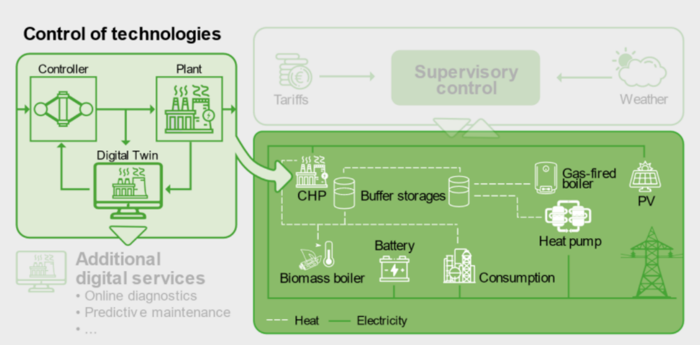

Estimation and Prediction of the Drying State of a Herb Drying Process

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Area 2.2
Automation and Control

Motivation

To ensure high product quality in commercial herb drying, herbs must be dried gently, which leads to relatively long drying times. Currently, the moisture content which determines the end of the drying process cannot be measured in real-time. Instead, it is assessed through random samples, often resulting in the drying process being stopped later than necessary. If the process could be stopped as soon as the moisture content reaches its target level, it would significantly reduce drying time, energy consumption, and overall costs. For more efficient operation and better process planning, one goal in the project SolSorpDry is the development of a Soft Sensor that provides real-time answers to the following key questions:

- Is the drying process already finished?
- When is the drying process expected to be finished?

To achieve this, the aim is to develop model-based algorithms for the **estimation of the current drying state** and **prediction of future evolution of the drying state**.

Description of the Setup

In the considered batch process, the herbs to be dried are placed in a chamber as indicated in Figure 1. Warm air enters at the bottom, causes the water bound in the herbs to evaporate and leaves through the top. The measured variables are the mass flow $\dot{m}_{a,in}$ at the inlet as well as the air temperatures $T_{a,in}$ and $T_{a,out}$ and absolute humidities $u_{a,in}$ and $u_{a,out}$ at the inlet and outlet, respectively. Additional important but unmeasured process quantities are the air mass flow $\dot{m}_{a,out}$ at the outlet, the dry mass m_d of the herbs and the mass of water m_w to be evaporated.

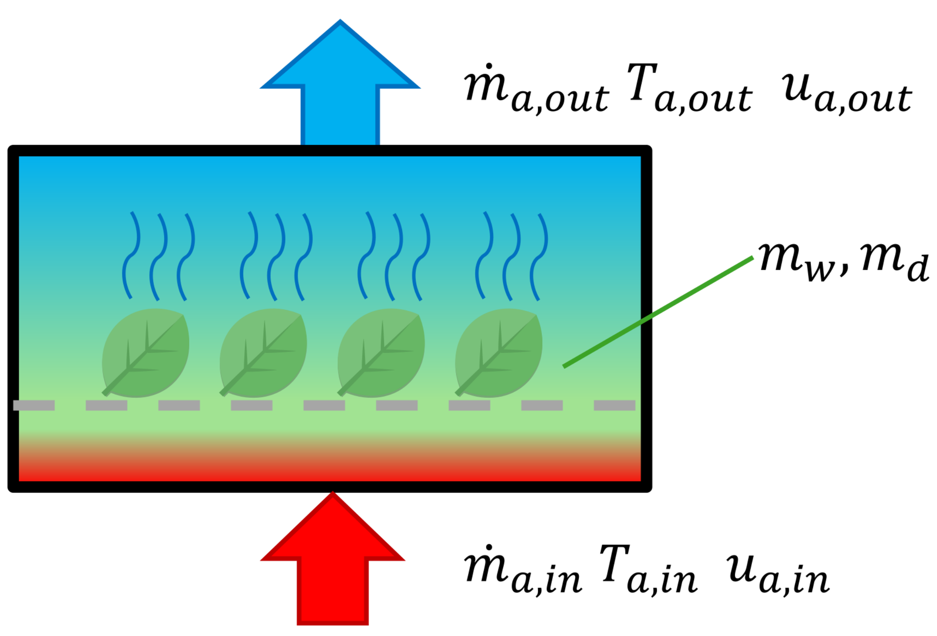

Figure 1: Schematic overview of the drying process including the relevant quantities.

Mathematical Model

The drying of the herbs is described by the dynamic model

$$\frac{dm_w}{dt} = -\underbrace{\frac{\beta}{k_{crit} \cdot m_d}}_{K} \cdot \underbrace{\left(u_{a,sat}\left(T_{a,in}\right) - u_{a,in}\right) \cdot \dot{m}_{a,in}^{0.7}}_{u} \cdot \underbrace{m_w}_{x}$$

for water mass m_w. The constant parameters β and k_{crit} depend on the herb itself and may vary between different batches. The mass flow of evaporated water $\frac{dm_w}{dt}$ can be calculated from available measurements in two ways, namely by applying either a **water mass balance** or an **energy balance**, and is therefore considered as a virtual measurement y. Summarizing the unknown parameters into a constant K and the input variables into u yields

$$\frac{dx}{dt} = -Kux \qquad (1)$$
$$y = -Kux + du,$$

where the unknown parameter d accounts for offset errors in the measurements.

