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Simulation assessment of a closed-loop controller designed by machine learning techniques.

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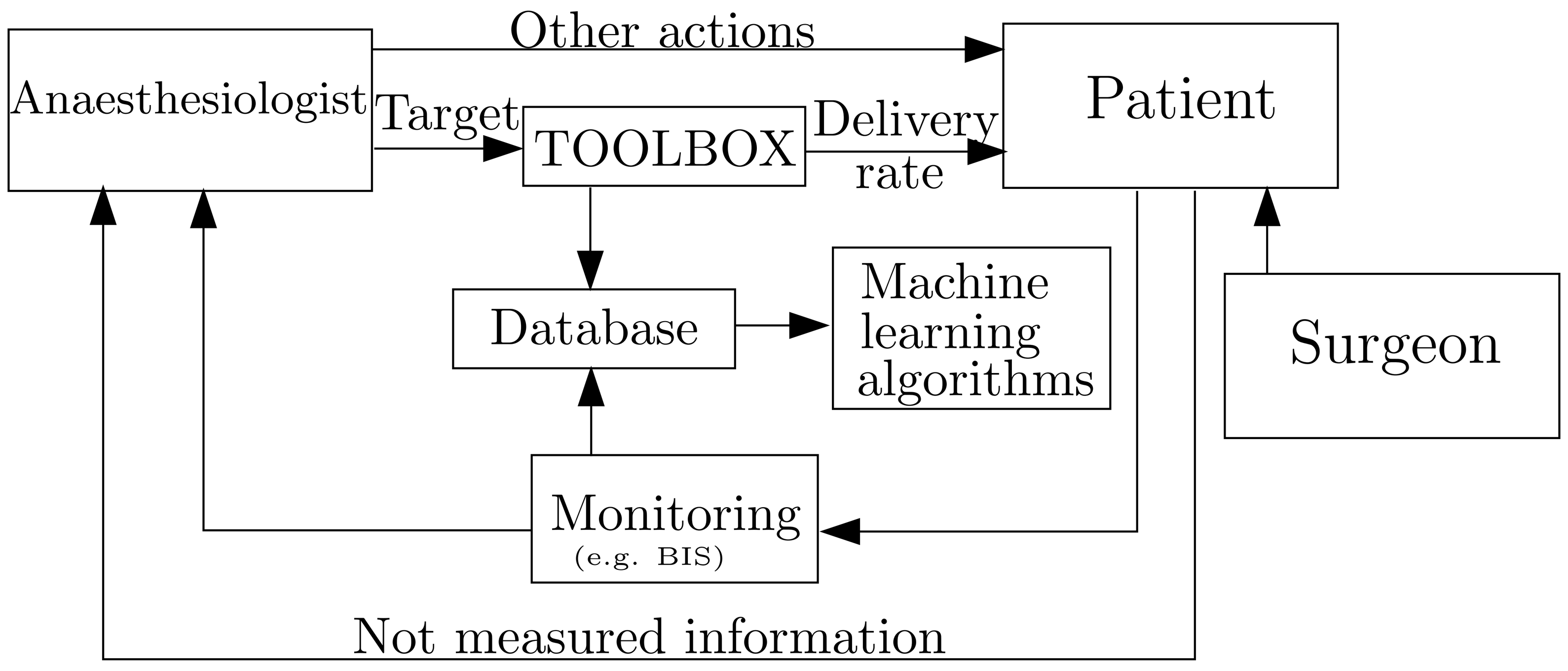
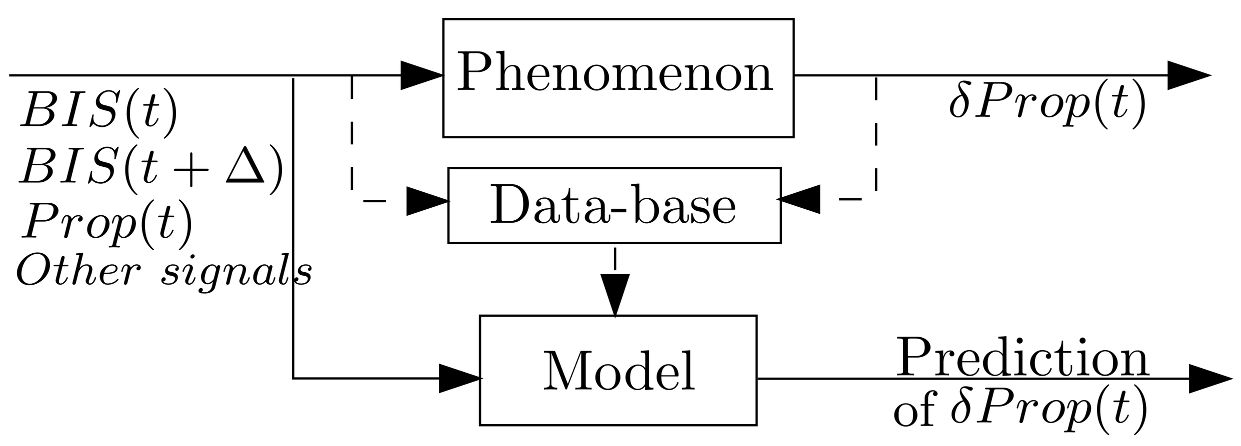
Background and Goal of the Study:

The research assesses a machine learning approach to the design of a closed loop strategy for controlling BIS by acting on Propofol titration [1]. Machine learning relies on a BIS guided TCI anaesthesia archive of 965 chirurgical interventions collected and stored by the TOOLBOX software [2].



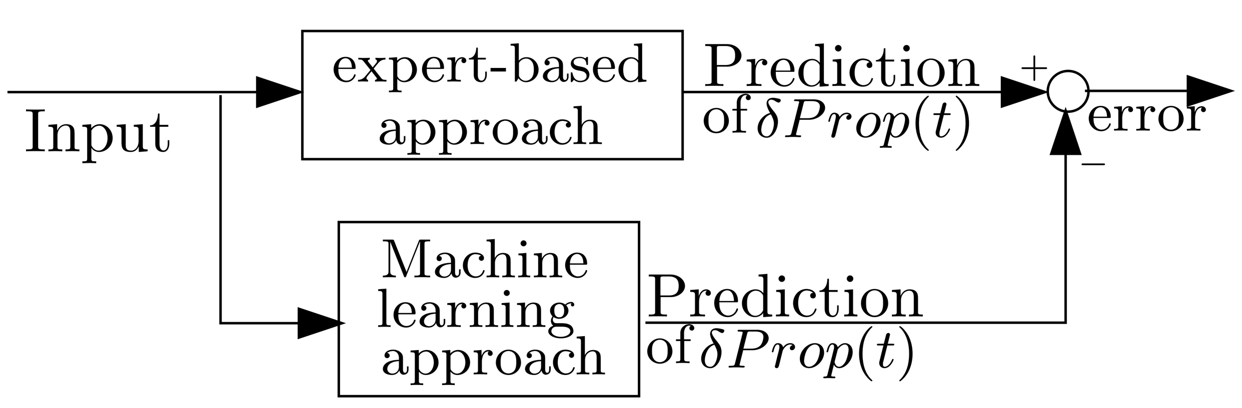
The proposed controller possesses adaptive control features and relies on the availability of several input signals measuring the patient condition and the operation state.



The purpose of the study is to compare, in a simulation setting, the control strategy proposed by our controller with the one adopted by an expert-based closed-loop controller currently under use at the Erasmus hospital. This expert-based closed-loop controller automatically titrates Propofol and Remifentanil according to a fixed set of rules programmed by the anesthetist.

Materials and Methods:

An inverse controller is estimated by applying Lazy Learning [3], a machine learning algorithm, to an archive of 965 chirurgical interventions. The resulting BIS closed-loop computes a modification of the current Propofol titration on the basis of the following signals: the current BIS value, the current Propofol titration, the current Remifentanil titration, the age and the weight of the patient. The action proposed by our closed-loop controller is compared to the control output of an expert-based closed-loop controller in 18 real archived TCI anaesthesias.



Let P_{eb} (prediction of the expert-based approach) be the target of Propofol (μg/ml) proposed by the existing closed-loop and P_{ml} (prediction of the machine learning approach) be the target of Propofol (μg/ml) proposed by our new closed-loop. We define PE (predictive error) as follows:

$$PE = P_{ml} - P_{eb}$$

To assess the actions of our new closed-loop, the following measures are computed:

- MDPE (median of the predictive error)

$$= median\left(\frac{PE}{P_{eb}} \cdot 100\right)$$

- MDAPE (median of the absolute predictive error)

$$= median\left(\left|\frac{PE}{P_{eb}}\right| \cdot 100\right)$$

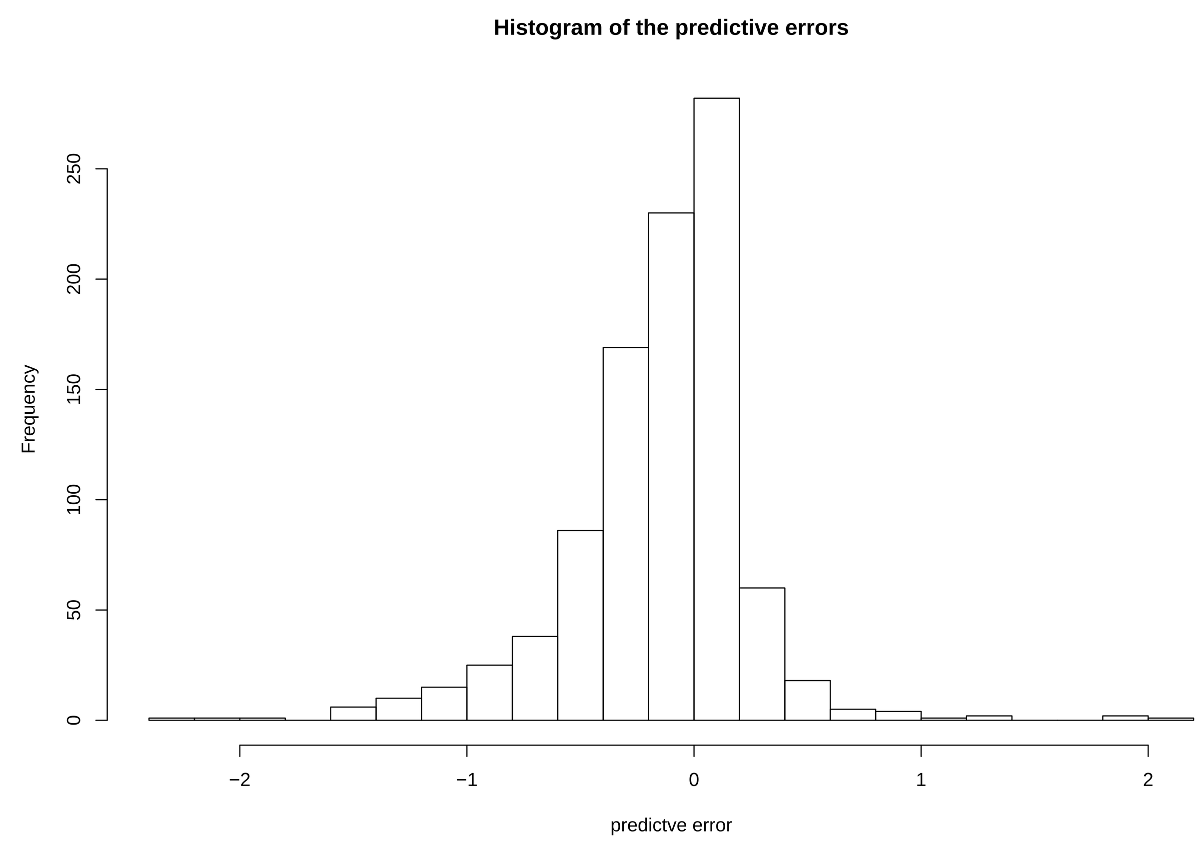
- NMSE (normalized mean squared error)

$$= \frac{mean\left((PE)^2\right)}{var(P_{eb})} = \frac{mean\left((P_{ml} - P_{eb})^2\right)}{mean\left((mean\,(P_{eb}) - P_{eb})^2\right)}$$

Results:

$MDPE$	$MDAPE$	$NMSE$
-6.1%	10.1%	0.19

The following plot shows a histogram of the prediction errors.



Discussions:

The Propofol titration behaviour of the two controllers is significantly different ($P << 0.01$) although the small value of the MDAPE indicates that the absolute amount of this difference is small. Also, since the average of the BIS signal, once regulated by the expert-based controller is under the target value, the negative sign of the MDPE, as well as the low value of the NMSE figure, show that the proposed method yield promising results.

Conclusion(s):

The preliminary simulation tests of our controller, based on a machine learning algorithm, appear to be promising. Future work will focus on tests in realistic conditions.

References

[1] O. Caelen, G. Bontempi, E. Coussaert, and F. Clément. Machine learning techniques to enable closed-loop control in anesthesia. In *To appear in the 19th IEEE International Symposium on Computer-Based Medical Systems*, June 2006.

[2] F. Cantraine and E. Coussaert. The first object oriented monitor for intravenous anesthesia. *PubMed - indexed for MEDLINE*, 16:3–10, 2000.

[3] Bontempi G, Birattari M, and Bersini H. Lazy learning for modeling and control design. *International Journal of Control*, 72(7/8):643–658, 1999.