$ tertutup penuh
 $110 < x < 120$

$$\frac{y-1}{0-1} = \frac{x-110}{120-110}$$

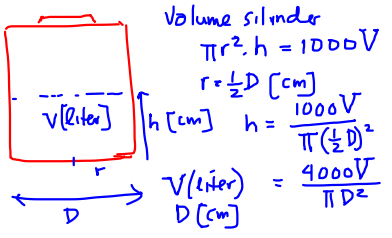
$$10(y-1) = -x + 110$$

$$y-1 = -0.1x + 11$$

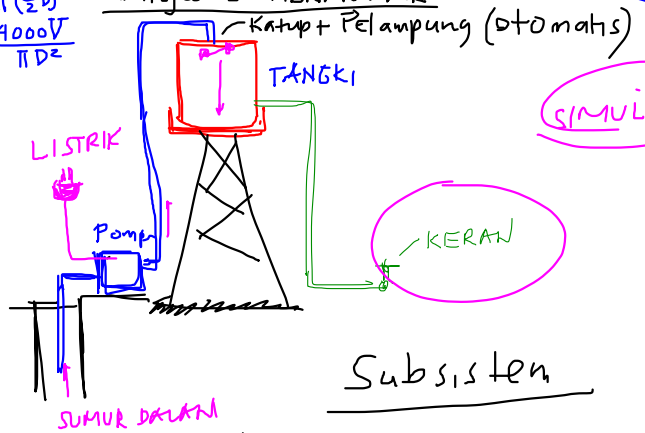
$$y = -0.1x + 12$$

→ masuk ke pelampung.m

check $(0 < y < 1)$
 $x = 110 \rightarrow y = -11 + 12 = 1$
 $x = 120 \rightarrow y = -12 + 12 = 0$

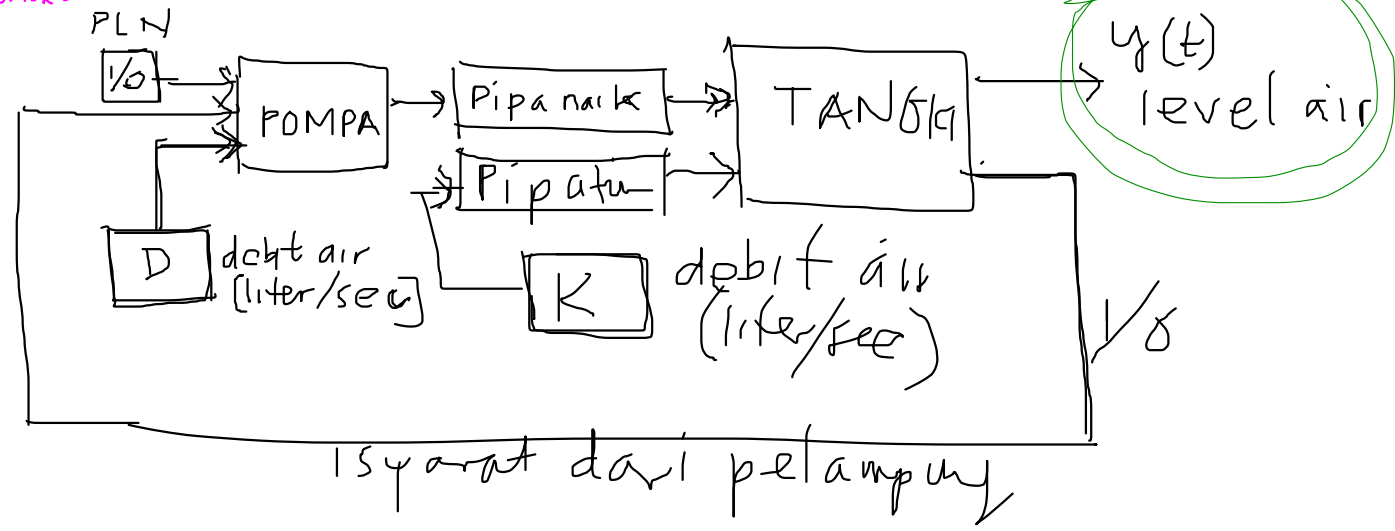


* Project 3 MENARA AIR



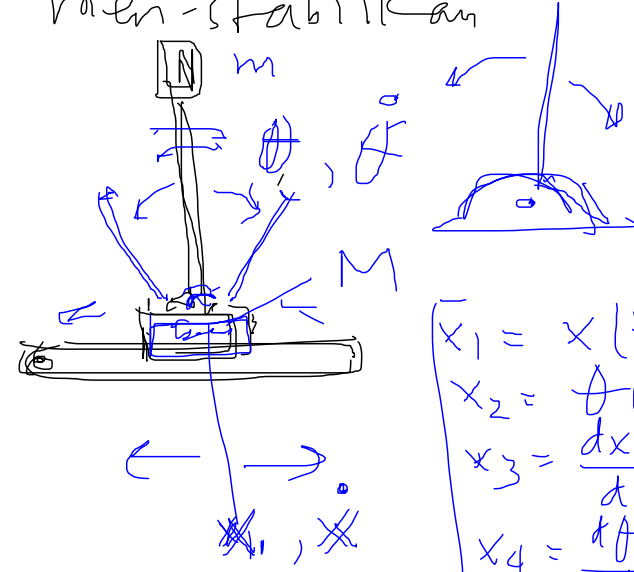
SIMULINK

Jika keran dibuka
 maka air mengalir
 ke luar dengan debit K liter/sec



Skipri
a/n ARIS
& Budi Muliyah

PROJECT 5 Penyeimbang Terbalik (Non-Linear, Unstable) men-stabilkan

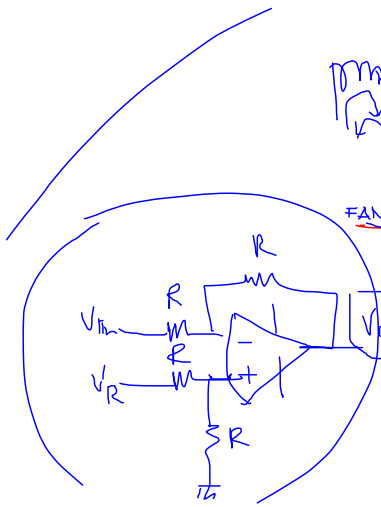
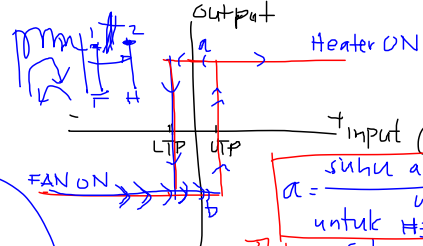


$$\begin{aligned} x_1 &= x(t) \\ x_2 &= \dot{x}(t) \\ x_3 &= \frac{dx(t)}{dt} \\ x_4 &= \frac{d^2x(t)}{dt^2} \end{aligned}$$

Review:

- * Project 1. VERIFIKASI SIMULINK $\rightarrow$ toleransi 10^{-3} ...
- * Project 2. SISTEM SUSPENSİ SEPEDA MOTOR
Linear, Stable
(minimisasi gangguan)
- * Project 3. MENARA AIR
Linear, Unstable
(Kendali ON-OFF, pelampung)
- * Project 4 PEMANAS RUANG
Non-Linear, Quasi-stable
(Kendali PID, minimisasi variasi suhu)

Karakteristik RELAY

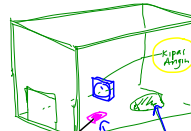


Tugas di lab:

* Menyalakan heater.
ukur. suhu awal
suhu akhir
waktu

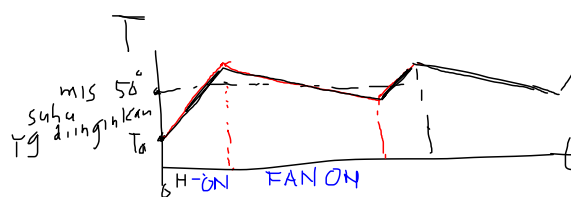
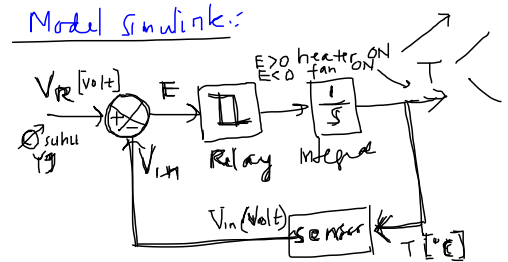
* Menyalakan fan:
ukur: suhu awal
suhu akhir
waktu

Project 4 PEMANAS RUANG

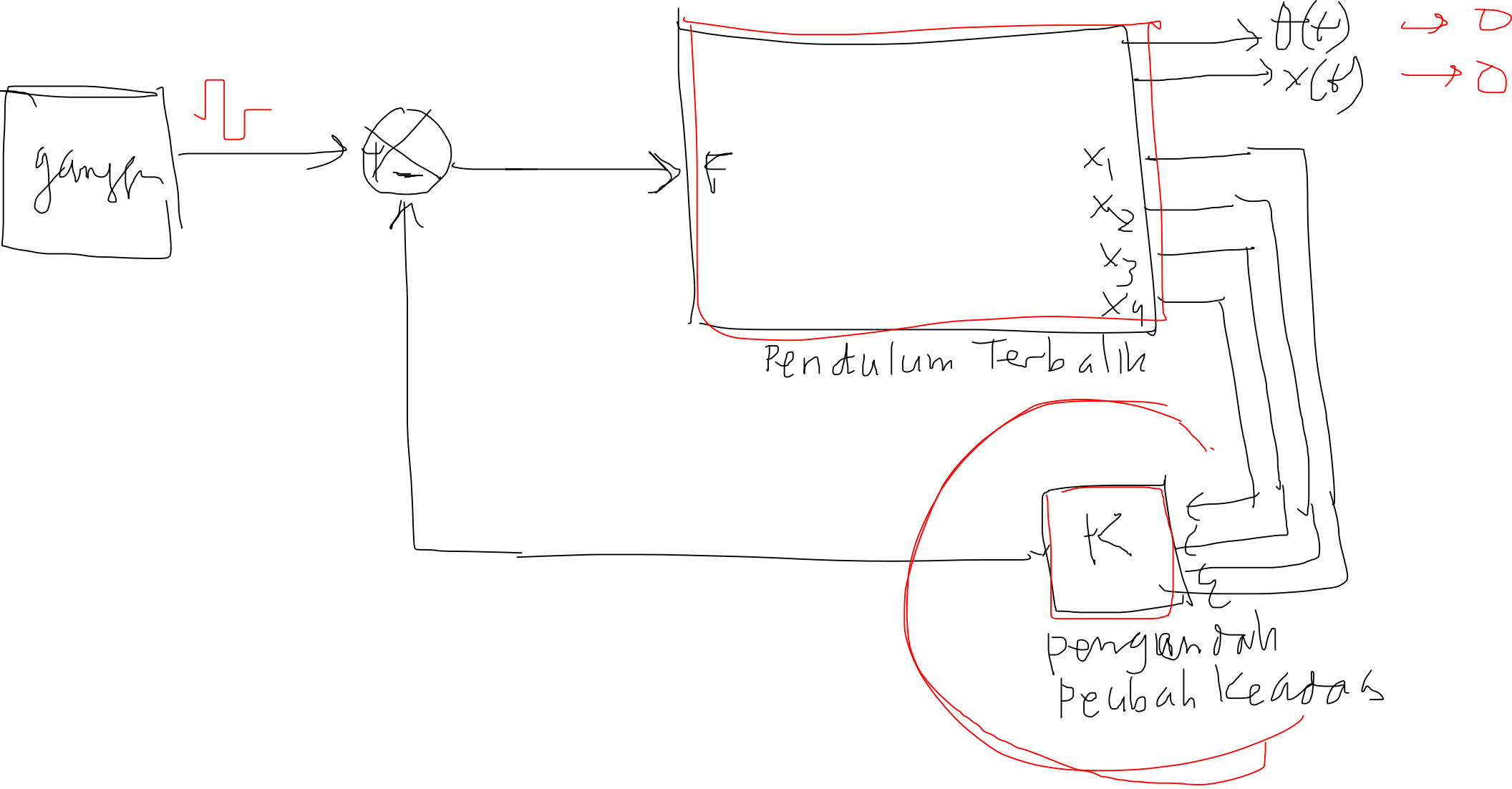


$$\begin{aligned} V_m > V_R & \rightarrow E < 0 \text{ FAN ON} \\ V_m < V_R & \rightarrow E > 0 \text{ Heater ON} \end{aligned}$$

Model Simulink:



$T_0 =$ suhu ruang



Perancangan SISTEM KENDALI 2014

Project Course → TIRAK ADA UJIAN!

- * Cari partner!
- * Akses MATLAB minimal Matlab 7

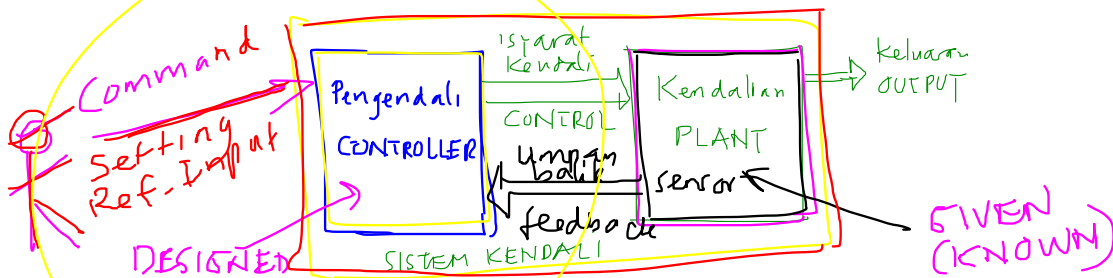
Setiap pekan mulai ba'da Asar hr SENIN

PBT301 atau 302 yang ada LED-nya, atau di LSKI.

Referensi Course Website:

<http://www.unhas.ac.id/rhiza/arsip/kuliah/>

Perancangan sistem Kendali



Merancang Sistem Kendali
(Control System Design)

- merancang CONTROLLER yang menghasilkan isyarat kendali (CONTROL) sehingga suatu Kendali (PLANT) yang diberikan menghasilkan keluaran (OUTPUT) yang diinginkan

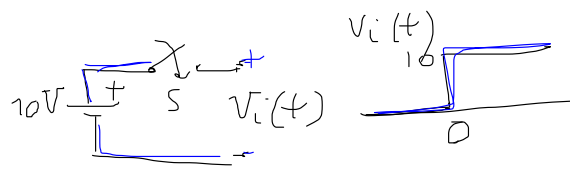
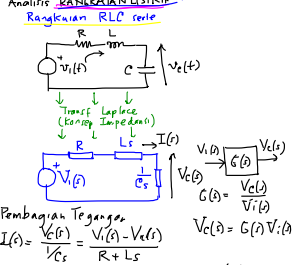
- * Sistem Kendali OPTIMAL
- * Sistem Kendali ADAPTIF
- * Sistem Kendali CERDAS

* Sistem Kendali PROSES → Process Plant

* Sistem Kendali KOKOH (Robust)

* dll.

next, VERIFIKASI SIMULINK
project 3



$$v_i(t) = 10u(t)$$

$$V_i(s) = \frac{10}{s}$$

$$V_c(s) = \frac{10}{s} \frac{K}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$V_c(t) = \mathcal{L}^{-1} \left[\frac{10K}{s(s^2 + 2\zeta\omega_n s + \omega_n^2)} \right]$$

analitik

→ Acuan EXACT

$$G(s) = \frac{K}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$K = K_c \quad \omega_n^2 = \frac{1}{LC} \rightarrow \omega_n = \frac{1}{\sqrt{LC}} \rightarrow f_n = \frac{1}{2\pi\sqrt{LC}}$$

$$2\zeta\omega_n = \frac{R}{L} \rightarrow \zeta = \frac{R}{2L\omega_n} = \frac{R}{2L} \sqrt{LC}$$

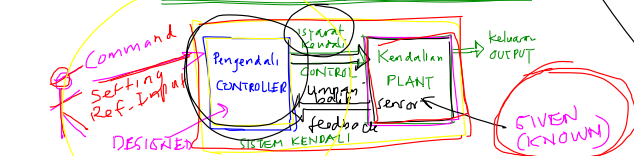
$\zeta > 1 \rightarrow$ overdamped

$\zeta = 1 \rightarrow$ critically damped

$0 < \zeta < 1 \rightarrow$ underdamped

$\zeta = 0 \rightarrow$ oscillation $\rightarrow f_n = \frac{1}{2\pi\sqrt{LC}}, R = 0$

Perancangan SISTEM KENDALI 2014
Project Course $\rightarrow$ TIRAK ADA UJIAN!
* Cari partner!
* Akses MATLAB minimal Matlab 7
Setiap pekan mulai bulan April ke SENIN
PBT 303 78781 atau 782 yang ada LCD nya, atau di LKSI.
Referensi Course Website:
<http://www.unhar.ac.id/strata/arsip/kuliah/>
Perancangan Sistem Kendali



Merancang Sistem Kendali (Control System Design)

- * Sistem Kendali OPTIMAL
- * Sistem Kendali ADAPTIF
- * Sistem Kendali CERDAS

* Sistem Kendali PROSES $\rightarrow$ Process Plant

* Sistem Kendali KOKOH (Robust)

* dll.

next, VERIFIKASI SIMULINK
project 3

ALAT DESIGN:
Simulink @ MATLAB

PEMODELAN & SIMULASI

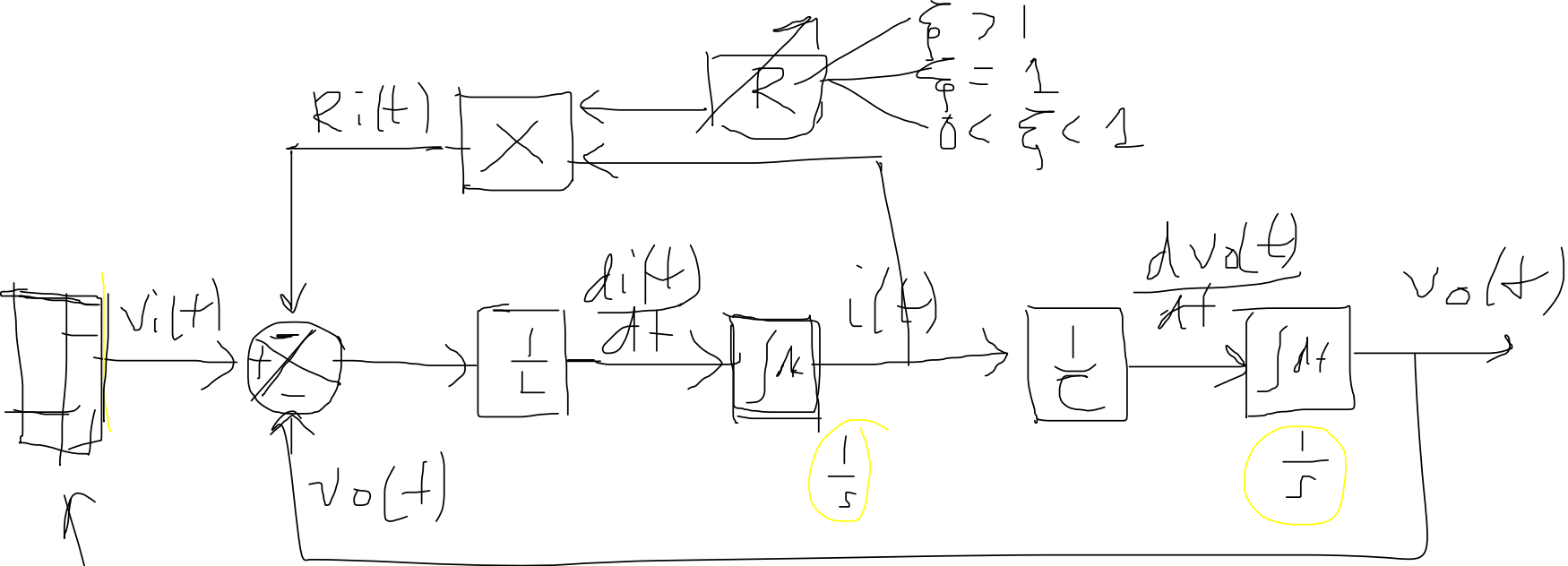
- * VALIDASI $\rightarrow$ Pengamat FISIK
- * VERIFIKASI

tanpa pengamatan FISIK

Pembandingan: ANALISIS

Hasil ANALITIK: EXACT akurat

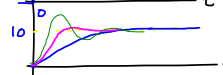
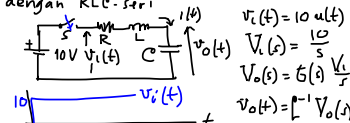
ERRORE galat



Isyarat untuk satu unit step

Project 1 Judul: VERIFIKASI SIMULINK Dikumpul 29/09/14

Verifikasi menggunakan analisis transien dari rangkaian pemuatan kapasitor dengan RLC-seri



Mitra 1: D411111 ABC
Mitra 2: D411110 DEF

R diambil 3 (tiga) kasus.

- * Kasus 1 $R \Rightarrow \xi_p > 1$
- * Kasus 2 $R \Rightarrow \xi_c = 1$
- * Kasus 3 $R \Rightarrow 0 < \xi < 1$

Analisis menggunakan transf. Laplace.

