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Assignment: Paper analysis of "ERG scheme for closed-loop Anesthesia

Title: An Explicit Reference Governor Scheme for Closed-Loop Anethesia

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Structure of the paper

- Abstract

I. Introduction

II. Modelling of the system
   a. Figure 1: PKPD model block diagram

III. Control Architecture
   a. Subheading: A. Pre-Stabilizing the Propofol Delivery System
   b. Figure 2: the iControl closed-loop anesthesia system
   c. Figure 3: Block Diagram of the propofol control system
   d. Subheading: B. Enforcing Constraints Handling Capability
   e. Figure 4: Approximation error for different hypnosis levels.

IV. Results and Discussion
   a. Figure 5: The unconstrained simulated responses of the 44 patients
   b. Table 1: Comparison of the obtained induction time

V. Conclusion
   a. Figure 6: The simulated responses of the 44 patients with the ERG scheme.

- References

Acronyms and their full meanings in order

- ERG – Explicit Reference Governor
- PK - PharmacoKinetic
- PD - PharmacoDynamic
- PID – Proportional Integral Derivative
- LBM –Lean Body Mass
- DSM – Dynamic Safety Margin

- NF – Navigation Field
- KF – Kalman Filter
- STD - Standard Deviation

Remarks seen in the paper

- *Remark 3.1:* By defining approximation error as $e(t) =$
  $y(t)\text{-}\hat{y}(t)$, the value of δ_0 can be determined as
- *Remark 3.2:* Since the states of the system are not directly
  measured during the experiments, to determine the Lyapunov
  function $V_i(\cdot)$, $i = 1,\cdots,7$ an estimator is needed
- *Remark 3.3:* To make sure that obtained matrix P_i through
  (31) is valid Lyapunov matrix for all patients, one possible
  way is to use Kharitonov theory [29], and replace the constraint $A^T P_i + P_i A \leq 0$ with the resulting four
  Kharitonov'sbased constraints.

Abstract summary

Methodology for controlling the depth of hypnosis in clinical anesthesia through the use of the the Explicit Reference Governor (ERG) philosophy.

Introduction Paragraph Summary

Paragraph 1: Defines anesthesia and the administration of it by the anesthesiologist during clinical surgery which is summarized as manual feedback control.

Paragraph 2: Three components of anesthesia are hypnosis, analgesia and neuromuscular blockade.

Paragraph 3: The three components of propofol hypnosis and the main challenges in administering the aforementioned with a coping mechanism recommended.

Paragraph 4: safety issues highlighted as the reason for utilization of constrained schemes in closed loop anesthesia.

Paragraph 5: formulation of control problem, proposal of control architecture, the use of the ERG framework because of listed strengths.

Paragraph 6: structure of the rest of the document

Results and Discussion Section

Fig 5	Fig 6
DOH Plot **Most patients have a DOH of 50% or less between 0-10 minutes with a good number at the risk of anesthetic overdose(DOH of <40%)**	All patients at a DOH of 50% approximately within the same time frame
I(t) **Most patients have a value above 200 and a few slightly overshooting 400 between 0-10 minutes**	All patients have an approximate value of 200 within the same time frame
Cp and Ce have a linear period of 2 minutes and then a slight overshoot before approaching steady state between 10-20 minutes	Cp and Ce values are approximately linear for the first five minutes and then approach steady state quickly

For figure 5 and 6, we see that the danger of overdose is seen in the DOH in figure 5 while there's no such danger with the implementation of the ERG.

Cp and Ce are basically similar.

The ERG adds an extra graph of v(t).

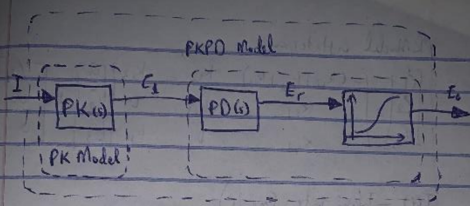
The key result will be the ensuring that there's no overdose on the anesthesia due to the ERG framework.

Conclusion Section

- I can see the structure. It follows a flow of repeating the intent of the paper, the methodology applied for the stated objective, the results based on the number of test subjects.
- Yes, I understand the conclusion as it summarizes the paper concisely and straight to the point.

