SAFETY LAYER FOR AN INSULIN DELIVERY SYSTEM

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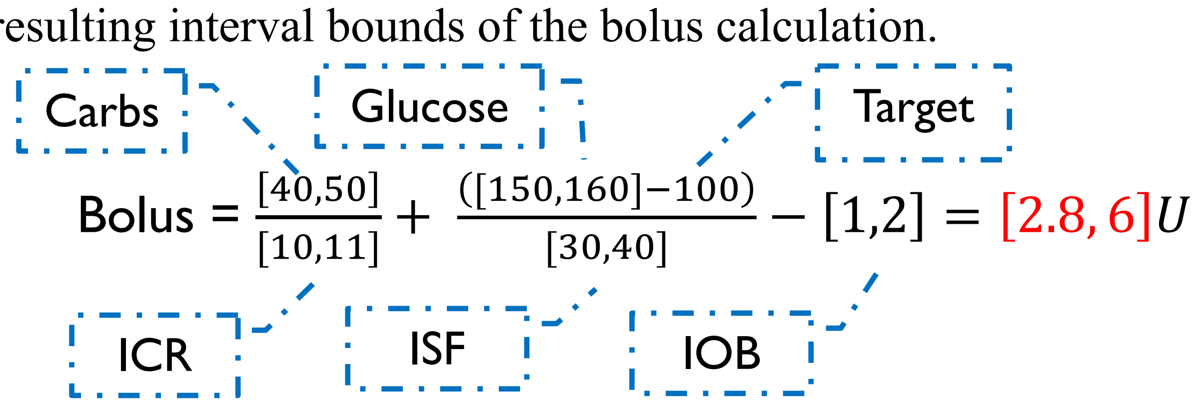
Objective

- In an **insulin delivery system** (insulin recommender or artificial pancreas), a safety layer is paramount in order to minimise risk of adverse events (hypo- and hyperglycaemia) due to potential malfunctioning of the system (algorithm/sensor/pump).
- This work presents a novel **safety layer** which includes: a dynamic insulin constraint; a predictive low-glucose insulin suspend; and an adaptive carbohydrate recommender.

Methods

Dynamic Insulin Constraint

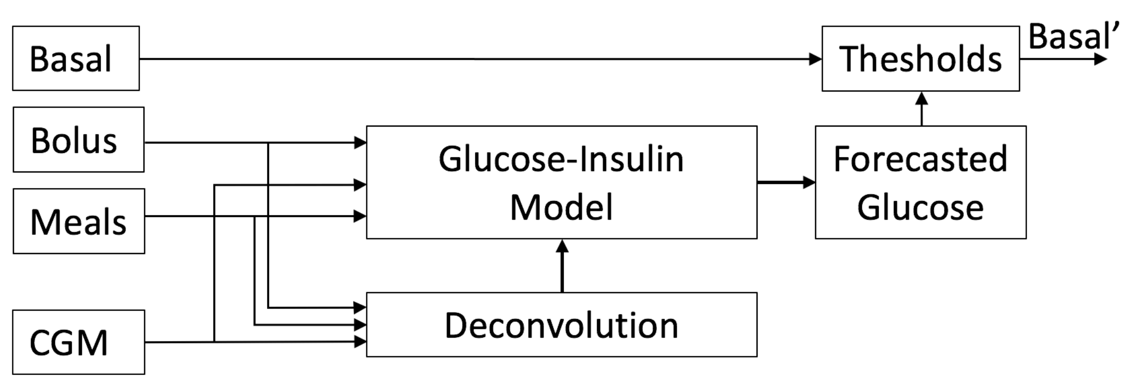
- An **insulin bolus calculator** in which, parameters (ICR, ISF), inputs (Carbs, Glucose), insulin-on-board (IOB) and output (Bolus) are considered to be **numerical intervals** [1] representing measurement, estimation errors and insulin requirements variability, is employed.
- Insulin doses from the delivery system are constrained by the resulting interval bounds of the bolus calculation.



$$Bolus = \frac{[40,50]}{[10,11]} + \frac{([150,160]-100)}{[30,40]} - [1,2] = [2.8,6]U$$

Predictive Low-glucose Suspend (LGS)

- The employed **glucose forecasting algorithm** is based on a composite minimal model of insulin-glucose dynamics [2] and a deconvolution technique [3] to estimate plasma glucose rate of appearance. Only one parameter is individualised.
- Basal insulin is halved, or suspended, once the predicted glucose crosses two predefined thresholds.