- * Kasus 1 $v_o(t) = \mathcal{L}^{-1} \frac{K_1}{s(s+a)(s+b)} \Rightarrow \text{EXACT}$
- * Kasus 2 $v_o(t) = \mathcal{L}^{-1} \frac{K_2}{s(s+a)^2} \Rightarrow \text{EXACT}$
- * Kasus 3 $v_o(t) = \mathcal{L}^{-1} \frac{K_3}{s(s^2 + 2\xi\omega_n s + \omega_n^2)} \Rightarrow \text{EXACT}$

AKURASI
perhitungan
GALAT
dan SIMULINK

Model Simulink

Hukum Ohm:

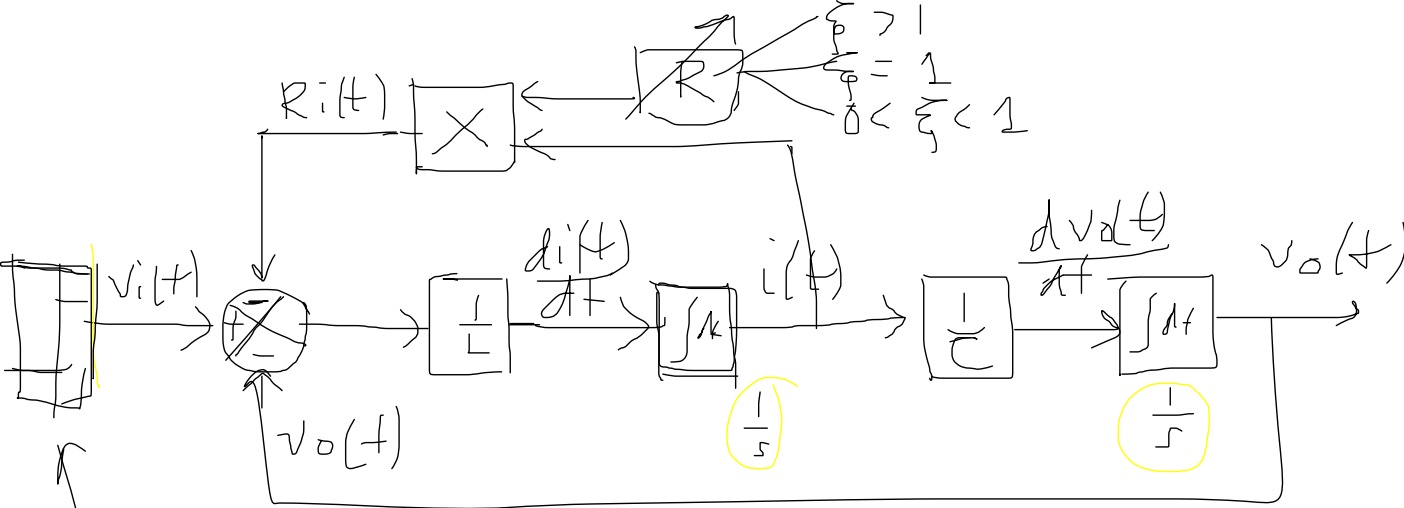
$$(1) v_i(t) - v_o(t) = Ri(t) + L \frac{di(t)}{dt}$$

$$\frac{di(t)}{dt} = \frac{1}{L} [v_i(t) - v_o(t) - Ri(t)]$$

$$(2) i(t) = C \frac{dv_o(t)}{dt}$$

$$\frac{dv_o(t)}{dt} = \frac{1}{C} i(t)$$

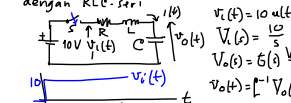
SOLUSI
ANALITIK



Isyarat untuk satu m (unit step)

Project 1 Judul VERIFIKASI SIMULINK Dikumpul 25/09/14

Verifikasi menggunakan analisis transien dari rangkaian pemuatan kapasitor dengan RLC seri



- $\xi > 1$, overdamped
 - $\xi = 1$, critically damped
 - $0 < \xi < 1$, underdamped
- Mitra 1: D41111 ABC
Mitra 2: D41110 DEF
R diambil 3 (tiga) kasus.
* Kasus 1 $R \Rightarrow \xi > 1$
* Kasus 2 $R \Rightarrow \xi = 1$
* Kasus 3 $R \Rightarrow 0 < \xi < 1$

Analisis menggunakan trans. Laplace

AWAN perhitung GALAT dan SIMULINK

Solusi ANALITIK

- * Kasus 1 $v_o(t) = \mathcal{L}^{-1} \frac{K_1}{s(s+a)(s+b)} \Rightarrow \text{EXACT}$
- * Kasus 2 $v_o(t) = \mathcal{L}^{-1} \frac{K_2}{s(s+c)^2} \Rightarrow \text{EXACT}$
- * Kasus 3 $v_o(t) = \mathcal{L}^{-1} \frac{K_3}{s(s^2 + 2\xi\omega_n s + \omega_n^2)} \Rightarrow \text{EXACT}$

Error (galat) dari 3 (tiga) macam Toleransi, misalnya 10^{-3} (default), 10^{-4} , 10^{-5} , ... dst.

$$E = \left| \frac{v_o(t) [\text{ANA}] - v_o(t) [\text{SIM}]}{v_o(t) [\text{ANA}]} \right| * 100\%$$

Model Simulink

Hukum Ohm:

$$(1) v_i(t) - v_o(t) = R i(t) + L \frac{di(t)}{dt}$$

$$\frac{di(t)}{dt} = \frac{1}{L} [v_i(t) - v_o(t) - R i(t)]$$

$$(2) i(t) = C \frac{dv_o(t)}{dt}$$

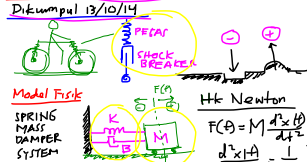
$$\frac{dv_o(t)}{dt} = \frac{1}{C} i(t)$$

$\xi > 1$, toleransi = 10^{-3}

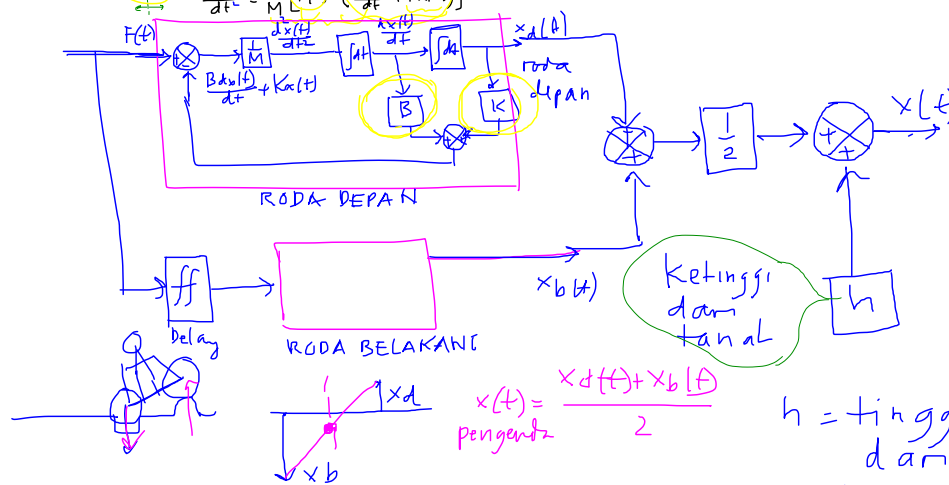
	v_o(t)		
Time	ANA	SIM	Error

* Bagaimana pengaruh toleransi terhadap Galat?

* Bagaimana perilaku Galat pada saat transien?

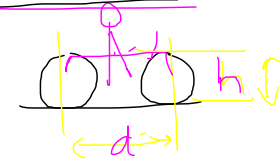


$$M = M_{motor} + M_{body}$$



Untuk Pelekan Depan :

* Dari motor: d dan h

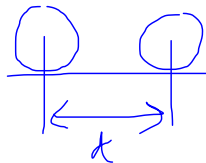


* Dari jalan: d_1 dari lobang
 d_2 dari polisi tidur

* Dari ... $M_{motor} + M_{body}$

h = tinggi sadel dari tanah ketika duduk

Delay tergantung * Kecepatan motor
[km/jam]



* Jarak roda depan dan roda blkg
 d [m]

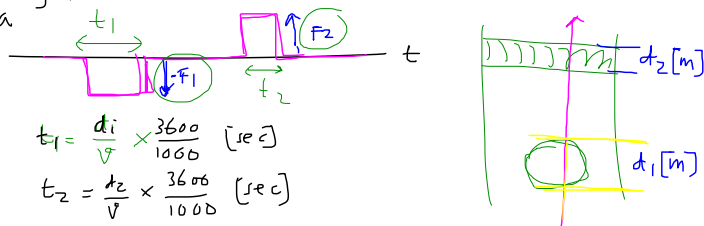
$$\text{Delay} = \frac{d \text{ [m]}}{v_x \left[\frac{1000 \text{ m}}{3600 \text{ sec}} \right]} = \frac{3600 d}{1000 v} \text{ [sec]}$$

$$d \text{ [m]}$$

$$v \text{ [km/jam]}$$

* Lobang dan polisi tidur

Guncangan Gaya



$$t_1 = \frac{d_1}{v} \times \frac{3600}{1000} \text{ [sec]}$$

$$t_2 = \frac{d_2}{v} \times \frac{3600}{1000} \text{ [sec]}$$

Project 2

* Pengukuran lapangan

- Dan motor d dan $h \pm \Delta h$ $\begin{matrix} +\Delta h \uparrow \\ -\Delta h \downarrow \end{matrix}$
- Dart lapangan: d_1 dan d_2 (lobang dan polisi tidur)
- M = Massa motor + badan pengendara

Pilih Kecepatan motor $5 \text{ km/jam} < v < 15 \text{ km/jam}$

(1) D4111ABC $\longrightarrow B = A, BC \text{ N sec/m}$

(2) D4111XYZ $\longrightarrow K = X, YZ \text{ N/m}$

* Percobaan kombinasi

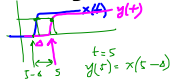
B tetap & $K = XYZ \text{ N/m}$ dan $K = 0,0XYZ \text{ N/m}$
K tetap & $B = ABC \text{ N sec/m}$ dan $B = 0,0ABC \text{ N sec/m}$

* Carilah kombinasi B dan K yang paling
"realistis" (cocok dengan keadaan sebenarnya)

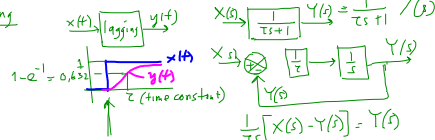
* DELAY dan LAGGING

Delay
(waktu tunda)

$$x(t) \xrightarrow{\text{DELAY}} y(t) = x(t - \Delta)$$



Lagging



$$\frac{1}{Ts + 1} [X(s) - Y(s)] = Y(s)$$

$$X(s) - Y(s) = (Ts + 1) Y(s)$$

$$X(s) = (Ts + 1) Y(s)$$

$$\frac{Y(s)}{X(s)} = \frac{1}{Ts + 1}$$

Project 2

* Pengukuran lapangan

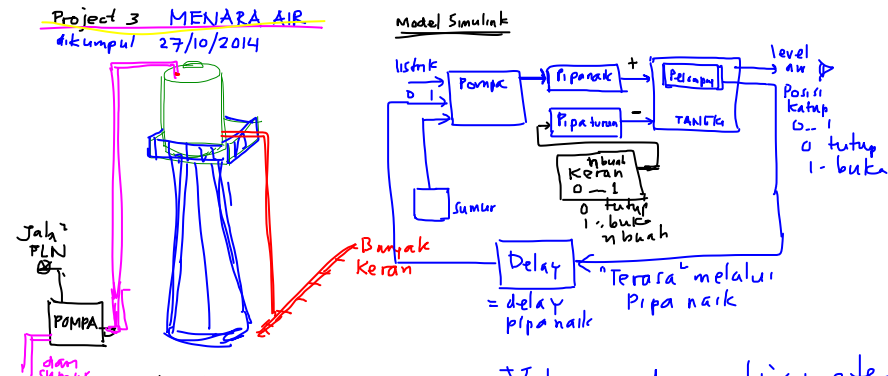
- Dari motor dan h±sh ± 0.1
- Dari lapangan: d_1 dan d_2 (lobang dan posisi tidur)
- M = Massa motor + badan pengendara
- Pilih Kecepatan motor $5 \text{ km/jam} < v < 15 \text{ km/jam}$
- (1) D41111ABC $\rightarrow B = A, BC \text{ N/sec/m}$
- (2) D41111XYZ $\rightarrow K = X, YZ \text{ N/m}$

- * Percobaan kombinasi
- B tetap & $K = XYZ \text{ N/m}$ dan $K = 0, 0XYZ \text{ N/m}$
- K tetap & $B = ABC \text{ N/sec/m}$ dan $B = 0, 0ABC \text{ N/sec/m}$

* Carilah Kombinasi B dan K yang paling "realistik" (cocok dengan keadaan sebenarnya)

Project 3 MENARA AIR

dikumpul 27/10/2014



Data Lapangan

* Volume dan diameter/tinggi tangki

* Debit Pompa $\rightarrow$ liter/sec.
(nyalakan pompa dari tangki keran sampai penuh)
Misalnya, 1100 liter dalam 45 menit

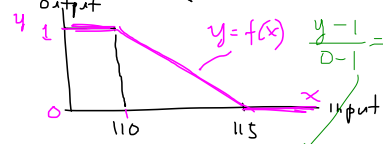
$$\text{Debit} = \frac{1100 \text{ liter}}{45 \times 60 \text{ sec}} = \dots$$

* Debit Keran : isi botol : 1 liter
berapa seconds :

* Delay : $\Rightarrow$ Pipa naik : start pompa
DENYAR sampai air tiba di atas tangki
 $\Rightarrow$ Pipa turun $\approx \frac{1}{2}$ delay pipa naik

input (level) 0 1/2 120
output (tanda) tutup 1/2 bulca
0 --- 1

120 cm
10 cm
level $\geq 115 \text{ cm} \rightarrow \text{output} = 0$
level $\leq 110 \rightarrow \text{output} = 1$



$$\frac{y-1}{-1} = \frac{x-110}{5}$$
$$y-1 = -\frac{1}{5}x + 22$$
$$\boxed{y = -\frac{1}{5}x + 23}$$

RELAY:

output (11strik)

ON

OFF

switch off point

switch on point

input drive relamping

Volume [liter] to Level [cm] $1 \text{ l} = 1000 \text{ cm}^3$



volume = $\pi \left(\frac{D}{2}\right)^2 \cdot h \text{ cm}^3$

$V = \varnothing \frac{\pi \left(\frac{D}{2}\right)^2 \cdot h}{1000} \text{ liter}$

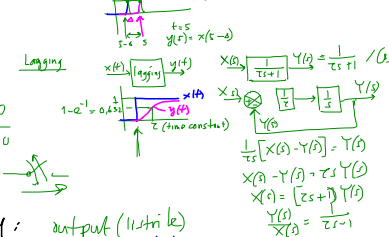
$1000 V = \pi \left(\frac{D}{2}\right)^2 h$

$h = \frac{4000 V}{\pi D^2} \text{ [cm]}$

Delay
(waktu tunda)

$\pi(t) \rightarrow \boxed{\text{DELAY}} \rightarrow y(t) = \pi(t - \Delta)$

$x(t) \rightarrow y(t)$



input drive voltage

switch on point

switch off point

- * Pengukuran lapangan
 - Den motor & den $h \pm sh$ + sh ↑
- sh ↓
 - Dart lapangan, d_1 dan d_2 (lobang dan polisi tidur)
 - M = Massa motor + beban pengendara

(1) $D4111ABC \rightarrow B = A, BC \text{ N sec/m}$
 (2) $D4111XYZ \rightarrow K = X, YZ \text{ N/m}$

K tetap & $B = 0,04 \text{ N sec/m}$ dan $B = 0,04 \text{ N sec/m}$

- * Carilah kombinasi B dan K yang paling "realistis" (cocok dengan keadaan sebenarnya).

dikumpul 27/10/2019

A diagram showing a green cylinder. A red line starts from the top left, goes up, then right, then down into the top of the cylinder. A blue line starts from the top right, goes up, then left, then down into the top of the cylinder.

Hand-drawn schematic diagram of a water level control system for a tank. The diagram shows a tank with a float valve (Pipa naik) and a pump (POMPA) connected to a water source (Jalan PLN). A control unit (Kontrol) receives input from the float valve and outputs to the pump. A delay block (Delay) is shown with the note "Terorasi melalui Pipa naik" and "= delay pipa naik". A handwritten note "03/1/2014" is present. The diagram is labeled "level air" and "Pompa".

Data Lapangan

* Volume dan diameter/tinggi tangki

* Debit Pompa $\rightarrow$ liter/sec.
(nyalakan pompa dari tangki yang
sampe' penuh)

Misalnya, 1100 liter dalam 45 menit

$$\text{Debit} = \frac{1100 \text{ liter}}{45 \times 66 \text{ sec}} = \dots$$

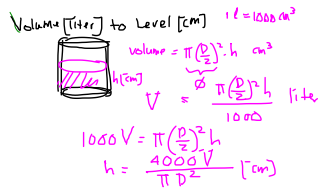
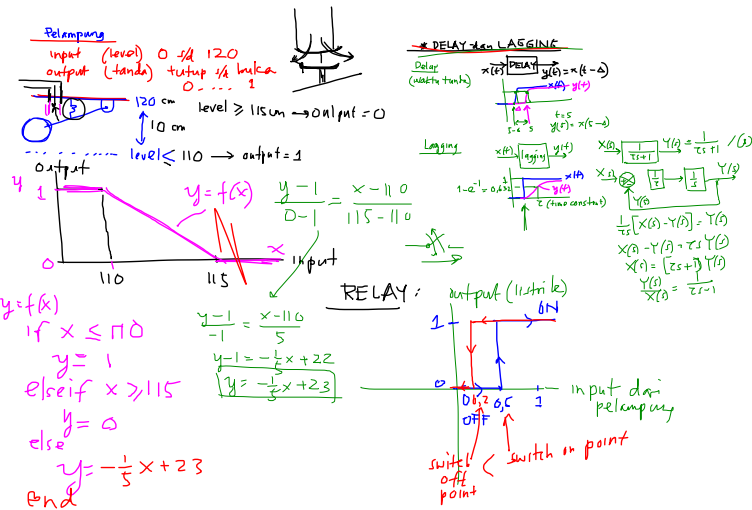
* Debit Keras : isi botol : 1 liter
berapa seconds :

* Delay : $\Rightarrow$ Pipa naik : start pompa
DENGAR! sampai air tiba
di atas tangki
 $\Rightarrow$ Pipa turun $\approx \frac{1}{2}$ delay
pipa
naik

Laporan berisi

- * Data lapangan
- * Analisis perancangan simulasi
- * Skenario

⇒ Pengisian sampai penuh → pelampung bekerja
⇒ Pengosongan sampai kosong → pompa padam.
(buka tutup keran)



Project 2

4. Pengaturan lajangan
- Den motor d_1 dan d_2 $\begin{matrix} \text{tali} \uparrow \\ -d_h \downarrow \end{matrix}$
 - Dant lapangan, d_1 dan d_2 (Isi bag dan pelisir fidur)
 - M = Massa motor + bahan pengendare
- Rikik kecepatan motor $5 \text{ km/jam} < v < 15 \text{ km/jam}$
- (1) D4111ABC $\rightarrow$ B = A, X, N sec/m
- (2) D4111xyz $\rightarrow$ K = x, yz N/m

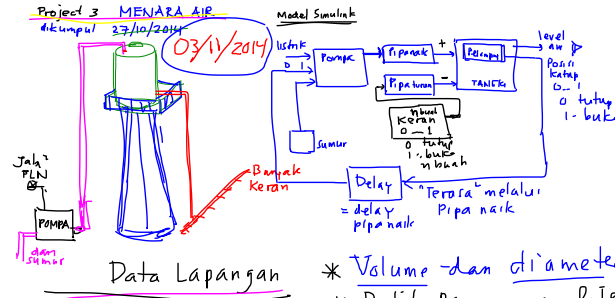
30 Percobaan kombinasi
B tetap & $K = XYZ \text{ N/m}$ dan $K = 0,0XYZ \text{ N/m}$
 K tetap & $B = ABC \text{ Nsec/m}$ dan $B = 0,0ABC \text{ Nsec/m}$

- * Carilah kombinasi B dan K yang paling "realistis" (cocok dengan keadaan sebenarnya)

Project 3 MENARA AIR

dikumpul 27/10/2014

03/11/2014



Data Lapangan

- * Volume dan diameter / tinggi tangki
 - * Debit pompa → liter/sec.
- (nyalakan pompa dari tangki lcrmy)

Misalnya, 1100 liter dalam 45 menit

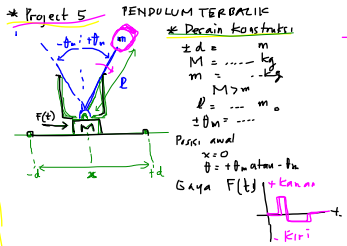
$$\text{Debit} = \frac{1100 \text{ liter}}{45 \times 60 \text{ sec}} = \dots$$

- * Debit Keran : isi botol : 1 liter
berapa seconds :

- * Delay : $\Rightarrow$ Pipa naik : start pompa sampai air tiba di atas tangki
- $\Rightarrow$ Pipa turun $\approx \frac{1}{2}$ delay pipa naik

* Penurunan fungsi $f_1(t)$ dan $f_2(t)$

Persamaan Lagrange: $L = T - V$
 $T = \text{Energi Kinetik}$
 $V = \text{Energi Potensial}$
 Arah x (linear): $\frac{d}{dt} \left[\frac{\partial L}{\partial \dot{x}_1} \right] - \frac{\partial L}{\partial x_1} = u = F(t)$
 Arah θ (melingkar): $\frac{d}{dt} \left[\frac{\partial L}{\partial \dot{x}_3} \right] - \frac{\partial L}{\partial x_3} = 0$
 $\dot{x}_1 = \dot{x}_2 = \frac{dx(t)}{dt}$
 $\dot{x}_3 = \dot{x}_4 = \frac{d\theta(t)}{dt}$



$V = mgh = mg l \cos \theta$
 $T = T_1 + T_2$
 $T_1 = \frac{1}{2} M \dot{x}_2^2$
 $T_2 = \frac{1}{2} m (\dot{x}_3^2 + \dot{x}_4^2)$
 $V = \frac{d}{dt} [x(t) + l \sin \theta(t)]$
 posisi serant arah x
 $= \frac{dx(t)}{dt} + l \cos \theta(t) \cdot \frac{d\theta(t)}{dt}$
 $= \dot{x}_2 + [l \cos x_3] \cdot \dot{x}_4$

$v_y = \frac{d}{dt} [l \cos \theta(t)]$
 posisi serant arah y
 $v_y = [l \sin \theta(t)] \cdot \frac{d\theta(t)}{dt}$
 $= [l \sin x_3] \cdot \dot{x}_4$

$T_2 = \frac{1}{2} m [\dot{x}_2 + l \dot{x}_4 \cos x_3]^2 + \frac{1}{2} m [l \dot{x}_4 \sin x_3]^2$
 $= \frac{1}{2} m [\dot{x}_2^2 + l^2 \dot{x}_4^2 \cos^2 x_3 + l^2 \dot{x}_4^2 \sin^2 x_3 + 2 \dot{x}_2 l \dot{x}_4 \cos x_3]$
 $= \frac{1}{2} m \dot{x}_2^2 + \frac{1}{2} m l^2 \dot{x}_4^2 + m \dot{x}_2 l \dot{x}_4 \cos x_3$

* State assignment
 $u = F(t)$
 $x_1 = x(t)$, posisi M
 $\dot{x}_2 = \dot{x}_1 = \frac{dx(t)}{dt}$, kecepatan M
 $x_3 = \theta(t)$, posisi sudut l
 $\dot{x}_4 = \dot{x}_3 = \frac{d\theta(t)}{dt}$, kecepatan sudut l
 * Persamaan keadaan:
 $\dot{x}_1 = x_2$
 $\dot{x}_2 = \text{fungsi } f_1(t) = \frac{d^2 x(t)}{dt^2}$
 $\dot{x}_3 = x_4$
 $\dot{x}_4 = \text{fungsi } f_2(t) = \frac{d^2 \theta(t)}{dt^2}$
 (tak linier, tak stabil)