Model-Based Estimation and Prediction

To estimate the current water mass x as well as the unknown parameters $K$and d, a **least-squares optimization approach** is performed which is based on already available measurement data of the current batch in combination with the model (1). The estimates are then used in the second step to predict the further course of the water mass with the help of the model (1) assuming constant drying conditions u.

Exemplary Results

Figure 2 shows exemplary results of a test run with mint. The estimates and the predictions of the water mass to be evaporated are depicted for three different estimation horizons. An additional weight measurement is used in this experimental setup to validate the results.

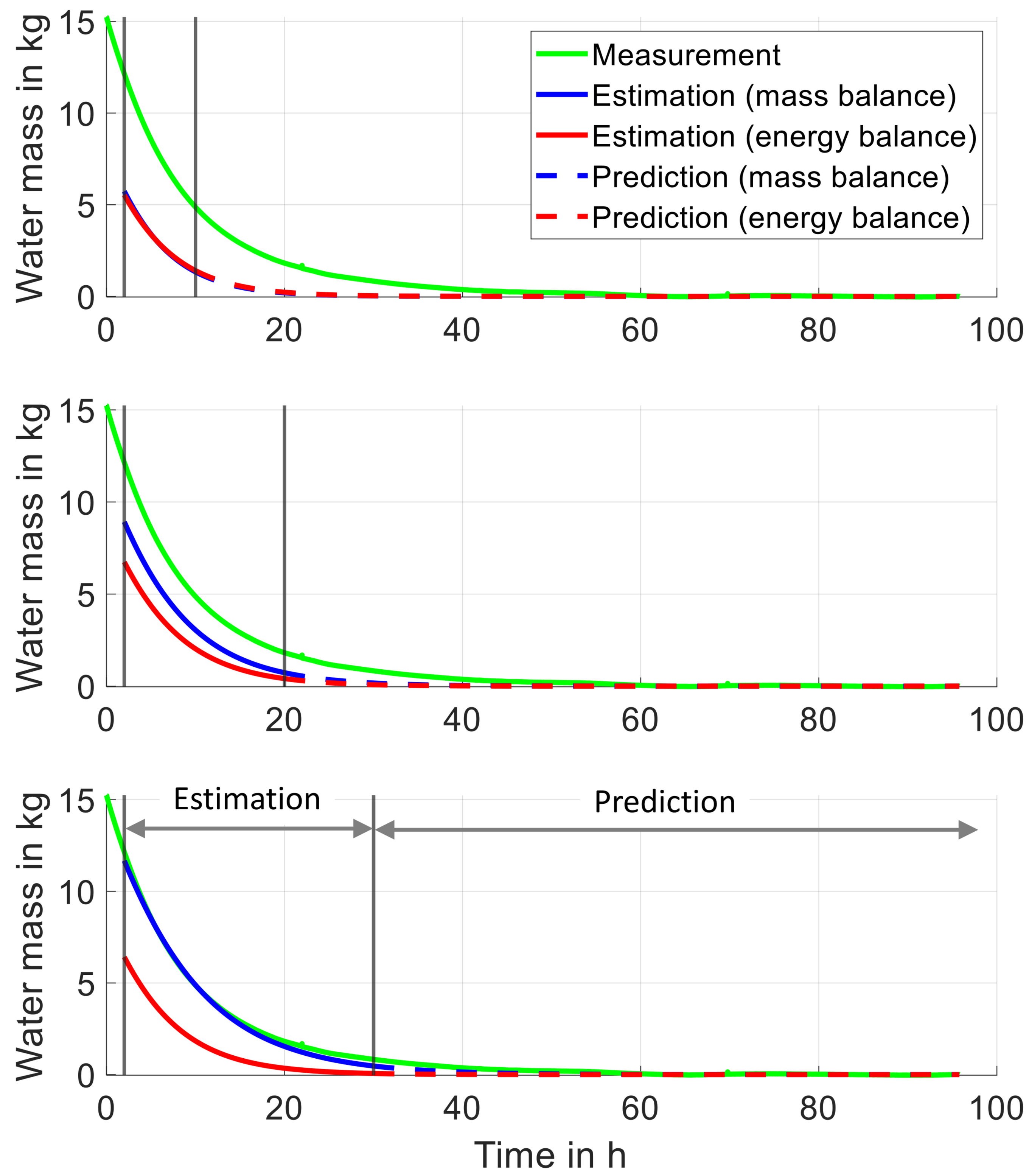

Figure 2: Estimates and predictions for different estimation horizons.

Conclusion and Outlook

While the results based on the energy balance do not improve significantly with a longer estimation horizon, the use of the water mass balance provides satisfactory results. Suitable criteria to detect or predict the end of the drying process are still needed. Furthermore, the current version of the estimation algorithm can not be implemented on a standard PLC (programmable logic controller) which motivates the application of sequential estimation algorithms like Kalman Filters in future work.

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