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# Clinical Assessment of Control Performance in Closed-Loop Anesthesia

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Background: Recently, several control systems for closed-loop anesthesia have been demonstrated both in simulation and clinical studies. A set of performance measures, proposed by Varvel et al. [1], have constituted the standard means of comparing systems. Because Varvel measures were developed for Target-Controlled Infusion (TCI), their relevance to closed-loop control is debatable. It is also pertinent to use different measures of performance during the induction, maintenance, and emergence phase of anesthesia. Varvel measures currently report for maintenance phase only.

Methods: This paper debates the adequacy of the Varvel measures, as applied to closed-loop anesthesia, and proposes an alternative set of measures [3]. For induction the phase, induction phase duration (ID) and percent overshoot (OS) are proposed. For the maintenance phase, integrated error, integrated absolute error (IAE), variability index (VI) and percentage of time outside the adequate range are proposed. For the emergence phase, emergence phase rise time is proposed. These proposed measures are widely accepted within the control community, reflect clinical relevance, separate measures for induction, maintenance and emergence of anesthesia, and separate outlier detection and performance evaluation. We analyzed 112 clinical cases that were collected from a study on closed-loop control depth of hypnosis (DOH) using the NeuroSense monitor and approved by the UBC Children's and Women's Research Ethic Board (H10-01174), Vancouver, Canada [2].

Results: We analyzed 112 clinical cases using both the Varvel measures and the new proposed measures (Table 1). IE conveys information about the average error. The IAE replaces the MDAPE and is obtained by taking the modulus of the sample-wise error. DOH values in the 40-60 range are considered clinically adequate. This range suggests that a maintenance phase like the one in Figure 1(a) should be more desirable than the one in Figure 1(b). However, basing the error metric on the median (as is the MDAPE), has the opposite effect. In the data below, the MDAPE of both figures are both 12.6, while the IAE are 6.62 and 6.78 respectively for Figure 1(a) and Figure 1(b). ID is defined as the time elapsed from the start of hypnotic drug administration to the time when the DOH falls to and remains under 60 for 30s. The ID of two patients is 3.95min and 4.45min respectively. The OS of these patients is 35.15% and 21.31% respectively.

Conclusion: For a full analysis of the clinical data, all three phases of induction, maintenance, and emergence require separate performance measures. Varvel measurements are currently only applied to the maintenance phase of anesthesia. The proposed performance measurements analyze all phases separately and differentiate other performance characteristics. The median-based measure of MDAPE does not distinguish between noise and momentary large errors, while the proposed IAE overcomes this limitation.

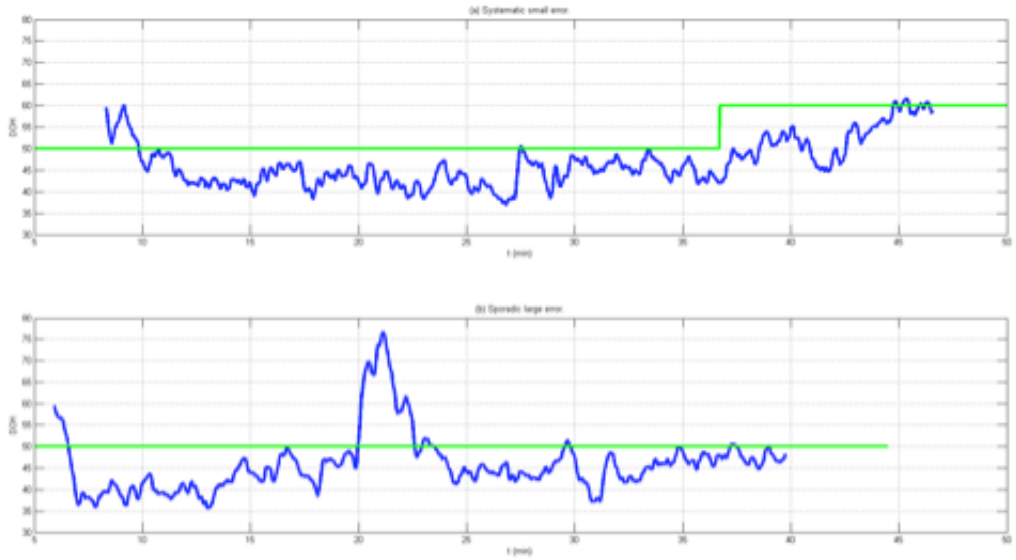
References

[1] Varvel JR, et al. Pharmacokinetics & Biopharmaceutics, vol 20, no. 1, pp. 63-94, 1992.

[2] van Heusden K, et al. IEEE Transactions on Control System Technology, in press.

[3] Soltesz K, et al. 21st Med. Control Conf. Crete, 2013.

## Figure 1




Two maintenance phase DOH profiles (blue), with corresponding setpoint (green).

## Figure 2

**Table 1**

| MDPE | MDAPE | Divergence | Wobble | Global Score | ID | OS | IE | IAE | VI | % Time Outside | ER |
|---|---|---|---|---|---|---|---|---|---|---|---|
| -9.00 | 9.40 | -0.61 | 6.80 | 20.47 | 5.53 | 49.23 | -5.41 | 6.09 | 1.89 | 0.21 | 7.97 |
| -3.80 | 6.33 | 0.09 | 5.60 | 13.02 | 4.45 | 21.31 | -2.10 | 4.28 | 1.49 | 0.08 | 5.00 |
| -18.83 | 20.50 | 0.35 | 5.23 | 58.21 | 0.25 | 79.42 | -7.42 | 10.89 | 1.68 | 056 | 4.55 |
| -3.67 | 9.17 | -0.75 | 10.17 | 27.51 | 5.58 | 89.37 | -4.74 | 7.56 | 1.63 | 0.3 | 5.35 |
| -9.40 | 14.80 | 0.14 | 10.40 | 36.86 | 2.27 | 35.28 | -2.68 | 8.55 | 1.31 | 0.32 | 3.65 |

Varvel and proposed performance measures of five random patients