$T = T_1 + T_2$
 $= \frac{1}{2} M \dot{x}_2^2 + \frac{1}{2} m \dot{x}_2^2 + \frac{1}{2} m l^2 \dot{x}_4^2 + m \dot{x}_2 \dot{x}_4 l \cos x_3$
 $V = m g l \cos x_3$

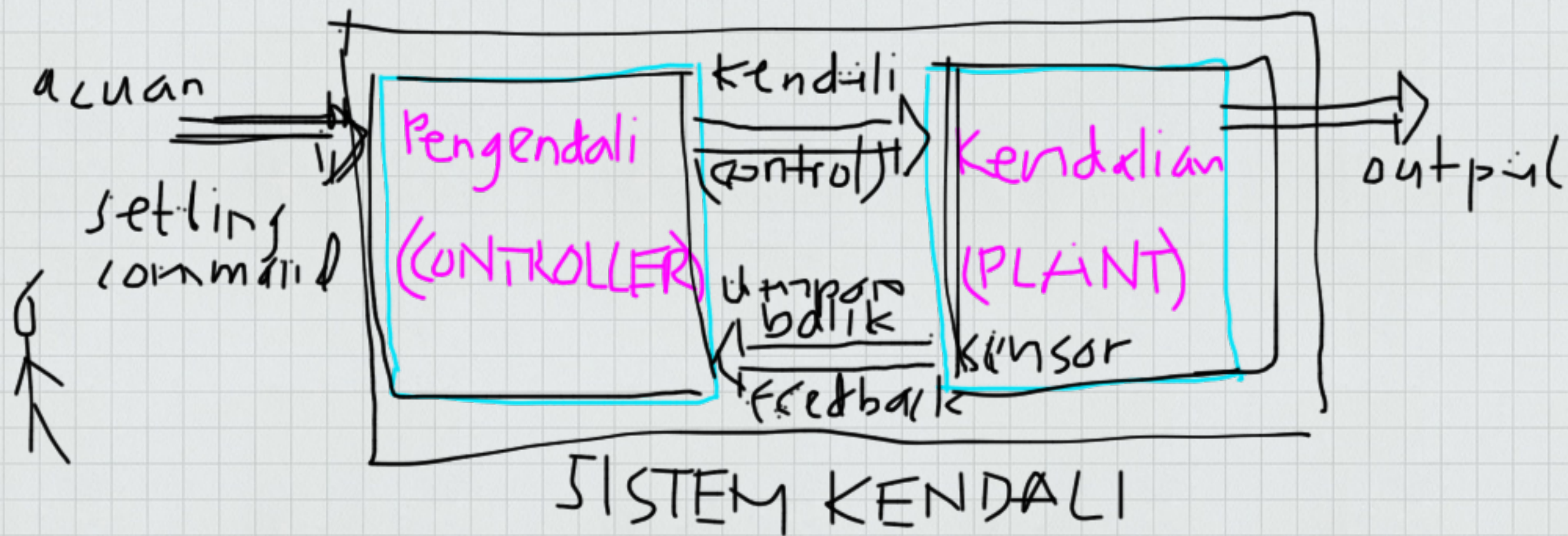
$L = T - V = \frac{1}{2} (M + m) \dot{x}_2^2 + \frac{1}{2} m l^2 \dot{x}_4^2 + m \dot{x}_2 \dot{x}_4 l \cos x_3 - m g l \cos x_3$
 arah linear: $\frac{d}{dt} \left[\frac{\partial L}{\partial \dot{x}_2} \right] - \frac{\partial L}{\partial x_2} = u = F(t)$
 $\frac{d}{dt} [(M + m) \dot{x}_2 + m l \dot{x}_4 \cos x_3] = F(t)$
 $(M + m) \ddot{x}_2 + m l \ddot{x}_4 \cos x_3 - m l \dot{x}_4 \sin x_3 \dot{x}_4 = F(t)$
 $(M + m) \ddot{x}_2 + m l \dot{x}_4 \cos x_3 - m l \dot{x}_4^2 \sin x_3 = F(t) \quad (1)$
 arah melingkar: $\frac{d}{dt} \left[\frac{\partial L}{\partial \dot{x}_4} \right] - \frac{\partial L}{\partial x_4} = 0$
 $\frac{d}{dt} [m l \dot{x}_2 \cos x_3 + m l^2 \dot{x}_4] - (-m \dot{x}_2 l \sin x_3) + m g l \sin x_3 = 0$
 $m l \ddot{x}_2 \cos x_3 + m l^2 \ddot{x}_4 - m \dot{x}_2 l \sin x_3 \dot{x}_4 + m l \dot{x}_2 \sin x_3 + m g l \sin x_3 = 0$
 $m l^2 \ddot{x}_4 + m l \ddot{x}_2 \cos x_3 - m g l \sin x_3 = 0 \quad (2)$

Dari pers (1) dan (2) diperoleh:

$\dot{x}_2 = \frac{F(t) - \frac{1}{2} m g \sin 2x_3 + m l \dot{x}_4^2 \sin x_3}{M + m \sin^2 x_3}$
 $\dot{x}_4 = \frac{g \sin x_3 - \dot{x}_2 \cos x_3}{l}$
 Matlab Function

Selanjutnya: Desain, menentukan gain matrix
 $K = [K_1 \ K_2 \ K_3 \ K_4]$

Perancangan SISTEM KENDALI (Control Systems Design)



Perancangan SISTEM KENDALI

- Kendalian TERSEDIA
- Kendalian BELUM ADA

TUJUAN PENGENDALIAN

- terkait dengan KELUARAN
- terkait dengan KESTABILAN
- terkait dengan KINERJA:

- * respon (cepat/lambat)
 - * akurasi (error)
 - * cost & benefit → index kinerja
- Sistem Kendali OPTIMAL
- * lingkungan:
- Sistem Kendali ADAPTIF
- * "kekukuhan" (robustness)

→ "SMART"

← AI

Fuzzy Control
ANN (JST) → Algo.

* Design Tools

- * Modelling
- * Analisis
- * Simulasi

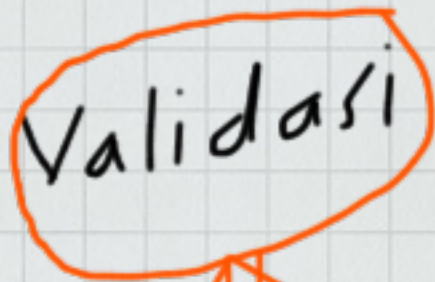
SciLab



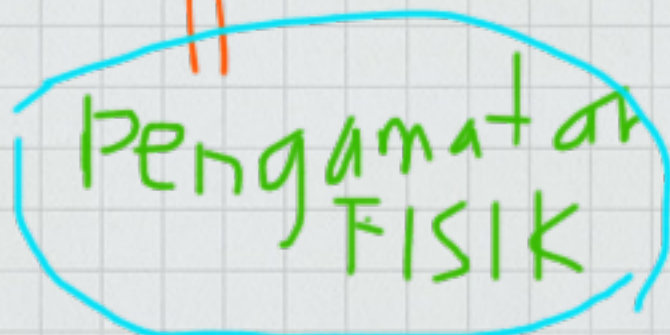
Dalam m.k. ini digunakan SIMULINK @ Matlab

Project 1: VERIFIKASI SIMULINK

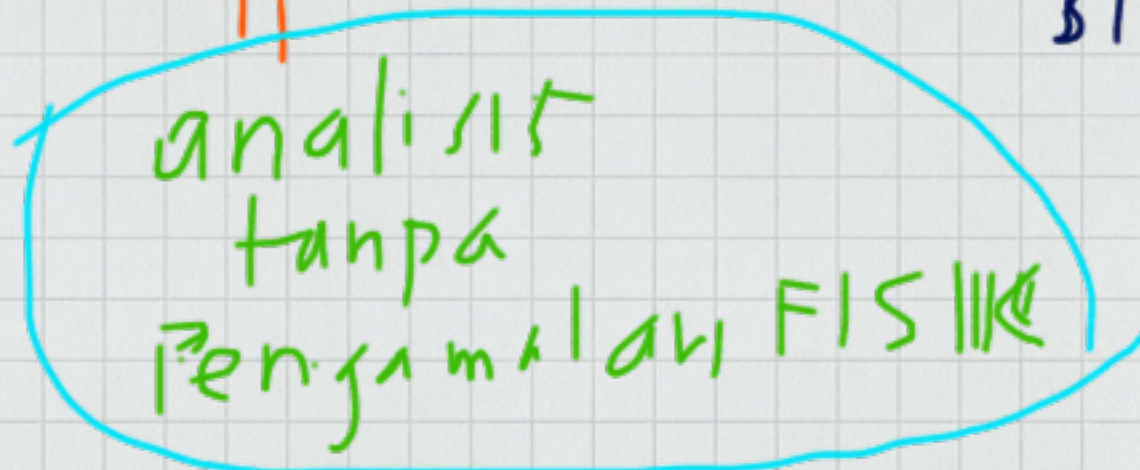
Validasi



Pengamat Fisik



analisis
tanpa
pengalaman FISIK



untuk menguji
kelayakan
SIMULINK
sbg. alat
perancangan

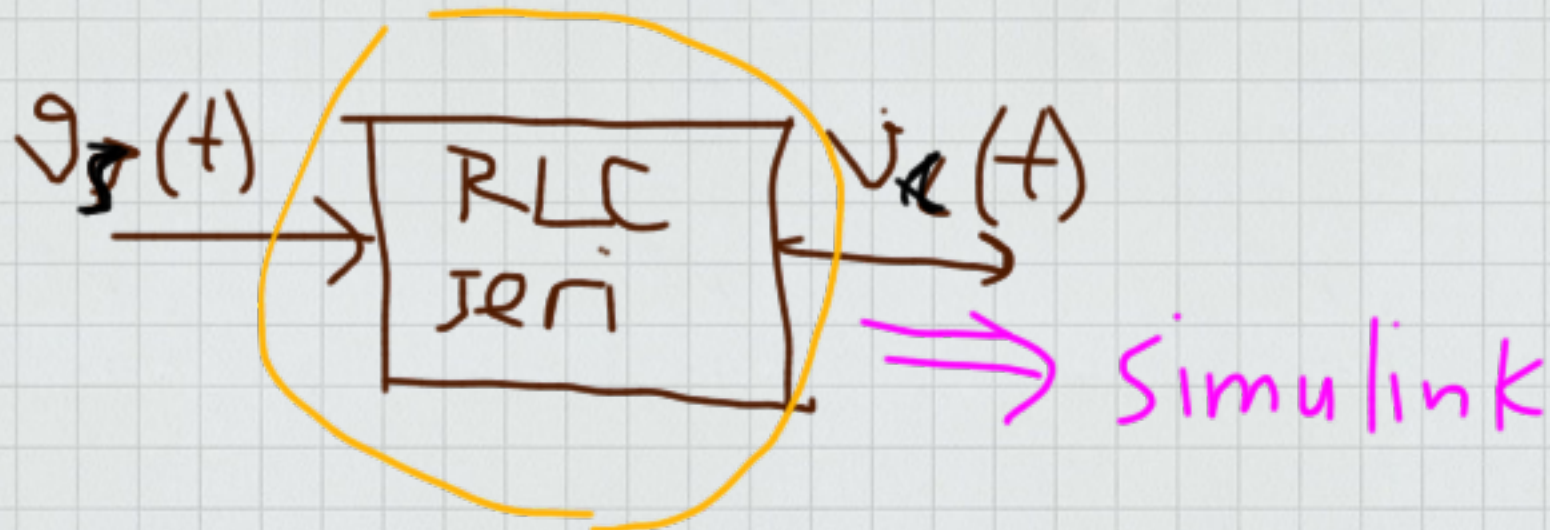
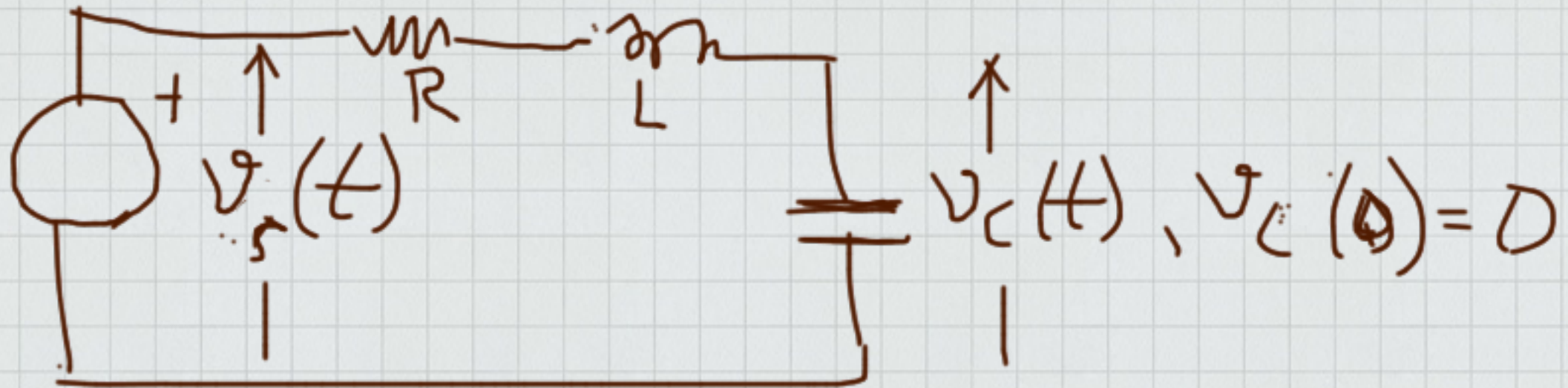
PROJECT 1 Verifikasi SIMULINK

deadline = 25 Sept. 2015

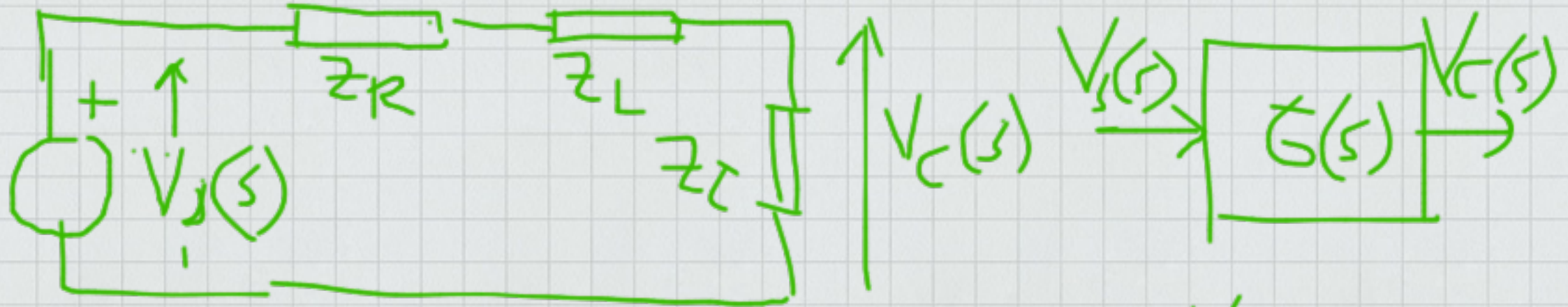
- diizinkan dikerjakan berpasangan
- tidak berganti pasangan sampai akhir sem.

Kasus: Pemuatan C melalui R & L seri

Analisis:



Konsep Impedansi



$$\begin{aligned} G(s) &= \frac{V_C(s)}{V_s(s)} = \frac{Z_C}{Z_R + Z_L + Z_C} = \frac{1/s}{R + Ls + 1/s} \\ &= \frac{1}{LCs^2 + RCs + 1} = \frac{1/LC}{s^2 + \frac{R}{L}s + \frac{1}{LC}} \\ &= \frac{K}{s^2 + 2\zeta\omega_n s + \omega_n^2} \end{aligned}$$

$\omega_n = \frac{1}{\sqrt{LC}} \text{ rad/sec}$
 $\zeta = \frac{R}{2} \sqrt{\frac{C}{L}}$

Misalnya $V_s(t)$ diperoleh dari
(saklar S ditutup pada
 $t=0$)

$$V_s(t) = 10 u(t)$$

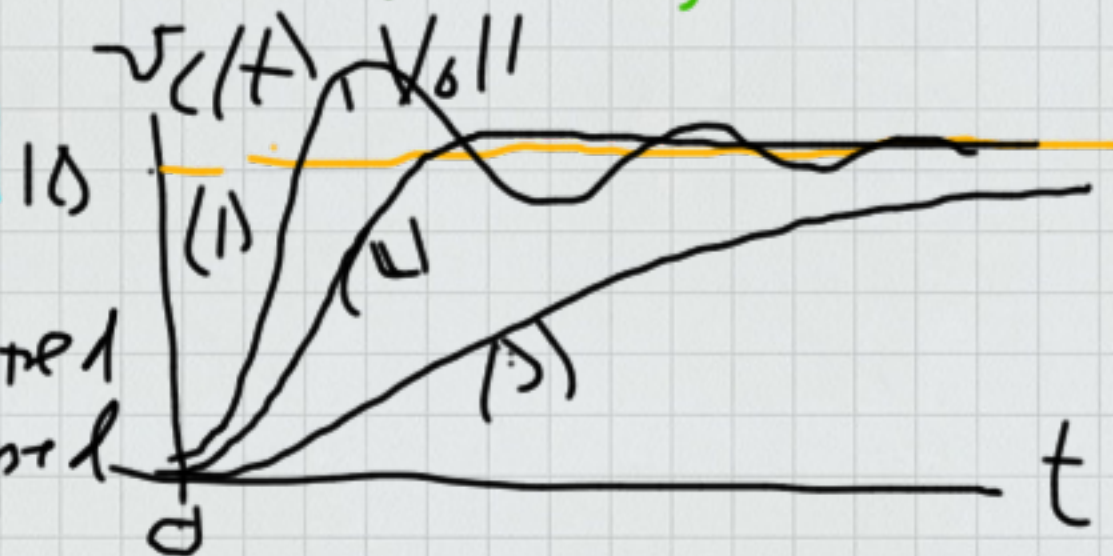
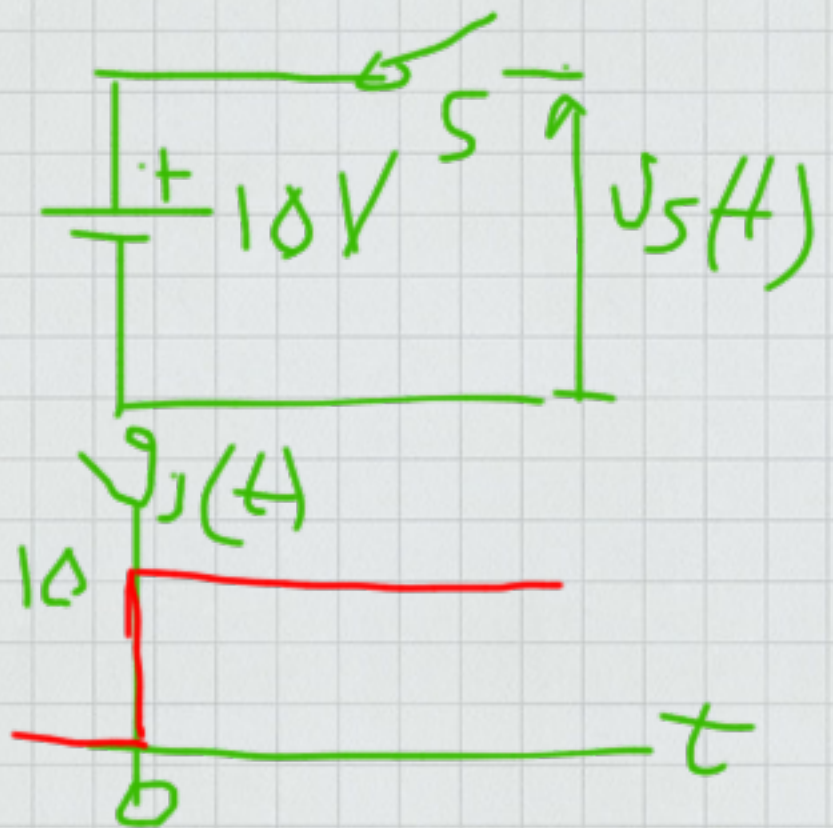
$$V_s(s) = \frac{10}{s}$$

$$V_c(s) = G(s) \cdot V_s(s) = \frac{K}{s(s^2 + 2\zeta\omega_n s + \omega_n^2)}$$

$$V_c(t) = \mathcal{L}^{-1} \cdot V_c(s)$$

3 kasus:

- (1) $0 < \zeta < 1$ underdamped
- (2) $\zeta = 1$ critically damped
- (3) $\zeta > 1$ overdamped



Menentukan nilai R, L dan C:

(1) $D41112 ABC \longrightarrow R = ABC \text{ K}\Omega$

(2) $D41112 XYZ \longrightarrow L = XYZ \text{ mH}$

* Tentukan C supaya $\xi_0 = 1 \rightarrow$ critically damped
Dengan Tabel Laplace $\rightarrow v_c(t) = \dots$
(hasil analitik)

* Perbesar nilai $R > ABC \text{ K}\Omega$ supaya $\xi > 1$
Dengan Tabel Laplace $\rightarrow v_c(t)$, overdamped

* Perkecil nilai $R < ABC \text{ K}\Omega$ supaya $0 < \xi < 1$
Dengan Tabel Laplace $\rightarrow v_c(t)$, under damped

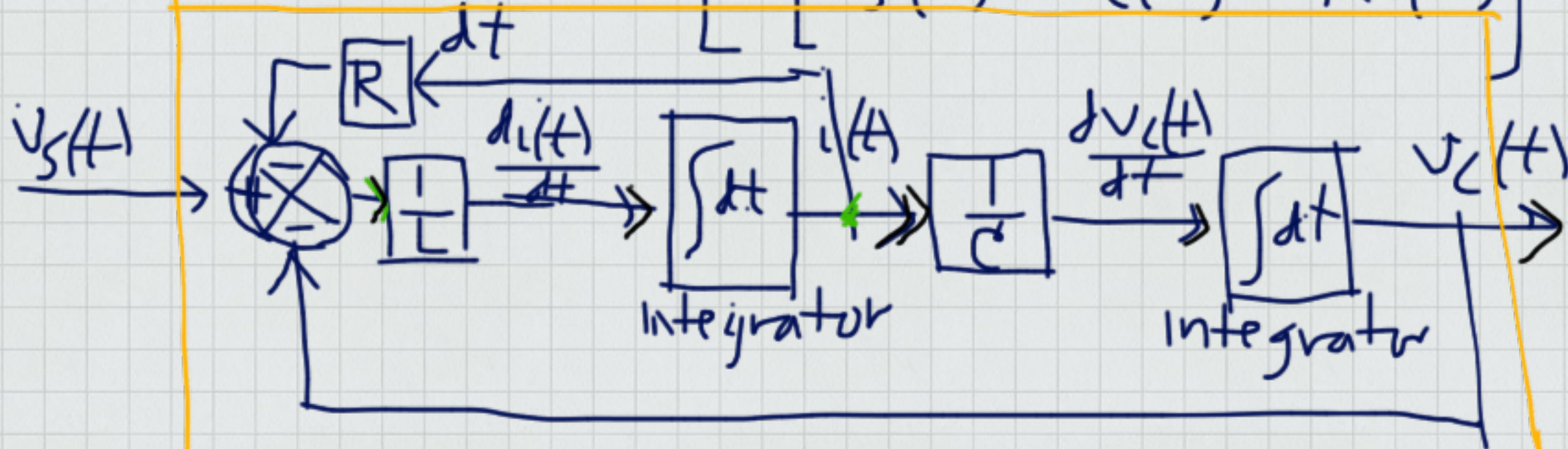
* Model Simulink

* Hukum Ohm:

$$\Rightarrow i(t) = C \frac{dV_C(t)}{dt} \rightarrow \frac{dV_C(t)}{dt} = \frac{1}{C} i(t)$$

$$\Rightarrow V_S(t) - V_C(t) = R i(t) + L \frac{di(t)}{dt}$$

$$\frac{di(t)}{dt} = \frac{1}{L} [V_S(t) - V_C(t) - R i(t)]$$



Dengan model Simulink di atas, dilakukan MINIMAL gx simulasi, dengan 3 nilai R yang berbeda dan masing-masing minimal di-simulasi dengan 3 macam nilai TOLERANSI. Hasil simulasi di-muat ke dalam spread sheet (xls, xlsx, csv)

time	$V_c(t)$ ANA	$V_i(t)$ SIM	Error $\left \frac{ANA - SIM}{ANA} \right \times 100\%$
0	0	0	0
↓ COPY Paste	↓ fungsi	↓ COPY paste	↓ dihitung