Question 10

(1)



① PK Model
② PD Model — first order, time delay

PK Model: Relates drug plasma concentration with the administered dose.
The Input I(s) is the infusion rate in mg/s.
The Output is C_1 which is the propofol concentration in the plasma

PD Model: relates the plasma concentration with the pharmacological end-effect. Its a first order plus time delay model.
Input is C_1 described above.
Output is E0 which is the clinical hypnotic effect

PK Model in state space

$$\begin{bmatrix}\dot{C}_1\\ \dot{C}_2\\ \dot{C}_3\end{bmatrix} = \begin{bmatrix}-(k_{10}+k_{12}+k_{13}) & k_{12} & k_{13}\\ k_{21} & -k_{21} & 0\\ k_{31} & 0 & -k_{31}\end{bmatrix}\begin{bmatrix}C_1\\ C_2\\ C_3\end{bmatrix} + \begin{bmatrix}1/V_1\\ 0\\ 0\end{bmatrix} I$$

$I(t)$ – Infusion rate (mg/s)
C_1 – propofol conc in the plasma
$C2$ – fast peripheral compartments
C_3 – slow peripheral compartments

PD Model

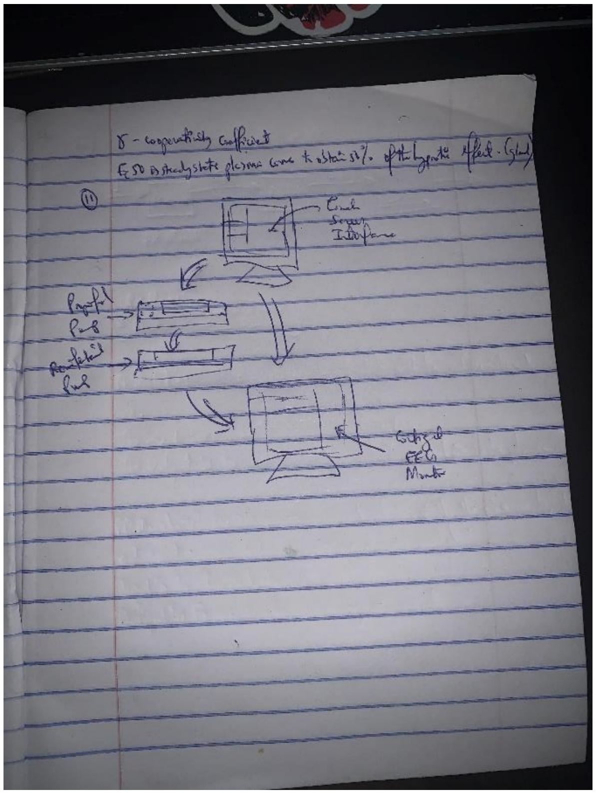
$$PD(s) = \frac{C_e(s)}{C_p(s)} = e^{-T_d s}\cdot\frac{K_{eff}}{s+K_d}$$

$C_p(t) = C_1(t)$ ~~transport delay~~
T_d in (s) – Transport delay
k_d in s^{-1} – rate of propofol distribution between plasma conc and the brain.

For the non-linear sedation function for the relation between $C_e(t)$ and $E_0(t)$

as $E_0(t) = \dfrac{(C_e(t))^{\gamma}}{EC_{50}^{\gamma} + (C_e(t))^{\gamma}}$

Question 11



I have read the PID section of the experience controls app.

PID controller design

$$G_{ff}(s) = k + \frac{k_i}{s}$$

$$G_c(s) = \frac{k_d N s}{s + N'}$$

LBM = 0.3281.W + 0.33929.H -29.5336 for male

W= 70kg H=168cm

LBM = 0.3281(70)+0.33929(168) -29.5336

LBM =22.967+57.0072-29.5336

LBM=50.4406

K=0.0243.LBM

Ki=0.000165.LBM

Kd=1.35.LBM

K = 1.2258

Ki=0.0083

Kd=68.0948

- The iControl is a platform developed for the clinical evaluation of the controller design. From the control viewpoint, the iControl system makes use of a robust PID that stabilizes the propofol delivery system
- Intergral windup or integrator windup refers to a situation in PID feedback controller where a large change in setpoint occurs and the integral terms accumulates a significant error during the rise thus overshooting and continuing to increase as this accumulated error is unwound.
- Equation 13 is a non linear system
- Ensures theres no overdose in administering anesthesia to patient
- ERG adds constraint handling capacity to the manual closed loop feedback method of administering anesthesia. It determines to add an invariant set that would contain the state trajectory if the currently auxiliary reference were to remain constant.
- The ERG generates v(t) (auxiliary reference) as its output which is used as the input signal to the rest of the system. It is independent of the rest of the system.