Adaptive Carbohydrate Recommender

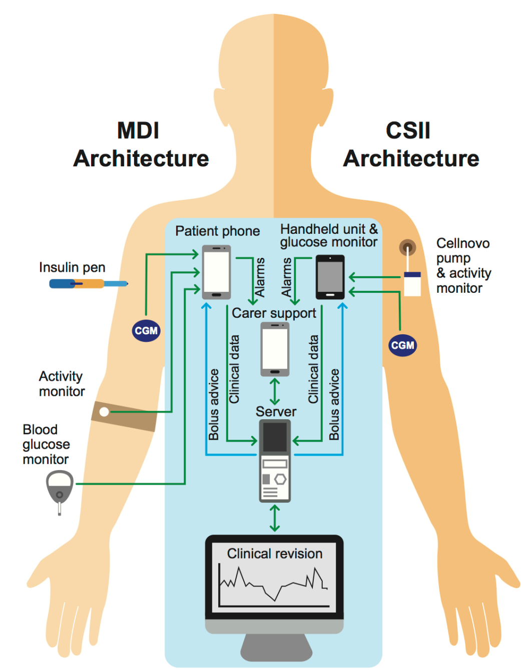
- Once a predefined glucose threshold is crossed, a carbohydrate dose (CHO) is computed based on the error between the predicted glucose (G_P), a predefined target (G_T), the carbohydrate sensitivity factor (CSF) and an estimation of the carbohydrate-on-board (COB).

$$CHO = \frac{(G_P - G_T)}{CSF} - COB$$

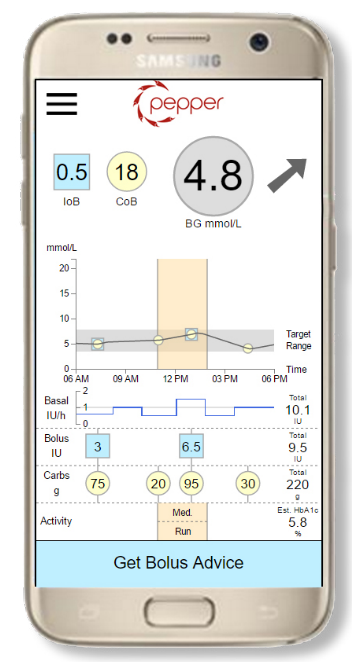
- A **Run-to-Run control algorithm** is employed to automatically adapt the carbohydrate sensitivity factor (CSF).

PEPPER Project

- **PEPPER** is an **EU-funded project** aiming to develop a mobile-based platform that will help people with type 1 diabetes to improve self-management of their condition [4].
- Together with an **AI-based insulin recommender**, the proposed **safety layer** is part of the PEPPER system, which has been implemented on a mobile platform and is about to be clinically tested.



PEPPER system architecture



PEPPER handheld GUI

Results

- *In silico* results with the UVa-Padova simulator (n=10 adults) show that the **dynamic insulin constraint** is able to eliminate severe hypoglycaemia (<50mg/dL) and severe hyperglycaemia (>400mg/dL) under realistic variability.
- Retrospective clinical tests show that the implemented **glucose forecasting algorithm** outperforms a state-of-the-art algorithm (AR model (order 3) with recursive identification) (rRMSE: 24.2% vs. 32.6% - horizon: 90min).
- When tested *in silico* (n=10 adults), the predictive **low-glucose suspend** significantly reduces the % time spent in hypoglycaemia (<70mg/dL) (3.2±3.5 vs. 0.71±0.96, $p<0.05$) without increasing the % time spent in hyperglycaemia (>180mg/dL) (18.7±10.0 vs. 19.6±8.2, p=0.3).
- *In silico* results (n=10 adults) show that the **carbohydrate recommender** significantly reduces the % time spent in hypoglycemia (3.2±3.5 vs. 0.77±1.08), $p<0.05$) without increasing the % time spent in hyperglycaemia 18.7±10.0 vs. 19.1±9.1, p=0.3).

Conclusion

- A novel safety layer for insulin dosing systems has the potential to improve glycaemic control in an adult type 1 population.

References

1. Moore, R. E. (1966). Prentice-Hall. ISBN 0-13-476853-1.
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