Contoh:

$$R = 282 \text{ k}\Omega$$

$$L = 288 \text{ mH}$$

$$\xi = \frac{R}{2} \sqrt{\frac{C}{L}} \rightarrow \xi = 1 \text{ (critically damped)}$$

$$\frac{282 \times 10^3}{2} \sqrt{\frac{C}{288 \times 10^{-3}}} = 1$$

$$C = 288 \times 10^{-3} \left(\frac{2}{282 \times 10^3} \right)^2 \text{ F}$$

with $\xi = 1$

$$= 14,486 \text{ pF}$$

$$G(s) = \frac{K}{(s+a)^2}$$

$$\rightarrow K = \frac{1}{LC} = \frac{1}{288 \times 10^{-3} \times 14.486 \times 10^{-12}}$$
$$= 2,397 \times 10^{11}$$

$$a = \sqrt{\frac{1}{LC}} = 489,591,68$$

$$V_i(s) = \frac{10}{s} \rightarrow V_c(s) = G(s) \cdot V_i(s) = \frac{10K}{s(s+a)^2}$$

$$v_e(t) = \int_{-1}^{0-1} \frac{10K}{s(s+a)^2}$$

$$K = \frac{1}{LC}$$

$$a = \sqrt{\frac{1}{LC}}$$

$$= \frac{10K}{a^2} \left(1 - \underline{e^{-at}} + \underline{ate^{-at}} \right)$$

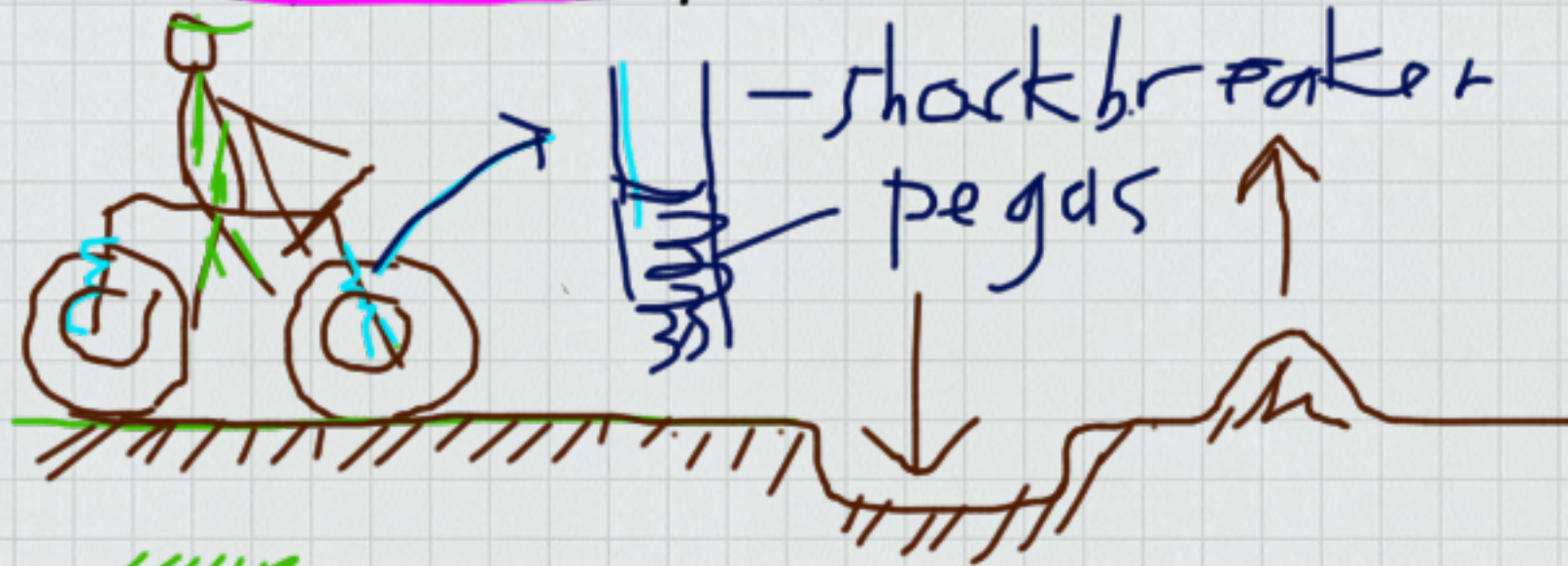
$$= 10 \left(1 - e^{-at} + ate^{-at} \right)$$

$$t=0 \rightarrow v_e(0) = 0$$

$$t \rightarrow \infty \rightarrow v_e(t) \rightarrow 10$$

* PROJECT 2 : Sistem Suspensi Sepeda Motor

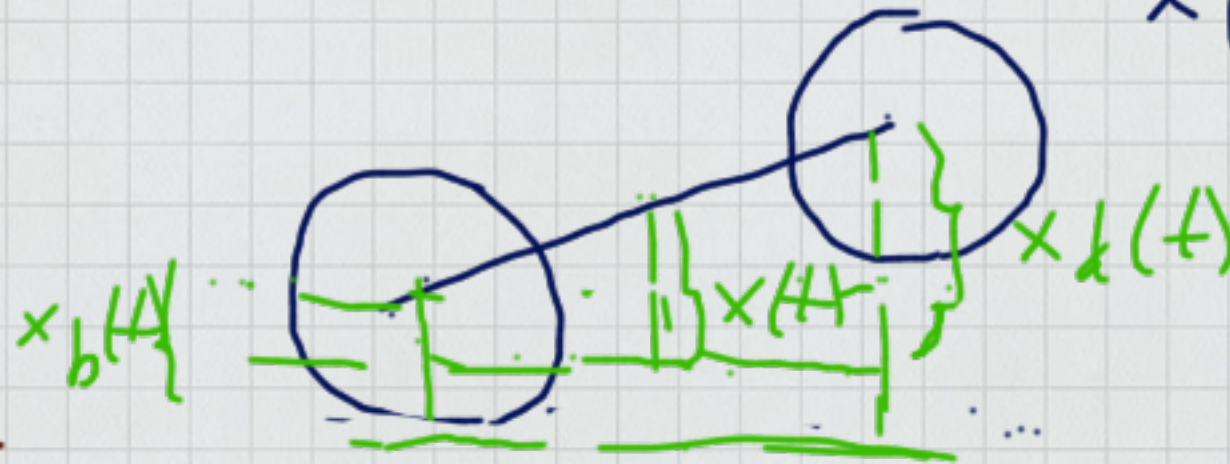
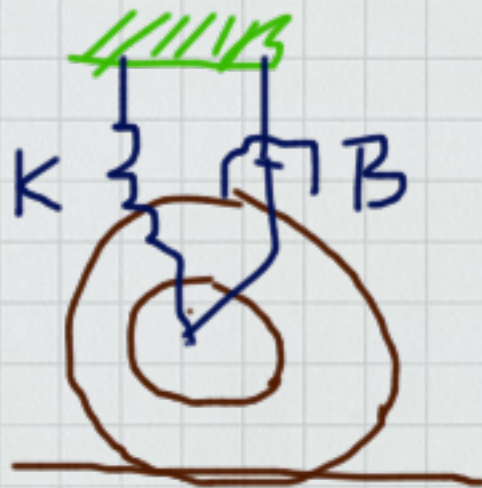
Dikumpulkan: 16/10/15



guncangan
pengendalian

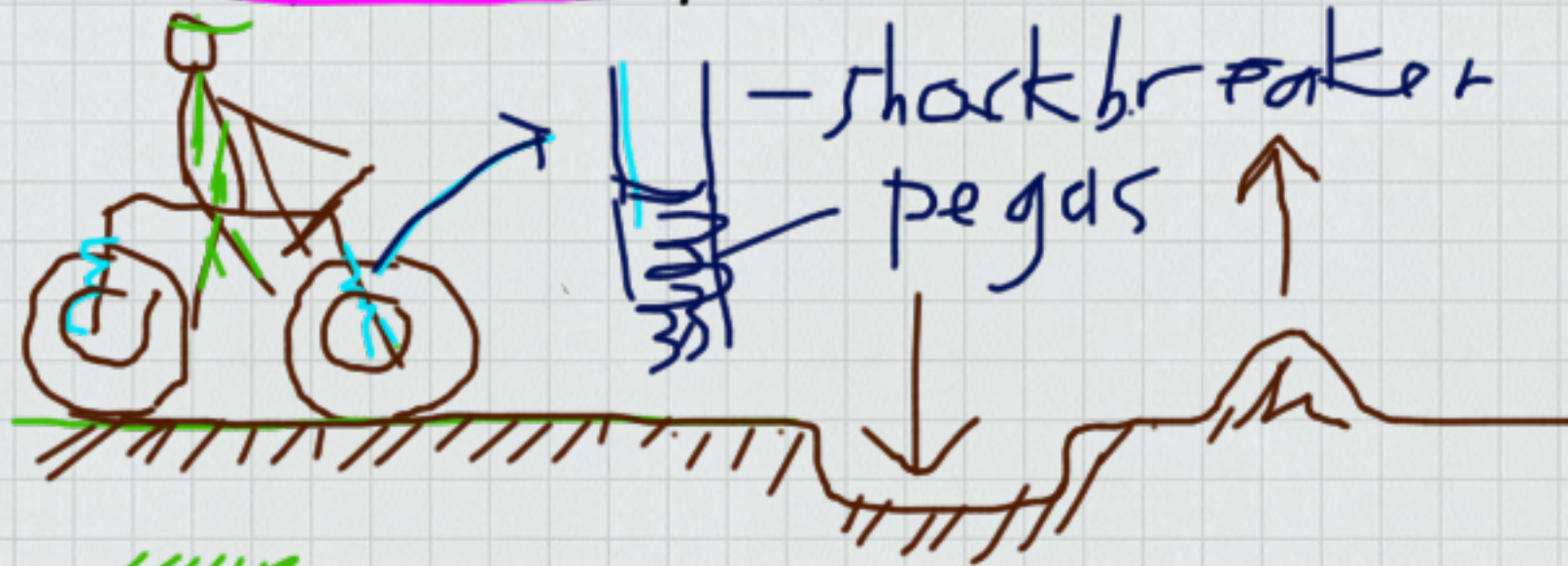
$$x(t) = \frac{1}{2}(x_d(t) + x_b(t))$$

↑
bela.
guncangan
roda depan



* PROJECT 2 : Sistem Suspensi Sepeda Motor

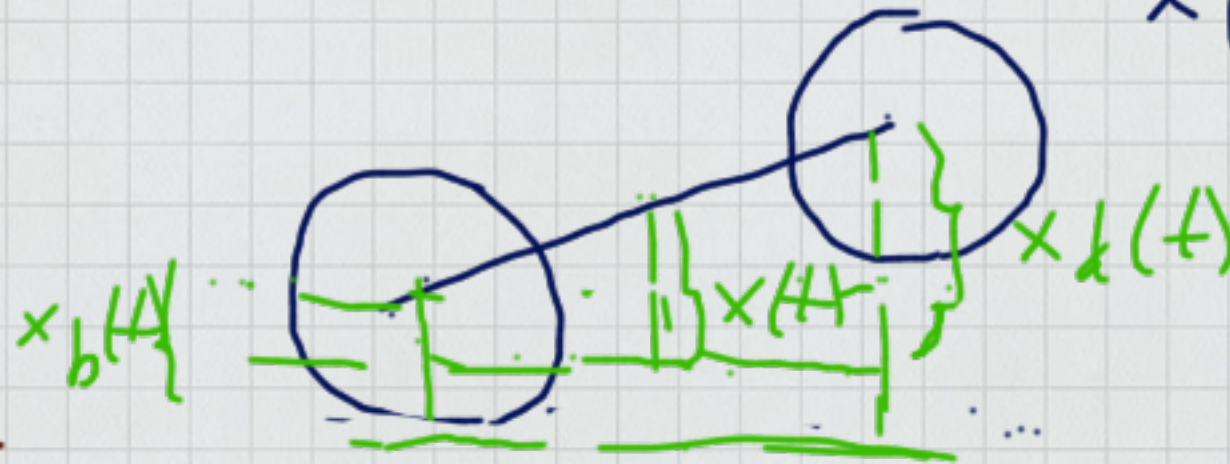
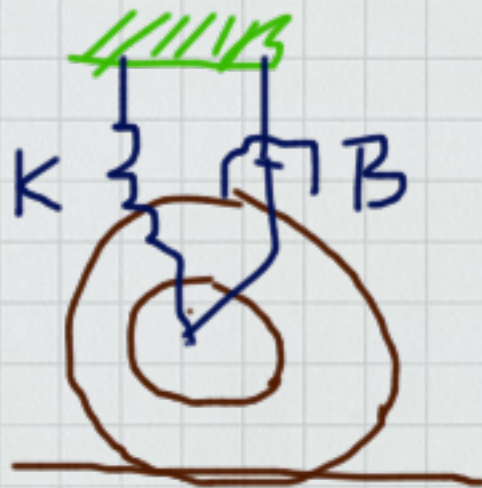
Dikumpulkan: 16/10/15

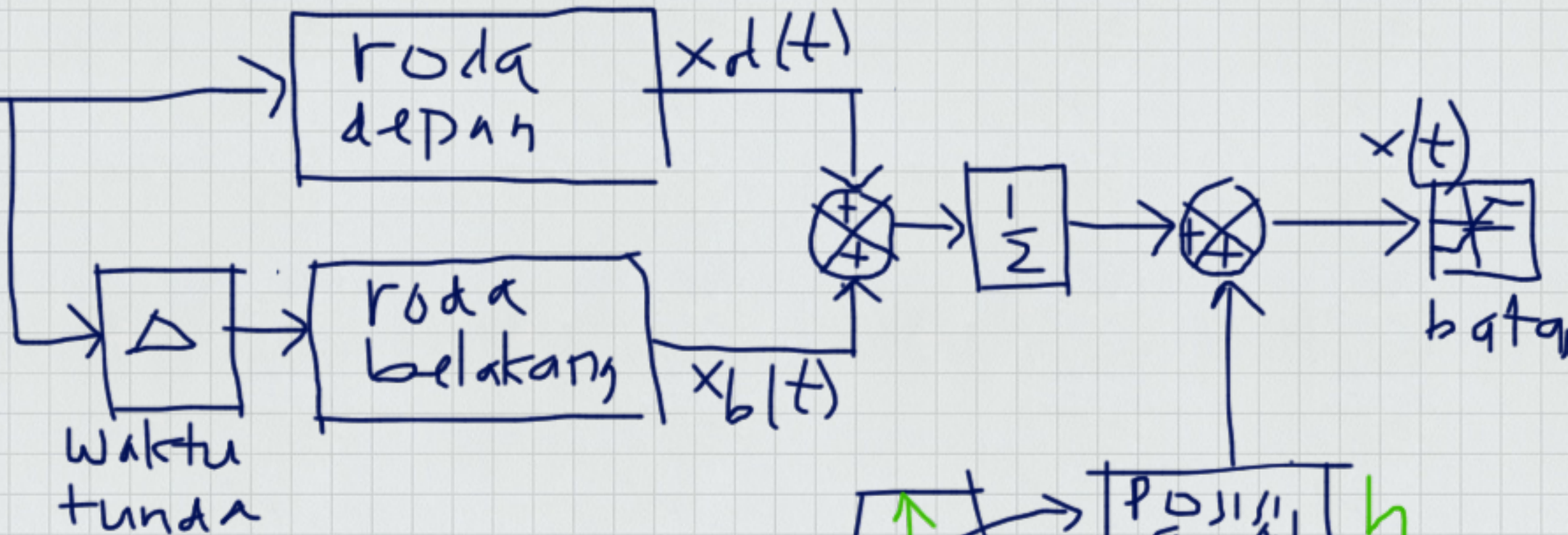


guncangan
pengendalian

$$x(t) = \frac{1}{2}(x_d(t) + x_b(t))$$

↑
bela.
guncangan
roda depan

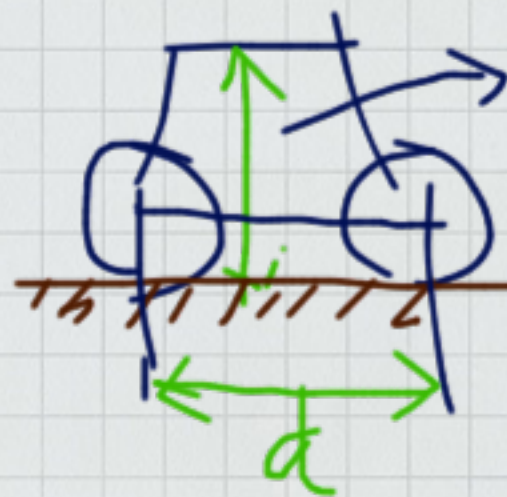


$F(t)$


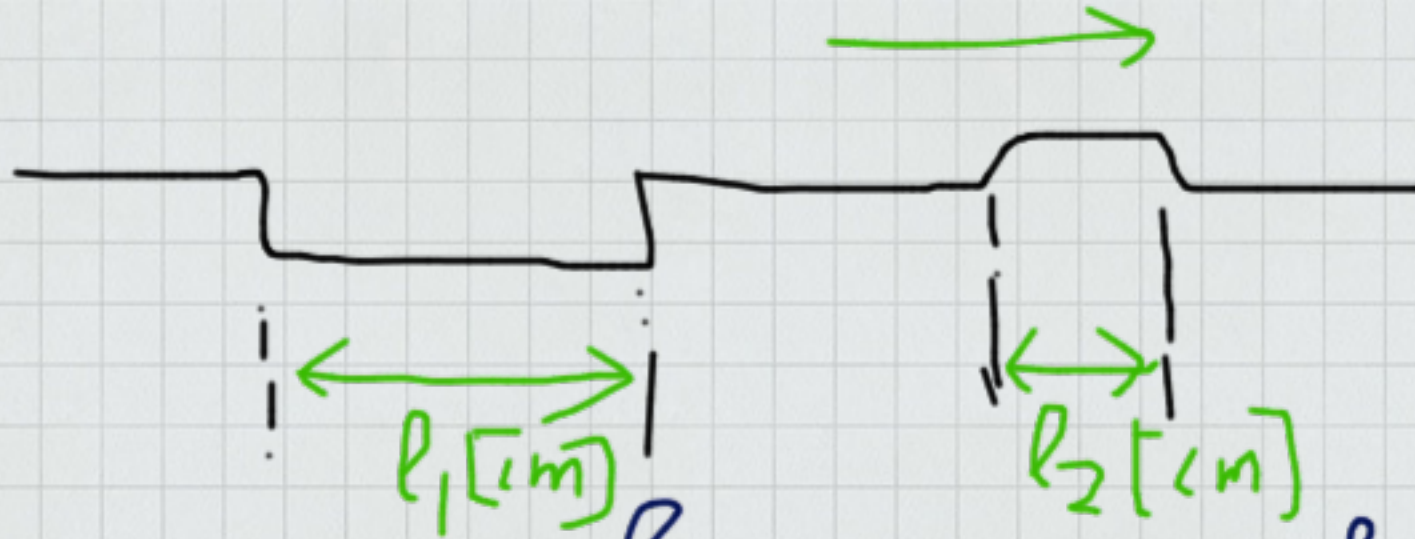
$$\Delta = \frac{d \text{ [cm]}}{v \left[\frac{100.000 \text{ cm}}{3600 \text{ sec}} \right]}$$

$$v = [\text{km/h}] \quad d = [\text{cm}]$$

$$\Delta = \frac{3600}{100.000} \frac{d}{v} \text{ [sec]}$$



$$\Delta = 0.036 \frac{d}{v} \text{ [sec]}$$



$$t_1 = 0,136 \frac{l_1}{v}$$

[sec]

$$t_2 = 0,136 \frac{l_2}{v}$$

[sec]

durasi: masuk lubang, naik polisi tidur

* Batas $x(t)$: $x(t)_{\min} \rightarrow h_{\max}$
 $x(t)_{\max} \rightarrow h_{\min}$

* "Delay" dan "lagging"

* Model sistem suspensi $\rightarrow$ $\begin{matrix} (K) & (M) \\ \text{Spring-mass-} \\ \text{damper} \\ (B) \end{matrix}$

* Data Pengukuran:

$d =$ (jarak roda depan dan belakang)
[m]



l_1 dan $l_2 \rightarrow$ diinjak motor

$x(t)_{min}$ dan $x(t)_{max}$: $x(t)$ NORMAL (dalam keadaan dikendarai)
 h_{min}, h_{max}, h

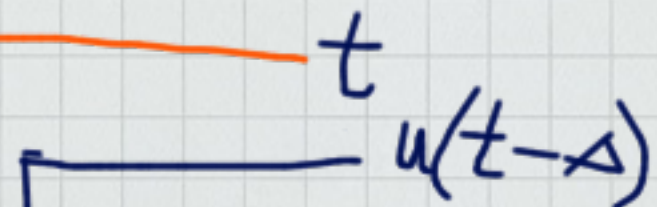
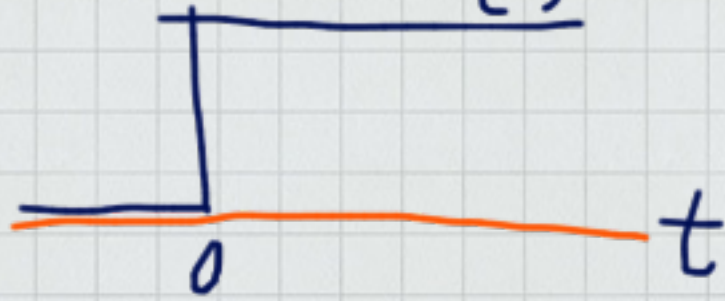
$v < 10 \text{ km/jam}$

M + penumpang/pengendara (kg)
 $\hookrightarrow$ berat motor (kg)

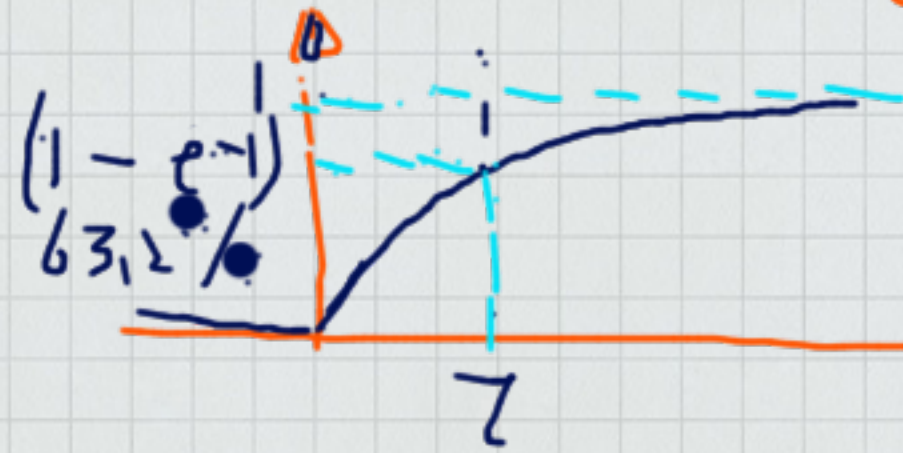
D411T ABCD
B } A, B, C, D
K }
 $K [N/m], B [N \cdot sec/m]$

* Delay dan Lagging

$u(t)$

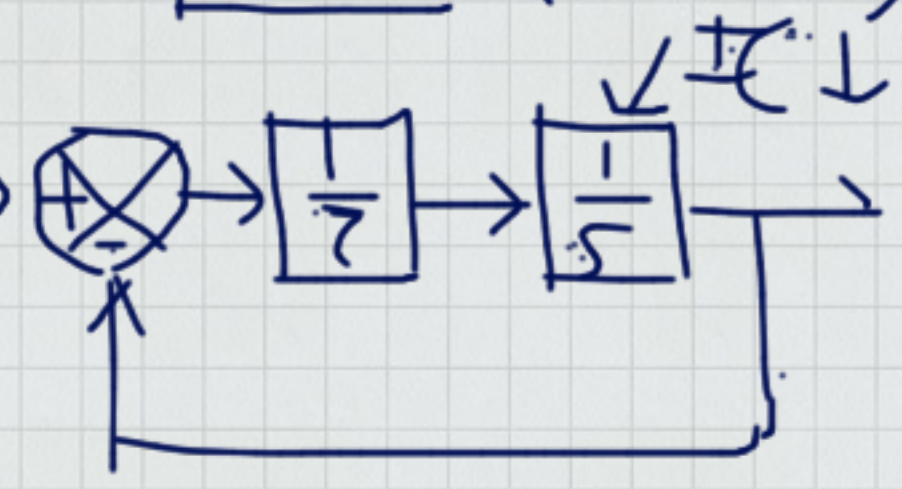
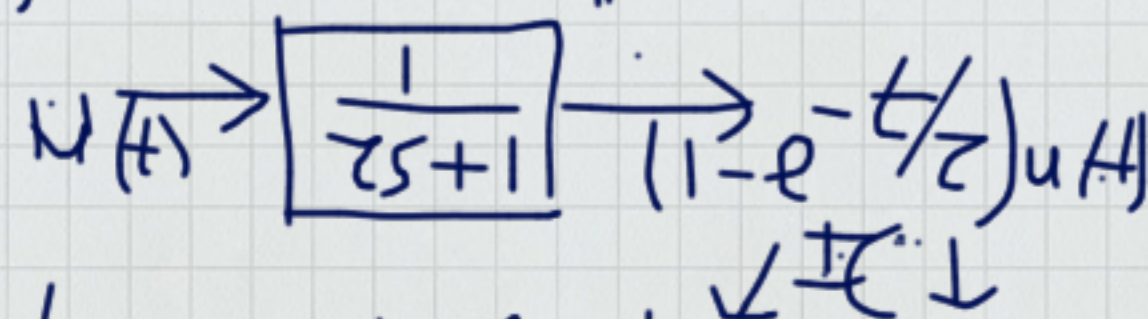
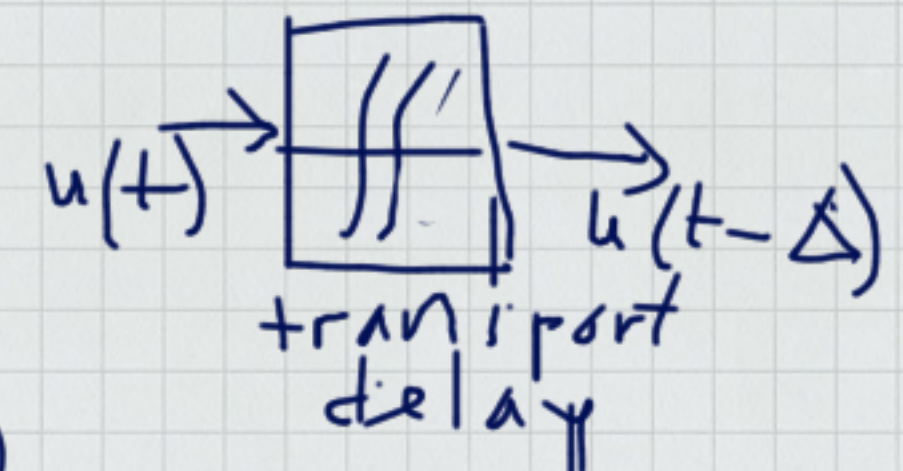
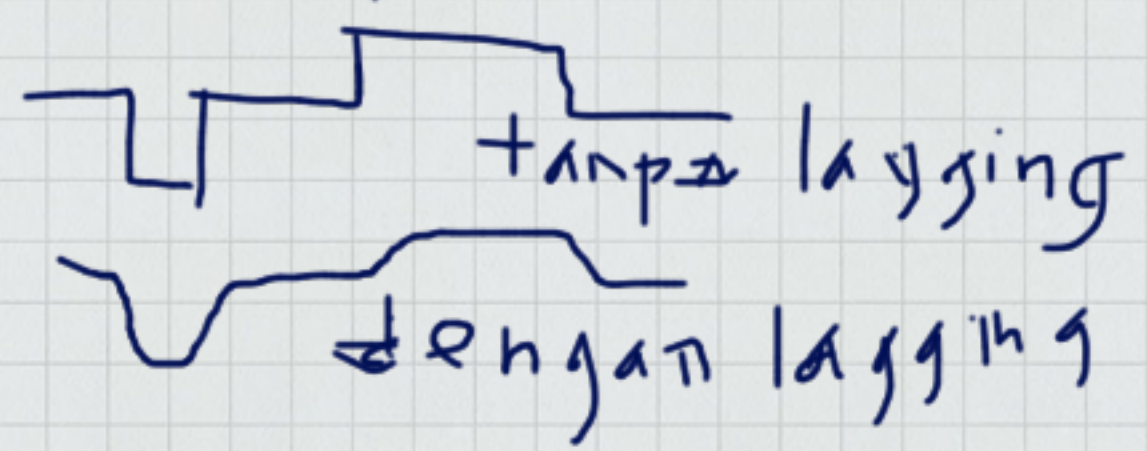


transport delay



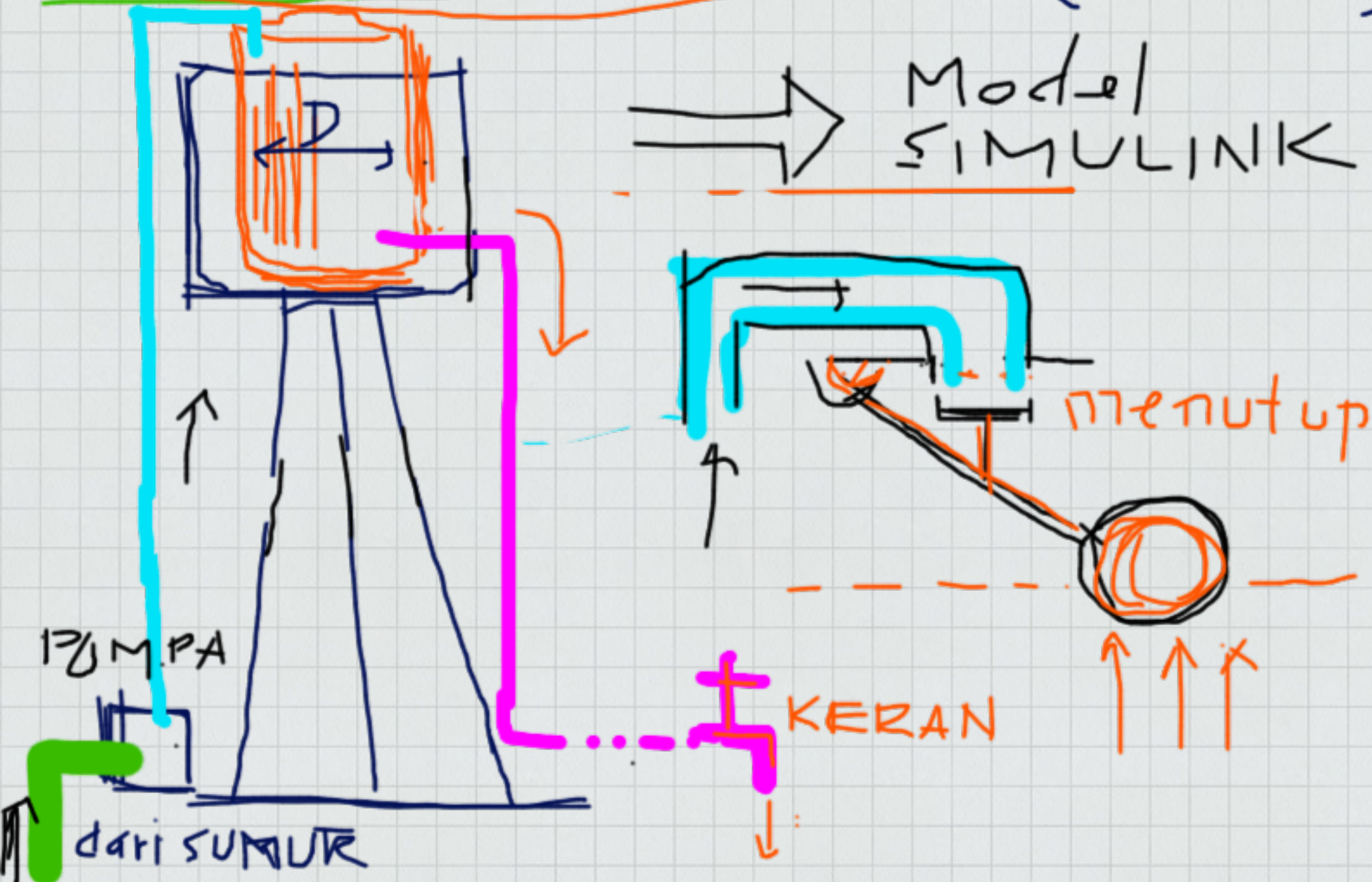
lagging

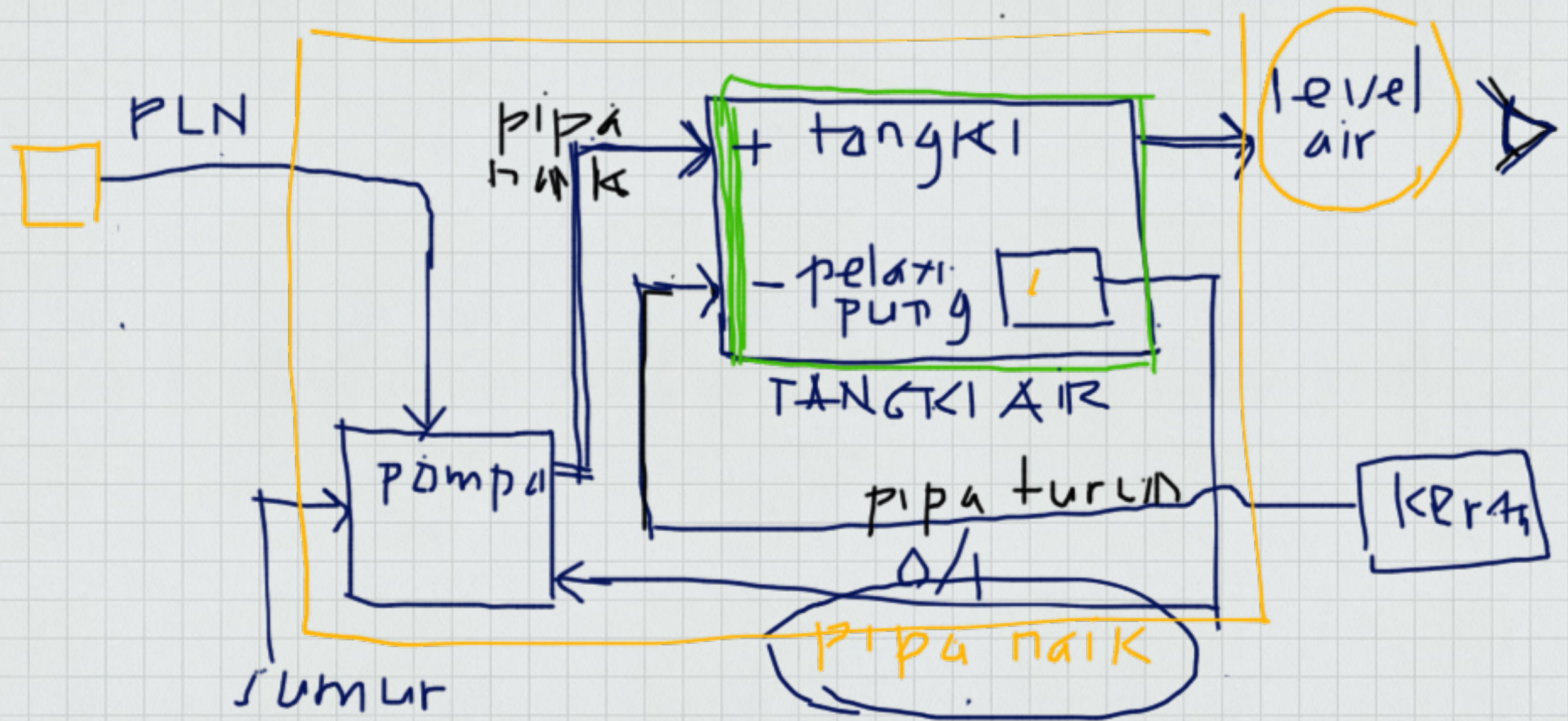
$\tau = \text{time constant}$



PROJECT 1 → dibagikan
PROJECT 2 → dikumpul

PROJECT 3 MENARA AIR (30/10/15)





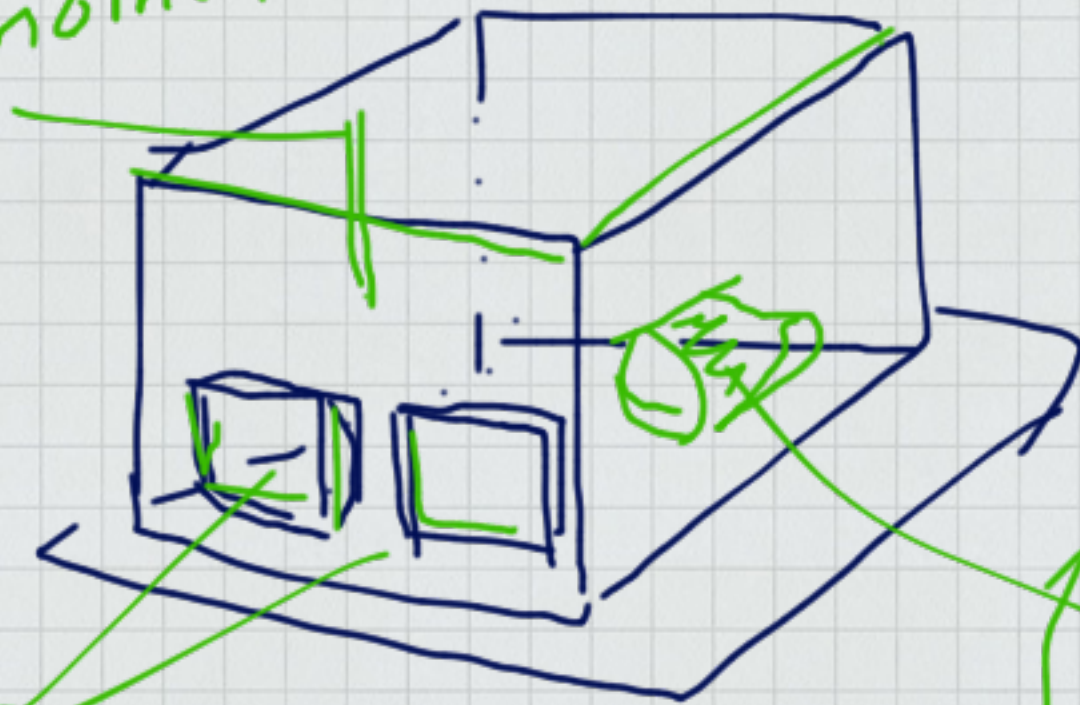
Data lapangan :

- * Tangki : Volume : V [liter]
Diameter D [cm]
- * Pompa : Debit Hisap/Dorong
- * Keran : Debit [liter/sec]

PROJECT 4 (dikumpul 20/11/2015)

Pengatur Suhu Ruangan

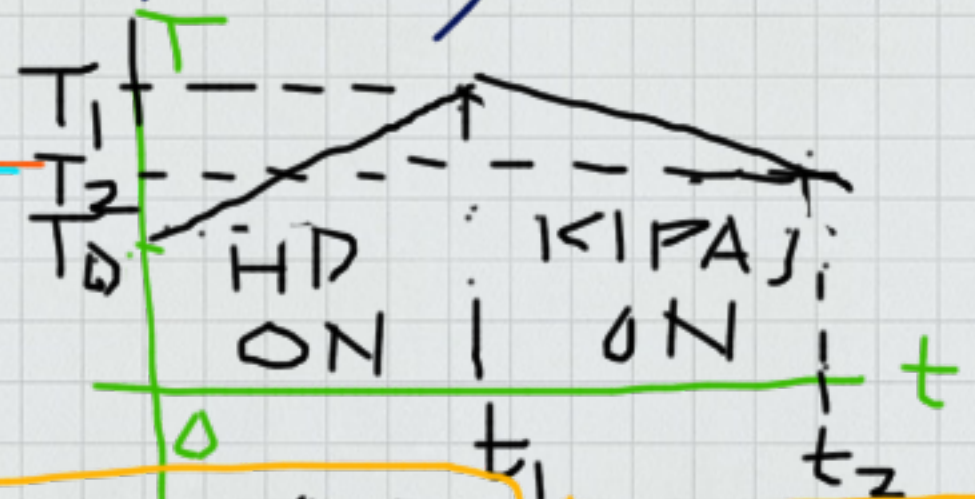
thermometer



KIPAS

Pengerina Rambut

HD



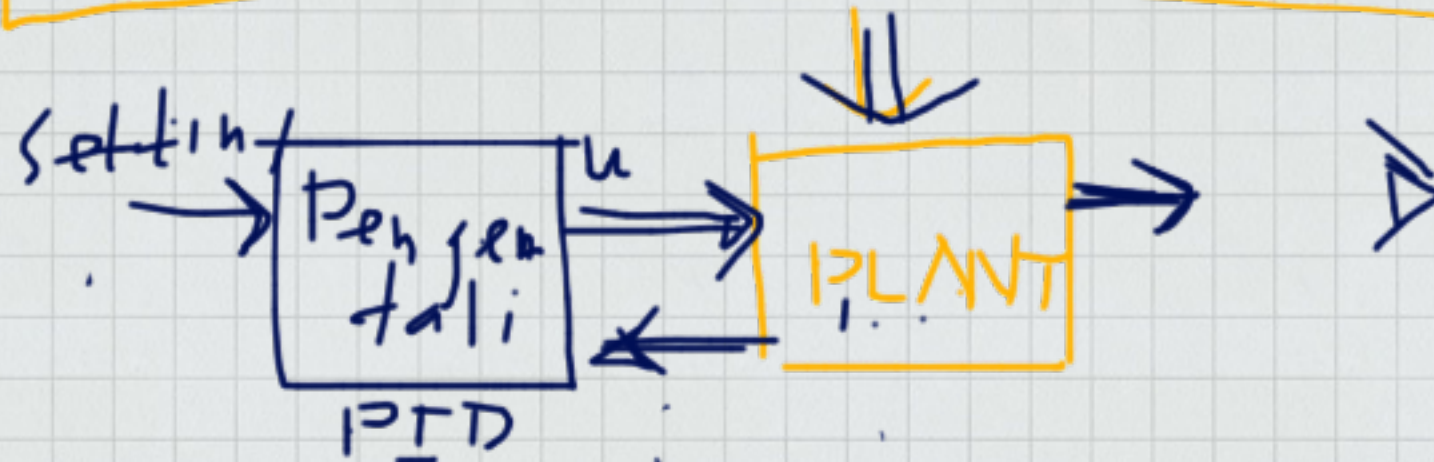
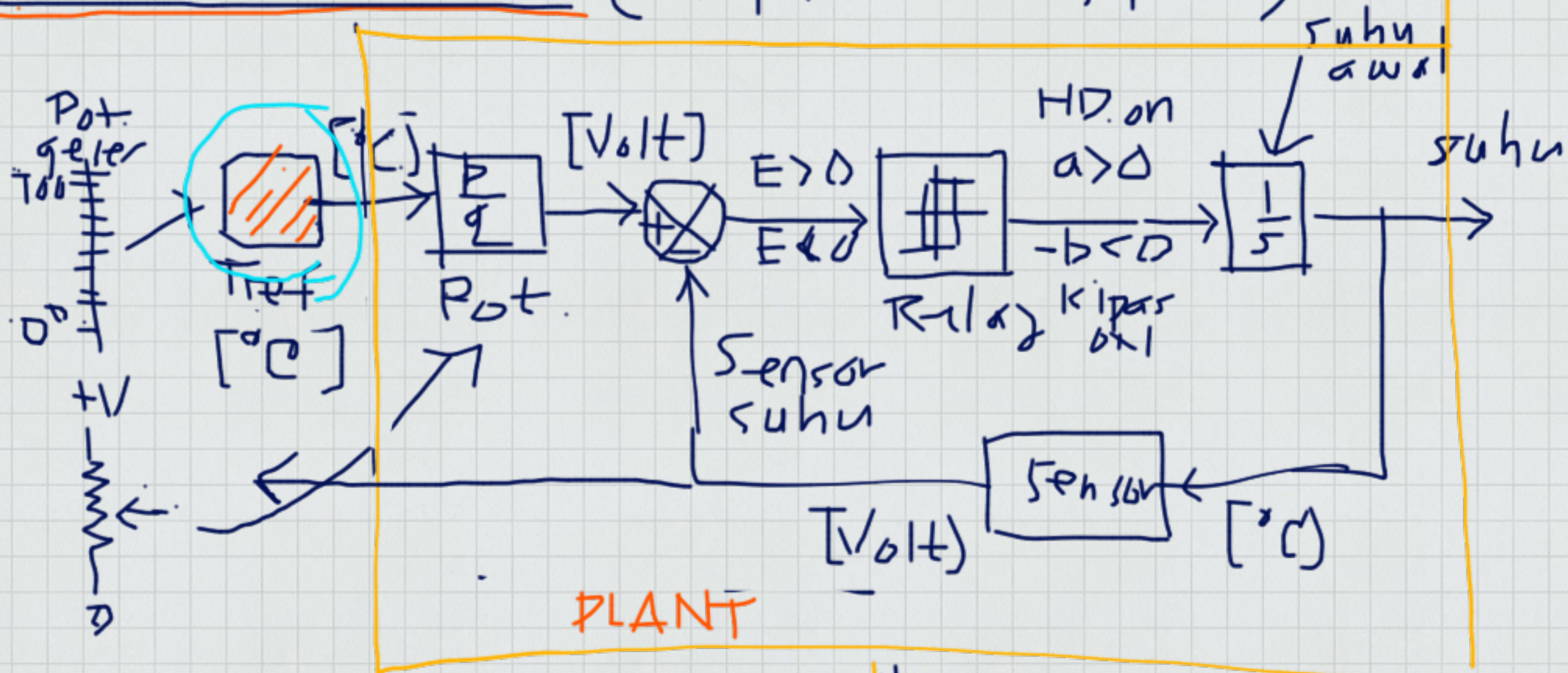
$$a = \frac{T_1 - T_0}{t_1}$$

$$b = \frac{T_1 - T_2}{t_2 - t_1}$$

Pengamatan:

- * Laju kenaikan suhu ketika Pengerina Rambut ON
- * Laju penurunan suhu ketika KIPAS ON

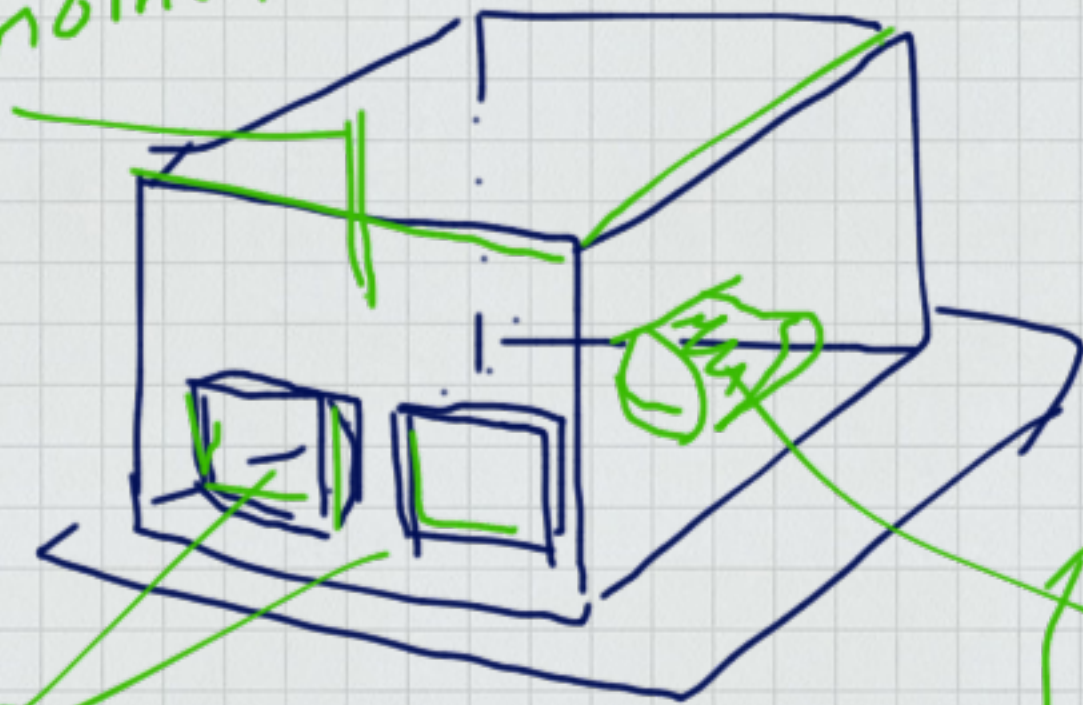
Model SIMULINK (tanpa kendali, plant)



PROJECT 4 (dikumpul 20/11/2015)

Pengatur Suhu Ruangan

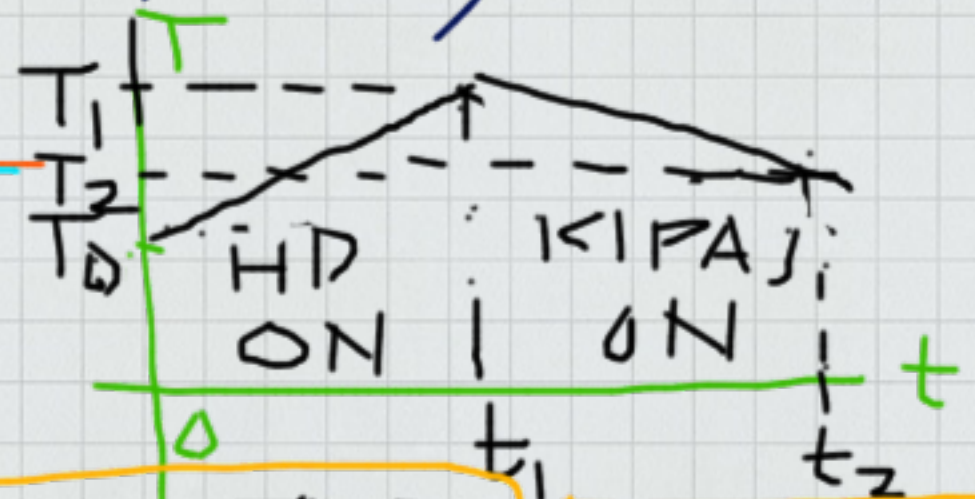
thermometer



KIPAS

Pengerina Rambut

HD



$$a = \frac{T_1 - T_0}{t_1}$$

$$b = \frac{T_1 - T_2}{t_2 - t_1}$$

Pengamatan:

- * Laju kenaikan suhu ketika Pengerina Rambut ON
- * Laju penurunan suhu ketika KIPAS ON

* Projects:

- * Project 1 = Verifikasi Simulink $\Rightarrow$ Toleransi Relatif
- * Project 2 = Sistem Suspensi Kendaraan
(Stable, linear, second order)
- * Project 3 = Menara Air (Stable, nonlinear)
- * Project 4 = Pengatur Suhu (quasi-stable, nonlinear)

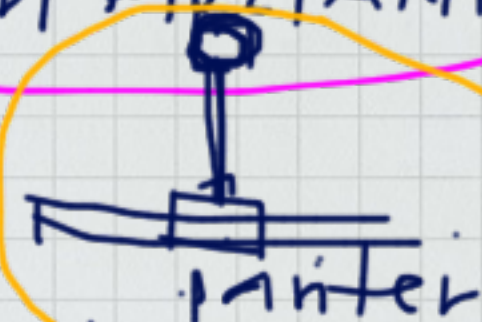
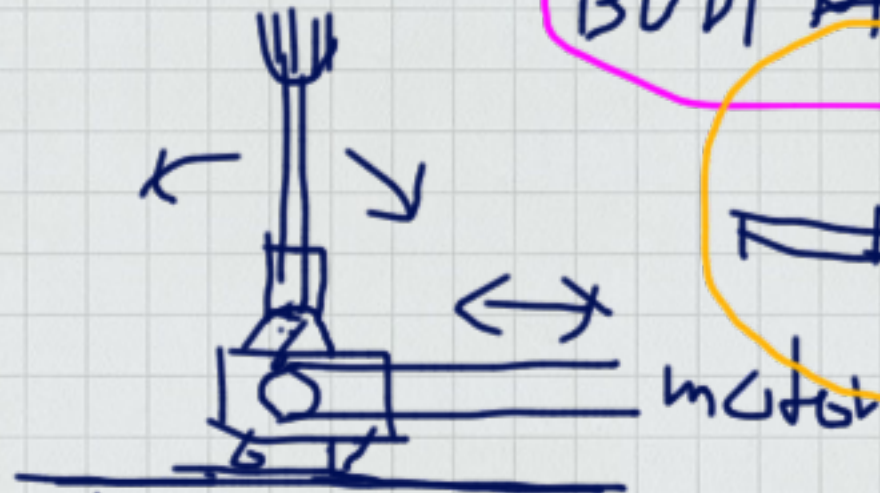
* PROJECT 5 - PENDULUM TERBALIK (Inverted Pendulum)

(Skripsi: a/n

ARIS
BUDI YAHYANI)

tip stable, nonlinear
plant 4th order

state variable feedback
 $A[4 \times 4]$



..... TSEL 3G 15.14 44%

unhas.ac.id

IE /rhiza/a/ Panic Atta... LBP Moho... how to set... en.m.wikip... Jokowi: Po... www.unha... Barrel - Wi... /rhiza/a... www.face...

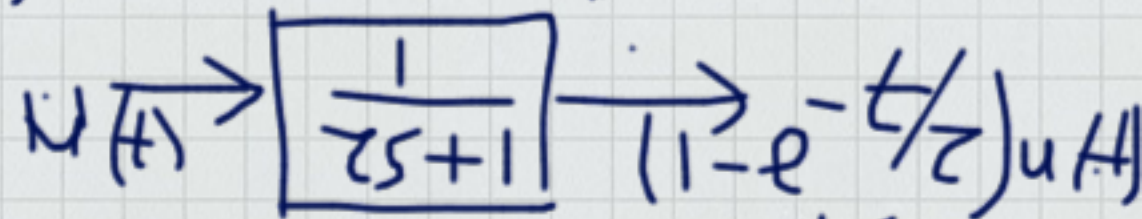
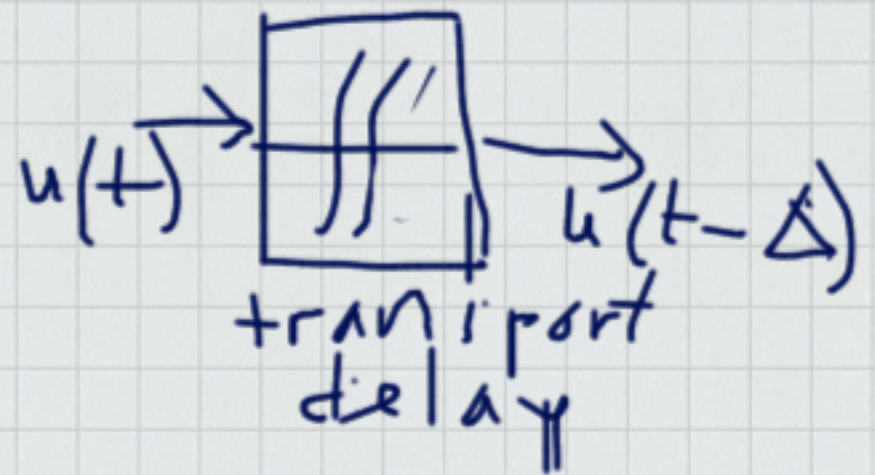
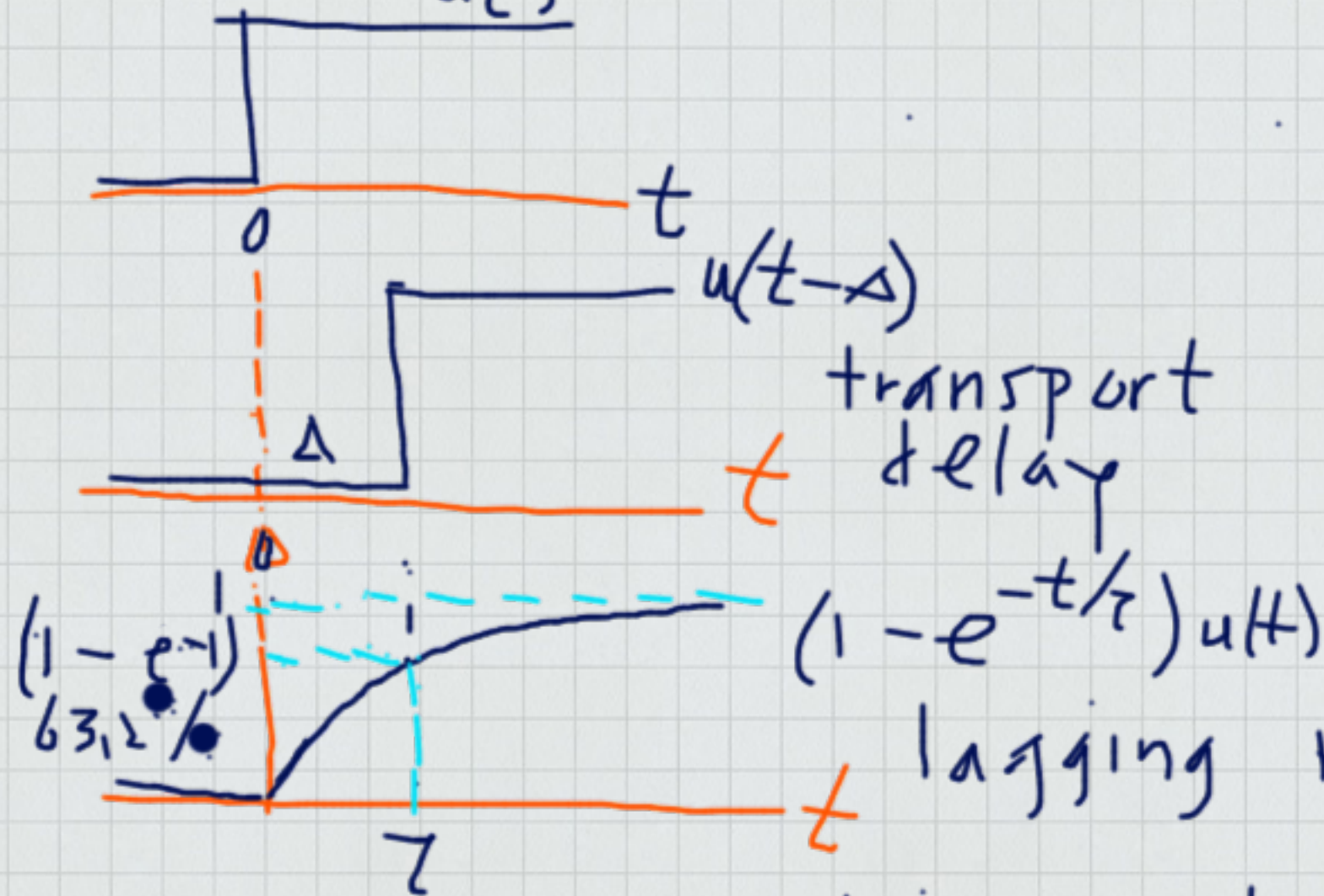
Index of /rhiza/arsip/kuliah/Perancangan-Sistem-Kendali/PSKendali2014/PROJECTS_2014

Name	Last modified	Size	Description
Parent Directory	-	-	-
Data_Suhu_Ruang_Project_4.ods	10-Nov-2014 16:01	11K	
Data_Suhu_Ruang_Project_4.xls	10-Nov-2014 03:01	8.5K	
PROJECT_1_Harry_Sullivan.docx	28-Sep-2014 09:42	147K	
Project_1_2014.mdl	15-Sep-2014 05:29	25K	
Project_1_2014.ods	22-Sep-2014 04:51	68K	
Project_1_2014.xls	22-Sep-2014 04:56	274K	
Project_2_2014.mdl	06-Oct-2014 05:13	42K	
Project_3_2014.mdl	27-Oct-2014 04:45	44K	
Project_4_2014.mdl	10-Nov-2014 21:10	45K	
Project_5_2014.mdl	01-Dec-2014 04:19	38K	
Project_5_2014/	11-Oct-2015 10:41	-	
delay_and_lagging.mdl	20-Oct-2014 05:08	23K	
pelampung.m	27-Oct-2014 04:23	120	
penggambar_delay.m	20-Oct-2014 04:30	236	
penggambar_menara_air.m	27-Oct-2014 04:30	314	
penggambar_motor.m	06-Oct-2014 04:54	146	
penggambar_suhu.m	10-Nov-2014 21:11	341	

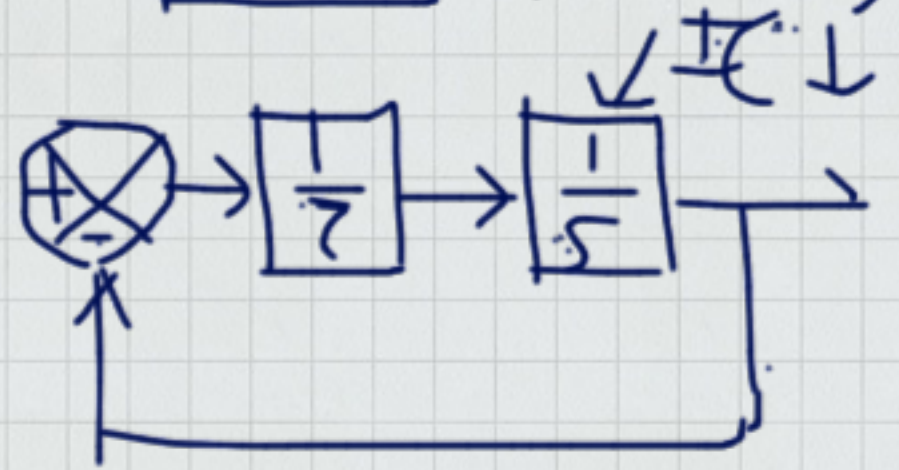
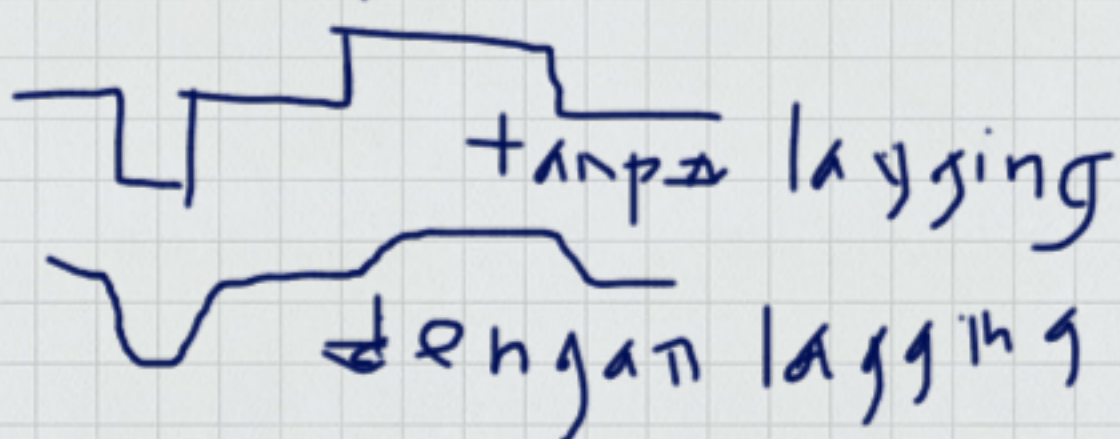
Untuk Tugas selama LIBUR 2x hari senin, unduh dan jalankan : Project_2_2014.mdl Konsultasi :

Setiap Selasa pagi setelah SKD

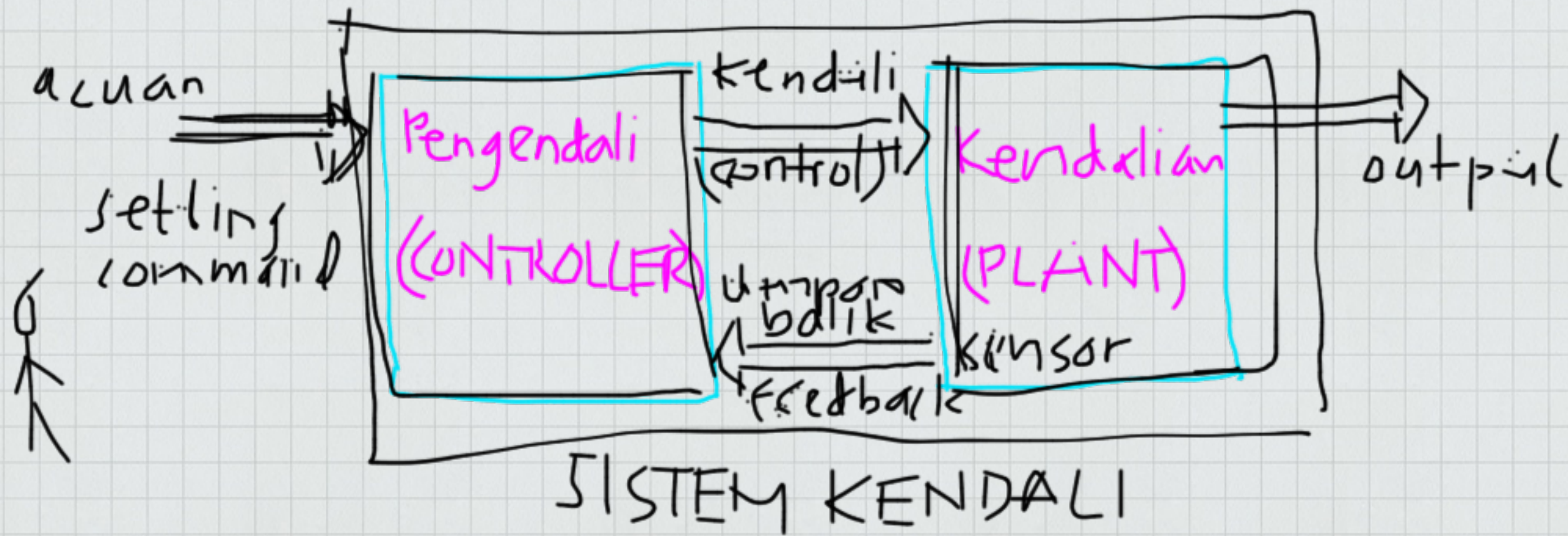
* Delay dan Lagging



$\tau = \text{time constant}$



Perancangan SISTEM KENDALI (Control Systems Design)



Perancangan SISTEM KENDALI

- Kendalian TERSEDIA
- Kendalian BELUM ADA

TUJUAN PENGENDALIAN

- terkait dengan KELUARAN
- terkait dengan KESTABILAN
- terkait dengan KINERJA:

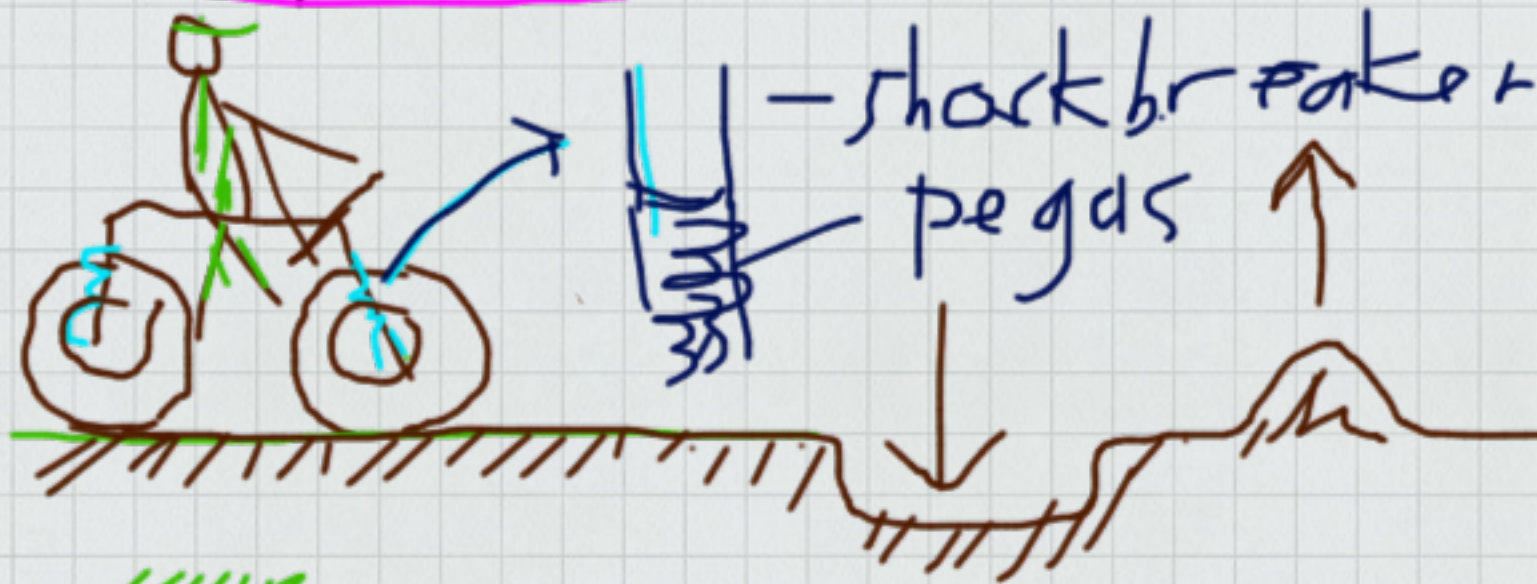
- * respon (cepat/lambat)
 - * akurasi (error)
 - * cost & benefit → index kinerja
- Sistem Kendali OPTIMAL
- * lingkungan:
- Sistem Kendali ADAPTIF
- * "kekukuhan" (robustness)

→ "SMART"

← AI

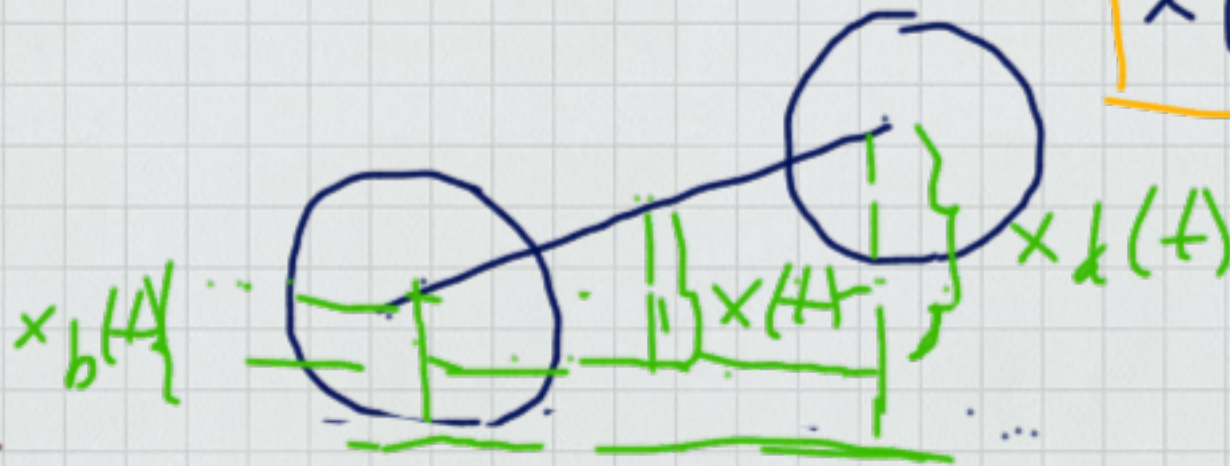
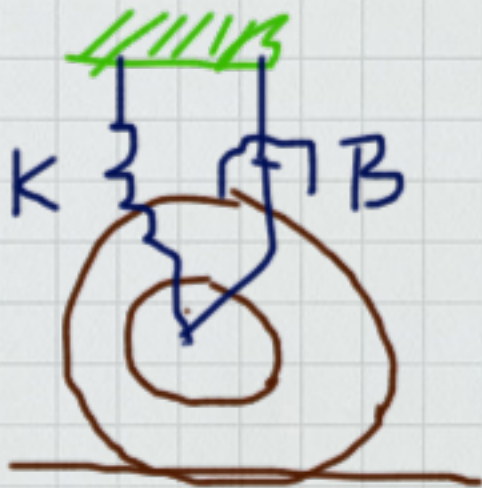
Fuzzy Control
ANN (JST) → Algo.

* PROJECT 2 : Sistem Suspensi Sepeda Motor



guncangan
pengendalian

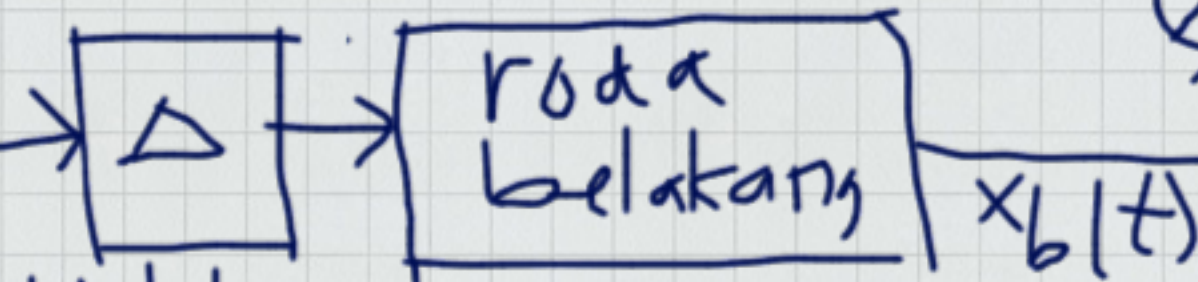
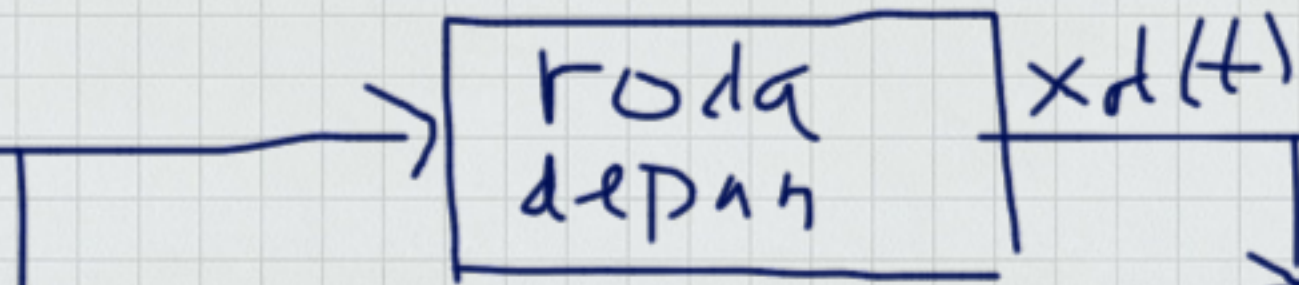
$$x(t) = \frac{1}{2}(x_d(t) + x_b(t))$$



belak.
guncangan kan
roda depan



$F(t)$

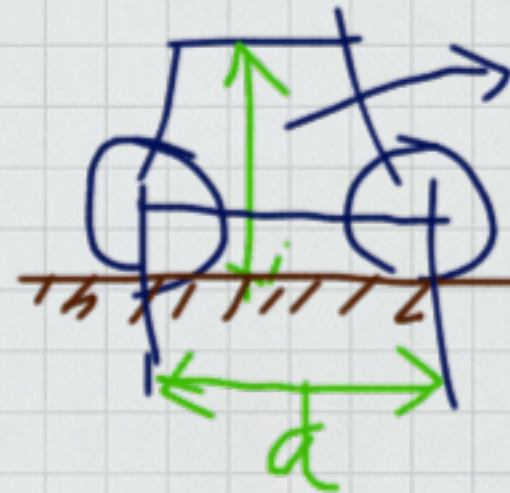


waktu tunda

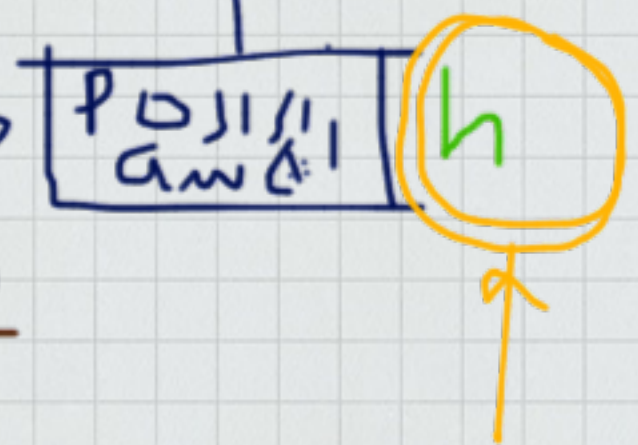
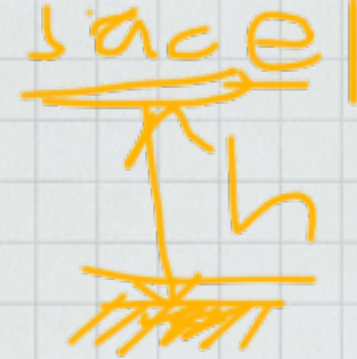
$$\Delta = \frac{d \text{ [cm]}}{v \left[\frac{100.000 \text{ cm}}{3600 \text{ sec}} \right]}$$

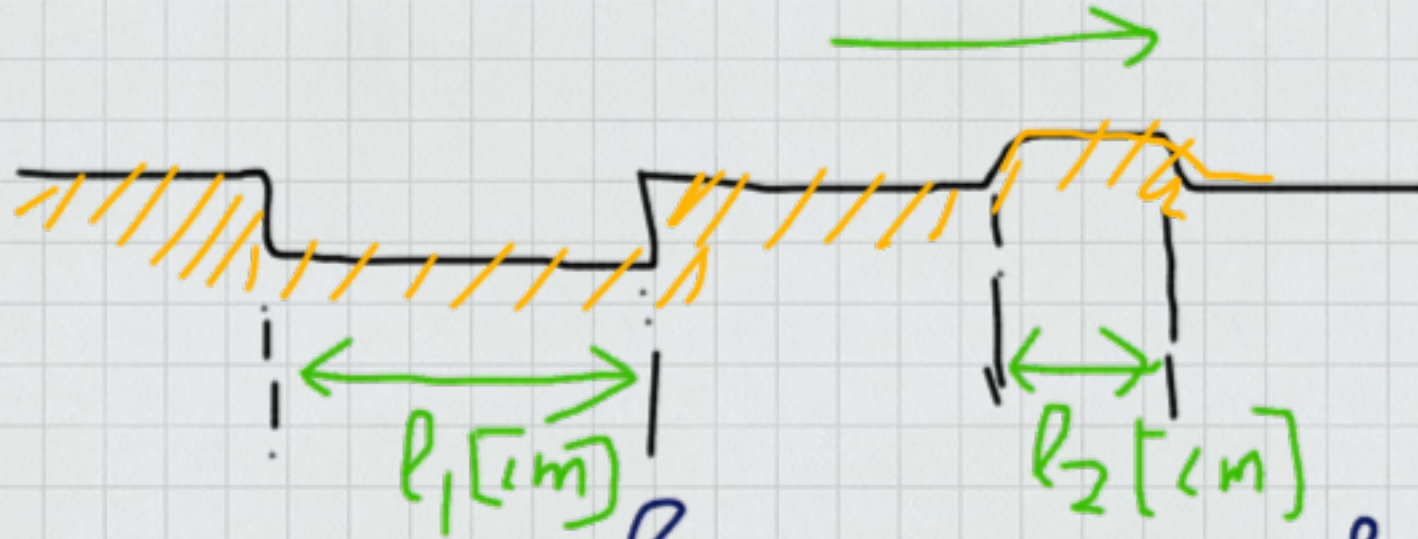
$v = [\text{km/jam}] \quad d = [\text{cm}]$

$$\Delta = \frac{3600}{100.000} \frac{d}{v} \text{ [sec]}$$



$$\Delta = 0.036 \frac{d}{v} \text{ [sec]}$$





$$t_1 = 0,136 \frac{l_1}{v} \quad [sec]$$

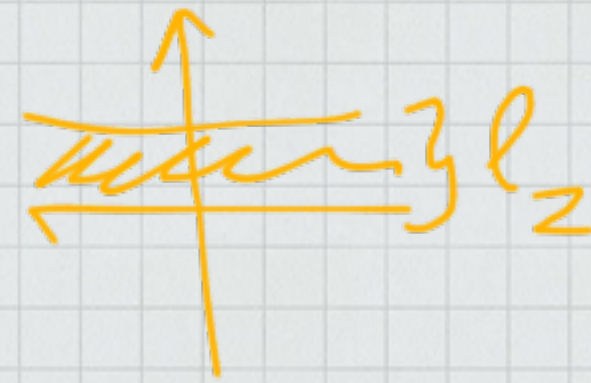
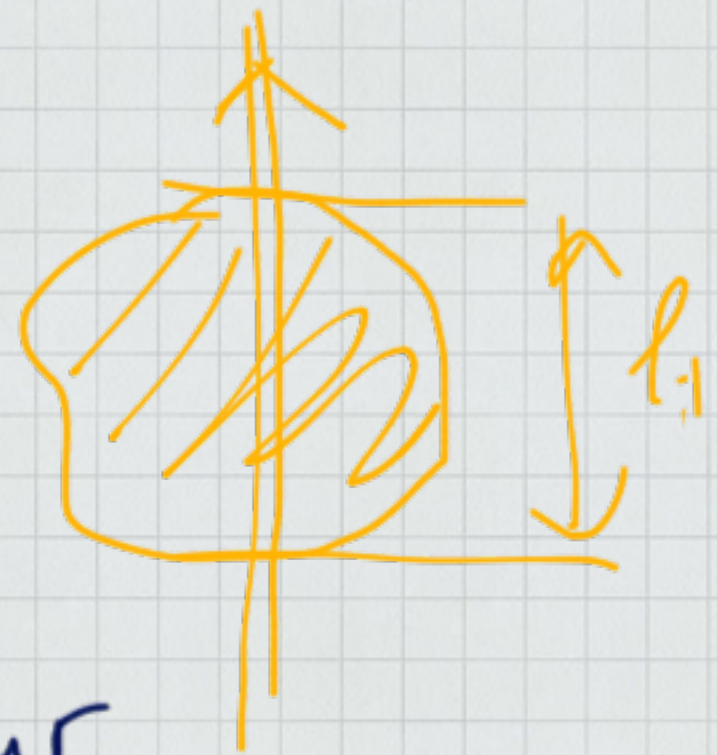
$$t_2 = 0,136 \frac{l_2}{v} \quad [sec]$$

durasi: masuk lubang, naik polisi tidur

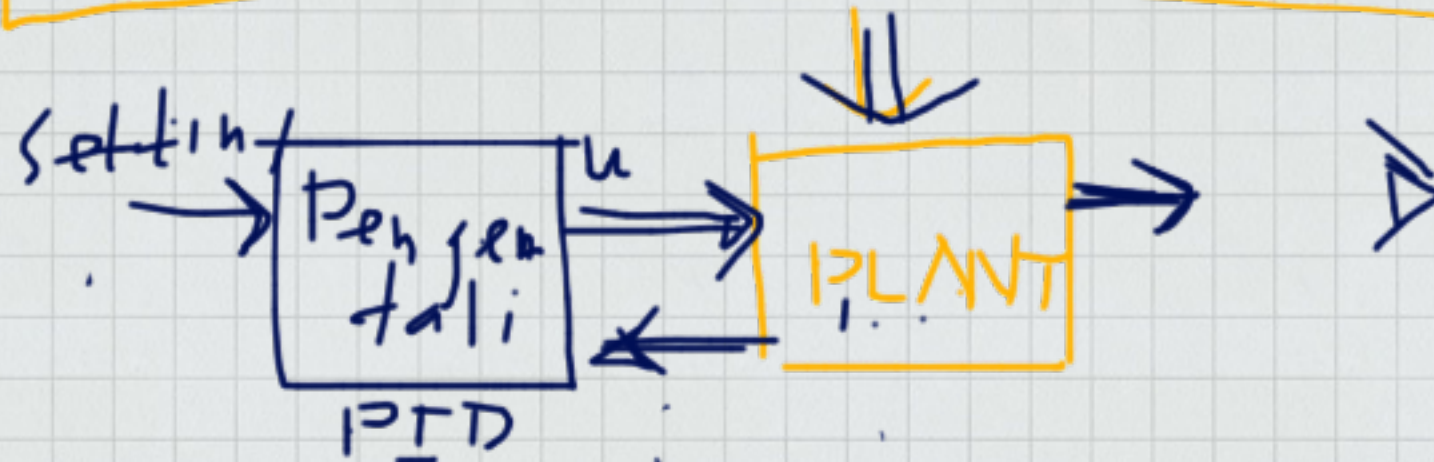
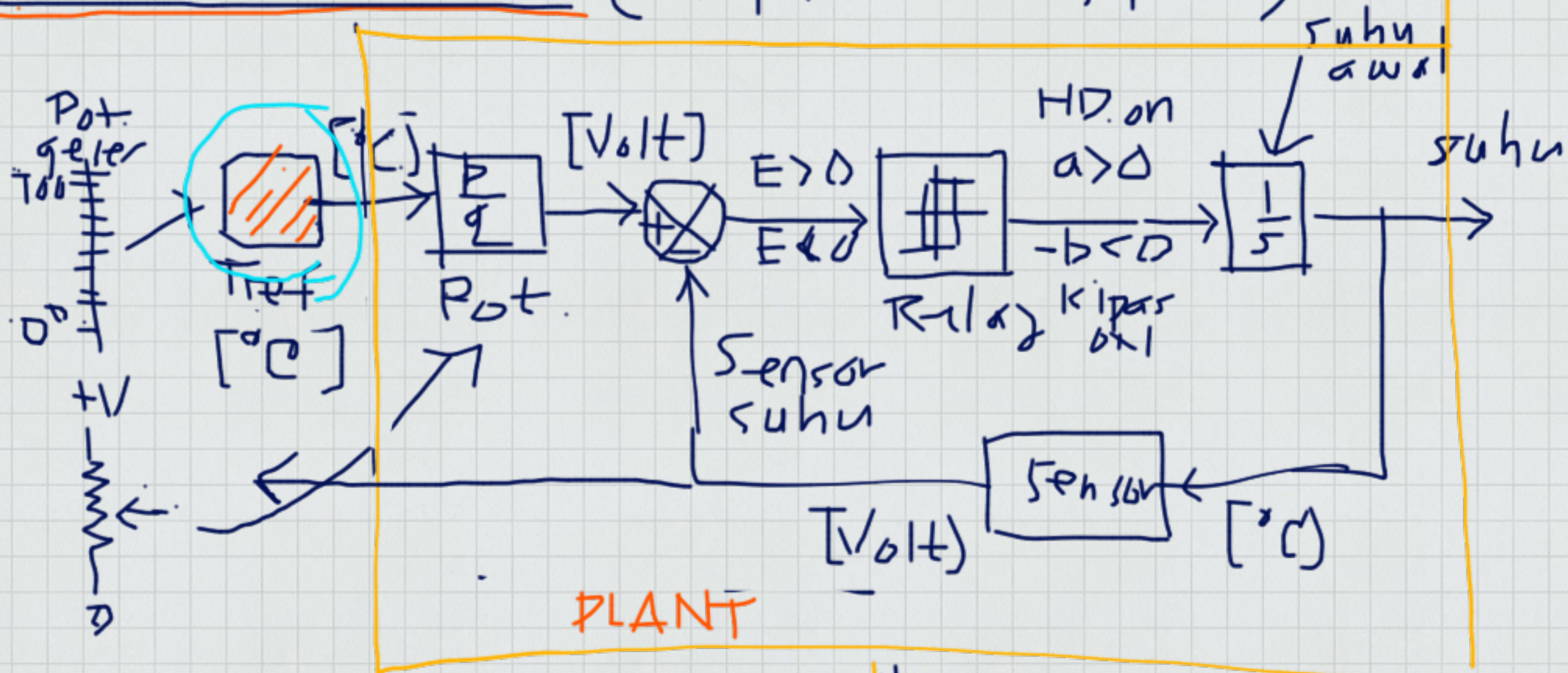
* Batas $x(t)$: $x(t)_{min} \rightarrow h_{max}$
 $x(t)_{max} \rightarrow h_{min}$

* "Delay" dan "lagging"

* Model sistem suspensi $\rightarrow$ $\begin{matrix} (K) & (M) \\ \text{Spring-mass-} \\ \text{damper} \\ (B) \end{matrix}$



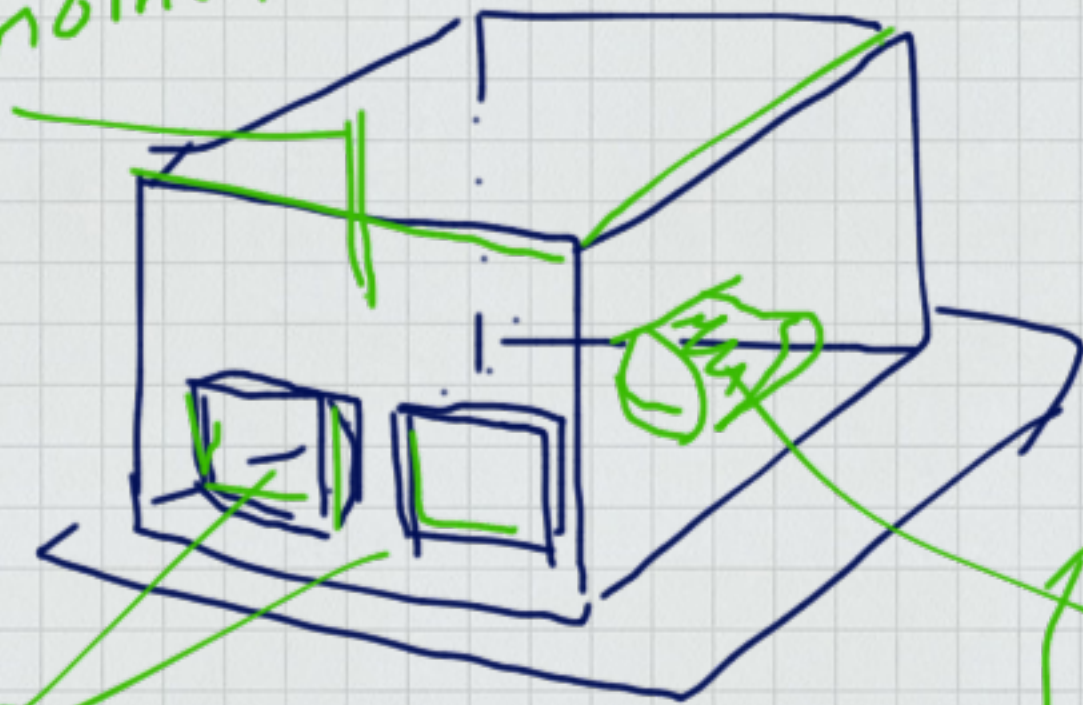
Model SIMULINK (tanpa kendali, plant)



PROJECT 4 (dikumpul 20/11/2015)

Pengatur Suhu Ruangan

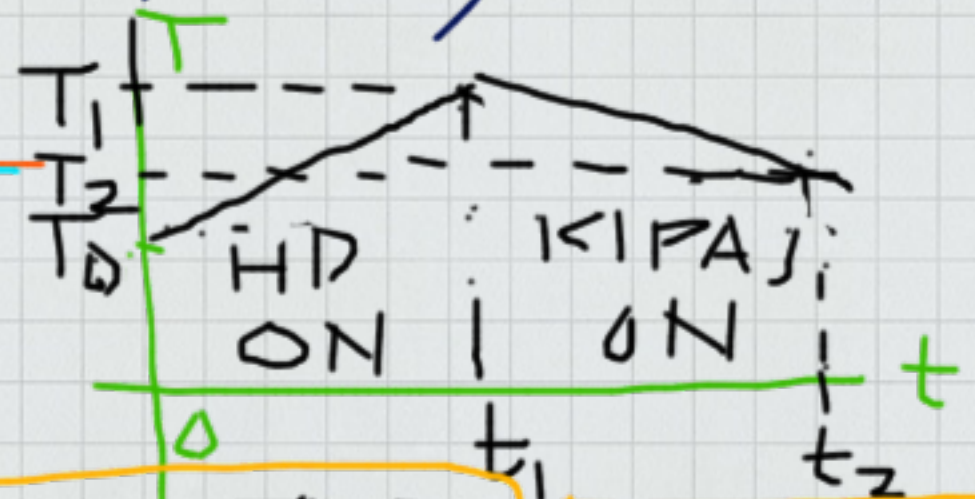
thermometer



KIPAS

Pengerina Rambut

HD



$$a = \frac{T_1 - T_0}{t_1}$$

$$b = \frac{T_1 - T_2}{t_2 - t_1}$$

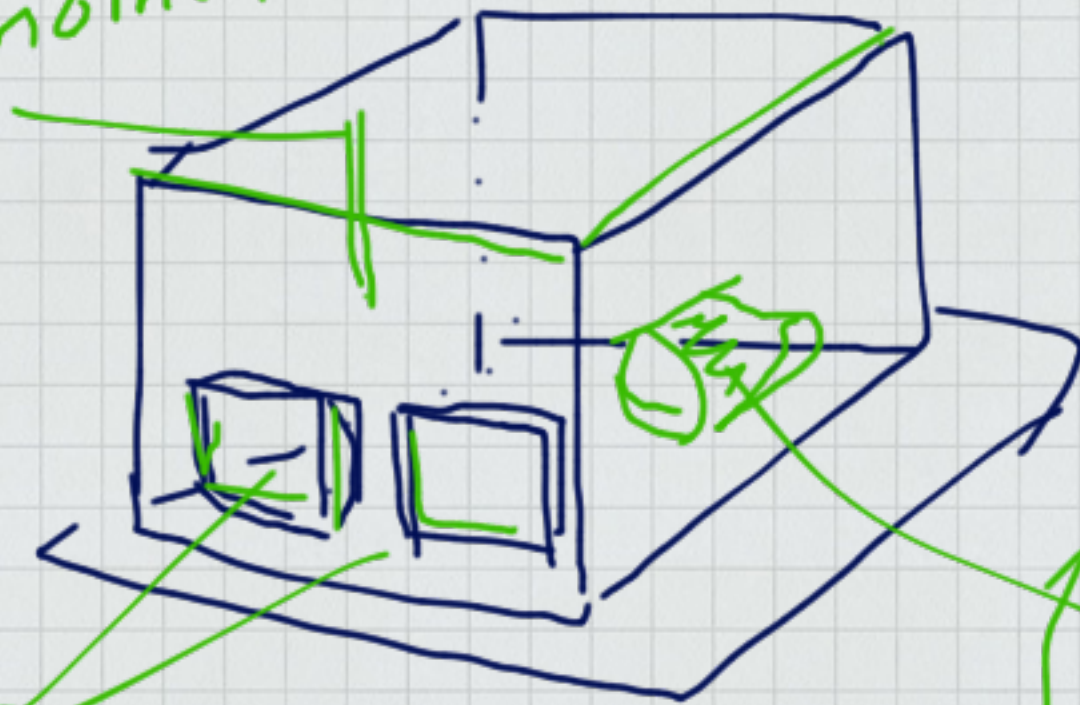
Pengamatan:

- * Laju kenaikan suhu ketika Pengerina Rambut ON
- * Laju penurunan suhu ketika KIPAS ON

PROJECT 4 (dikumpul 20/11/2015)

Pengatur Suhu Ruangan

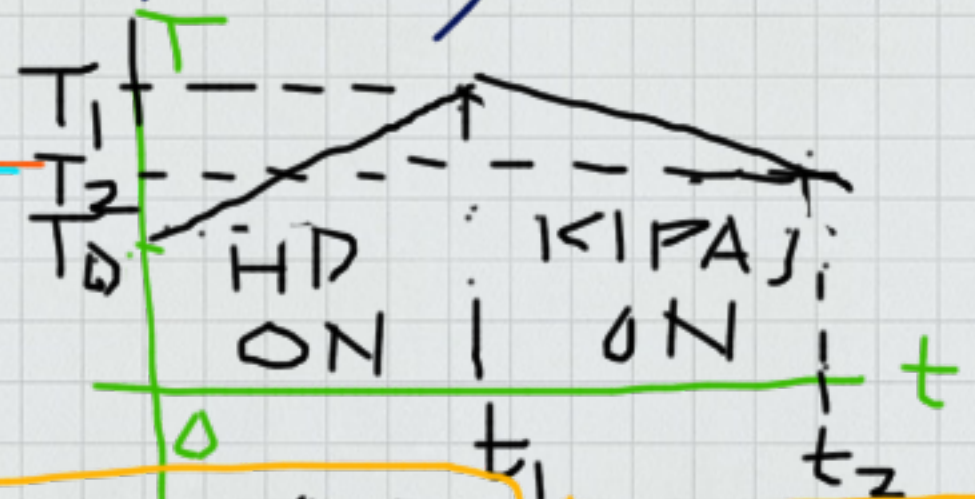
thermometer



KIPAS

Pengerina Rambut

HD



$$a = \frac{T_1 - T_0}{t_1}$$

$$b = \frac{T_1 - T_2}{t_2 - t_1}$$

Pengamatan:

- * Laju kenaikan suhu ketika Pengerina Rambut ON
- * Laju penurunan suhu ketika KIPAS ON

→ PERANCANGAN PENGENDALI PENDULUM TERBALIK

* Kendalian tak-linier dan tak stabil Unstable and Non-Linear Plant.

Dengan menggunakan persamaan LAGRANGE, diperoleh Persamaan (Keadaan) sebagai berikut:

$$\dot{x}_1 = x_2$$

$$\dot{x}_3 = x_4$$

$\dot{x}_2$ dan $\dot{x}_4$ dapat diperoleh dari solusi 2 (dua) persamaan berikut (2 persamaan, 2 tak diketahui).

$$(1) (M+m)\dot{x}_2 + m\dot{x}_4 \cos x_3 - m\dot{x}_4^2 \sin x_3 = F(t)$$

$$(2) m\dot{x}_4^2 + m\dot{x}_2 \cos x_3 - mgl \sin x_3 = 0$$

yang menghasilkan solusi:

$$\dot{x}_2 = \frac{F(t) - \frac{1}{2}mg \sin 2x_3 + m\dot{x}_4^2 \sin x_3}{M + m \sin^2 x_3}$$

$$\dot{x}_4 = \frac{g \sin x_3 - \dot{x}_2 \cos x_3}{l}$$

* LINEARISASI

Untuk menerapkan rancangan Sistem Kendali dengan Umpan Balik Peubah Keadaan (State Variable Feedback), maka kendalian tak-linier harus di-linierisasi terlebih dahulu, yaitu dengan meng-asumsikan pendulum berdiri tegak dengan $\theta(t)$ dan $\frac{d\theta(t)}{dt}$ KECIL setiap saat, atau $x_3 \rightarrow 0$ dan $x_4 \rightarrow 0$.

dengan: $x_3 \rightarrow 0$ maka $\sin x_3 \approx x_3$ dan $\cos x_3 \approx 1$
 $x_4 \rightarrow 0$ maka $x_4^2 \rightarrow 0$

Jadi, dari:

$$(1) (M+m)\dot{x}_2 + m\dot{x}_4 = F(t)$$

$$(2) m\dot{x}_4^2 + m\dot{x}_2 - mgl x_3 = 0$$

$$\dot{x}_4 = \frac{mgl x_3 - m\dot{x}_2}{m\dot{x}_4^2} = \frac{g}{l} x_3 - \frac{1}{l} \dot{x}_2$$

substitusi ke (1):

$$(M+m)\dot{x}_2 + m\left[\frac{g}{l} x_3 - \frac{1}{l} \dot{x}_2\right] = F(t)$$

$$(M+m)\dot{x}_2 + mg x_3 - m\dot{x}_2 = F(t)$$

$$M\dot{x}_2 + mg x_3 = F(t)$$

$$\dot{x}_2 = -\frac{mg}{M} x_3 + \frac{1}{M} F(t)$$

substitusi ke (2)

$$\dot{x}_4 = \frac{g}{l} x_3 - \frac{1}{l} \left[-\frac{mg}{M} x_3 + \frac{1}{M} F(t)\right]$$

$$= \frac{(M+m)g}{Ml} x_3 - \frac{1}{Ml} F(t)$$

* PERSAMAAN KEADAAN hasil LINIERISASI: , $F(t) = u$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & -\frac{mg}{M} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & \frac{(M+m)g}{Me} & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \\ 0 \\ -\frac{1}{Me} \end{bmatrix} u$$

Bisa diperiksa matrix A nilai-eigen-nya [dengan perintah MATLAB $\text{eig}(A)$] tidak semua di sebelah kiri sumbu khayal pada bidang kompleks, jadi tidak stabil.

Untuk menstabilkan pendulum digunakan 'GAIN MATRIX' $K = [K_1 \ K_2 \ K_3 \ K_4]$ agar matrix $\hat{A} = [A - BK]$ nilai-eigen-nya ditempatkan SEMUA di sebelah kiri sumbu khayal pada bidang kompleks dengan menggunakan perintah "place":

$$K = \text{place}(A, B, \text{lambda})$$

$$(\text{lambda}) = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} \begin{array}{l} \text{semua di sebelah kiri sumbu khayal} \\ \text{pada bidang kompleks} \\ \text{(TENTUKAN SENDIRI !)} \end{array}$$

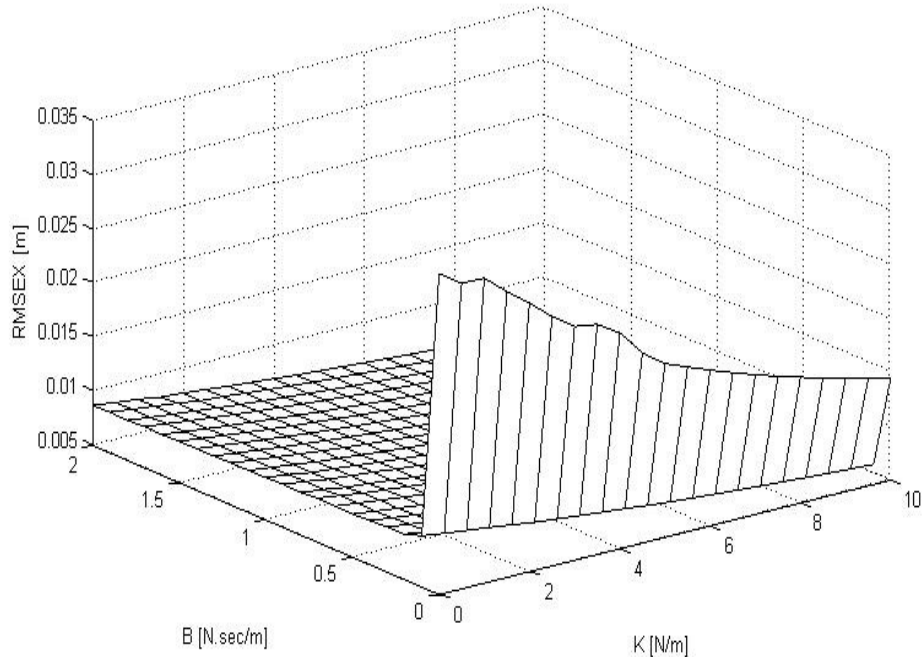
* Dengan memperhitungkan "gain" dari sensor-sensor, nilai-nilai $[K]$ dapat diterapkan pada simulasi.

* Perhatian: * Yang di-stabilkan oleh K adalah kendali hasil linierisasi, oleh karena itu ada kemungkinan ketika diterapkan pada model tak-linier-nya "gain matrix" K ternyata tidak menstabilkan. Dalam hal ini nilai-nilai $\lambda_1, \lambda_2, \lambda_3$ dan λ_4 yang dipilih dapat dipilih ulang.

* Gain matrix $[K_1 \ K_2 \ K_3 \ K_4]$ diterapkan pada pengendali dengan memperhitungkan gain dari sensor-sensor.

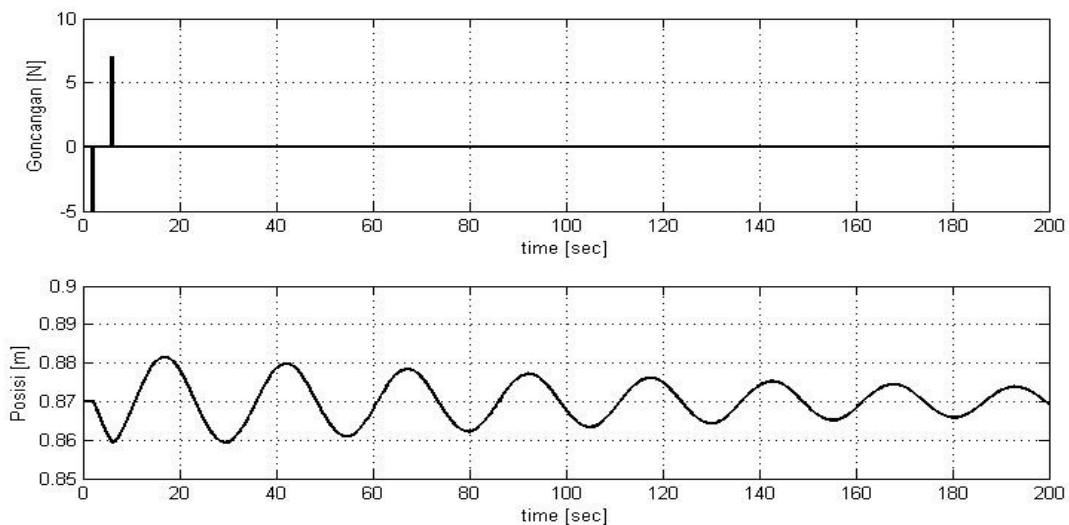
TUGAS untuk PROJECT 2/2018 Sistem SUSPENSII Sepeda Motor

1. Buatlah program MATLAB dengan menggunakan perintah “**sim**” dan “**mesh**” dalam program tersebut sehingga dihasilkan gambar 3D sebagai berikut (atau lebih bagus lagi) dengan membuat variasi nilai **B** dan **K** dalam simulasi Sistem Suspensi Sepeda Motor:



2. Dari gambar di atas, carilah sepasang nilai **B** dan **K** yang menghasilkan **RMSEX** yang minimum, jelaskan “strategi” anda mencari pasangan **B** dan **K** tersebut.

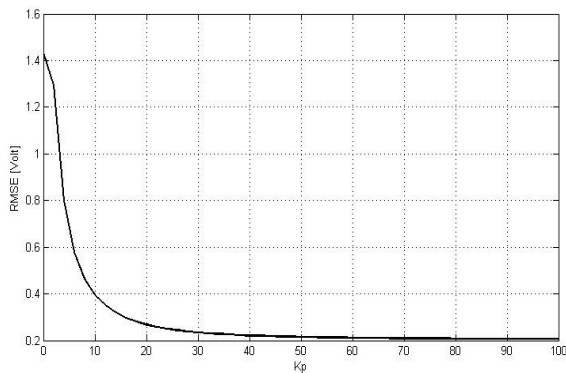
3. Gunakan nilai B dan K yang diperoleh di atas untuk mendapatkan tanggapan (*response*) seperti (tidak perlu persis sama, makin beda makin baik) di bawah ini:



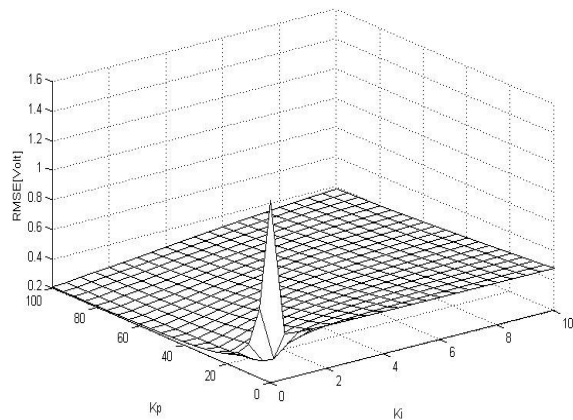
TUGAS untuk PROJECT 3/2018 Pengatur SUHU Ruangan

1. Buatlah program MATLAB dengan menggunakan perintah “**sim**”, “**plot**” dan “**mesh**” dalam program tersebut sehingga dihasilkan berbagai grafik sebagai berikut (atau lebih bagus lagi) dengan membuat variasi nilai **K_p**, **K_i** dan **K_d** dalam simulasi Pengatur SUHU Ruangan yang dikendalikan dengan **Pengendali P, I, PI, PD dan PID**:

Contoh untuk **Pengendali P**:

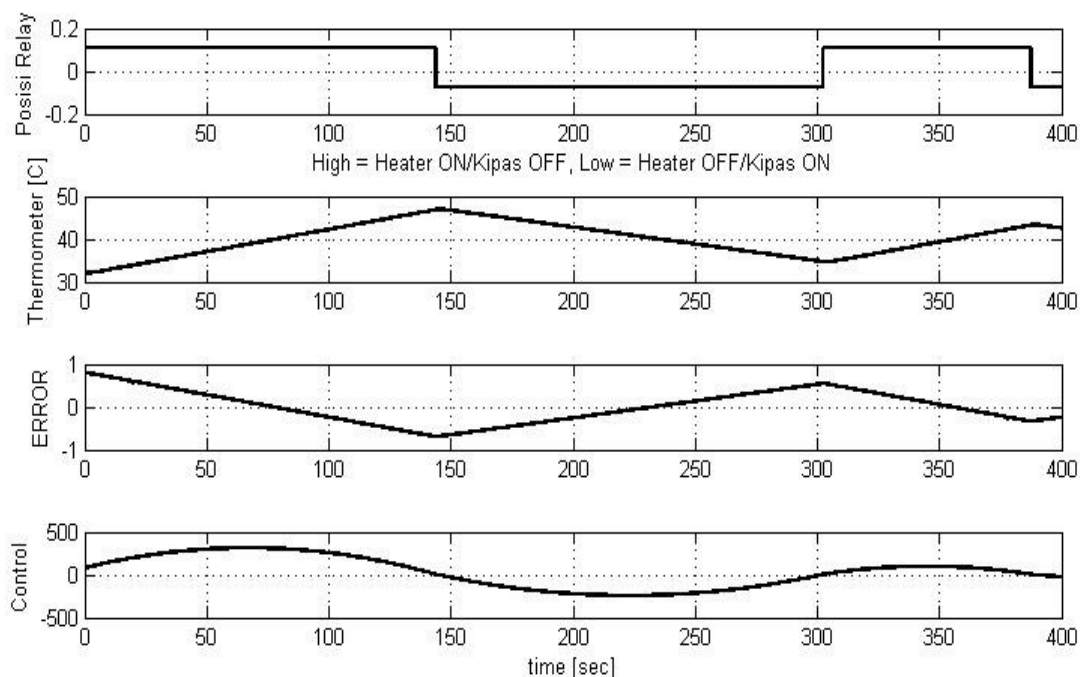


Contoh untuk **Pengendali PI**:



2. Dari 5 (lima) gambar seperti di atas, carilah Pengendali yang menghasilkan **RMSE** yang minimum, jelaskan “strategi” anda mencari **nilai-nilai $K_p \geq 0$, $K_i \geq 0$ dan $K_d \geq 0$** tersebut.

3. Gunakan **nilai-nilai $K_p \geq 0$, $K_i \geq 0$ dan $K_d \geq 0$** yang diperoleh di atas untuk mendapatkan tanggapan (*response*) seperti (tidak perlu persis sama, makin beda makin baik) di bawah ini:



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* Gain matrix $[K_1 \ K_2 \ K_3 \ K_4]$ diterapkan pada pengendali dengan memperhitungkan gain dari sensor-sensor.

③ Merancang "state variable feedback", K_1, K_2, K_3 dan K_4 (gain matrix) untuk menempatkan $\lambda_{1,2,3,4}$ dengan place (λ, A, B)

A dan B adalah linearisasi model pendulum terbalik.