Continuous calibration of a digital twin: a particle filter approach

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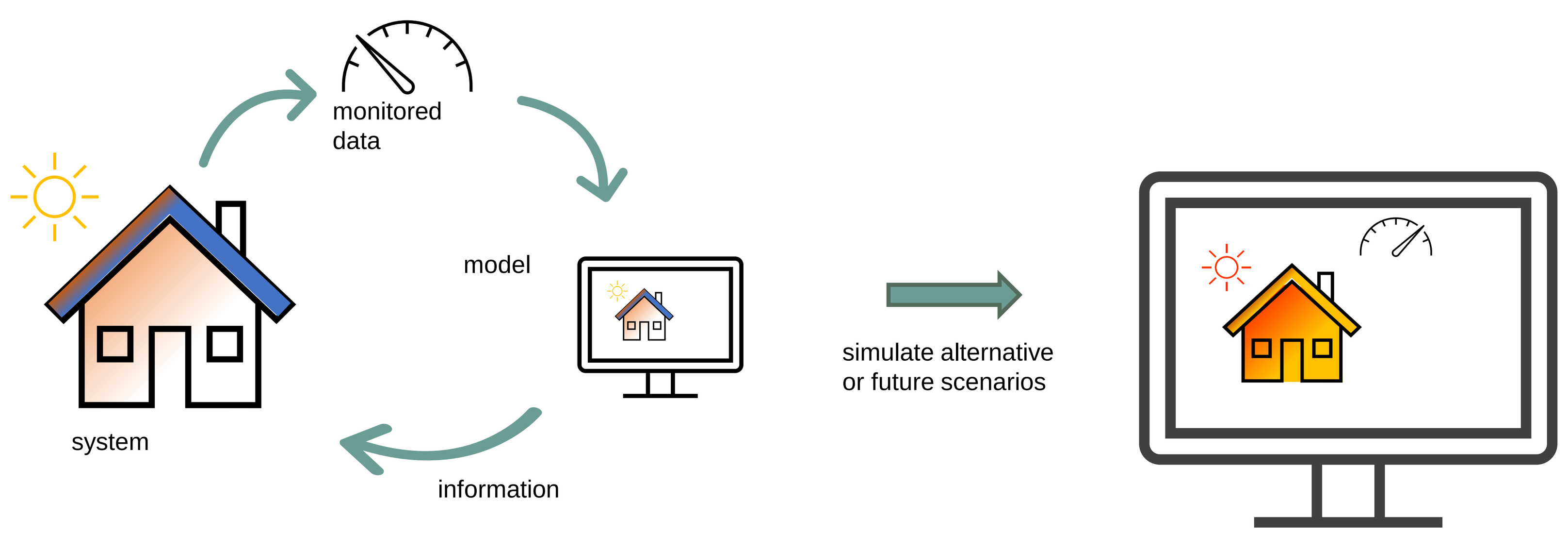
NEURAL INFORMATION PROCESSING SYSTEMS

The digital twin

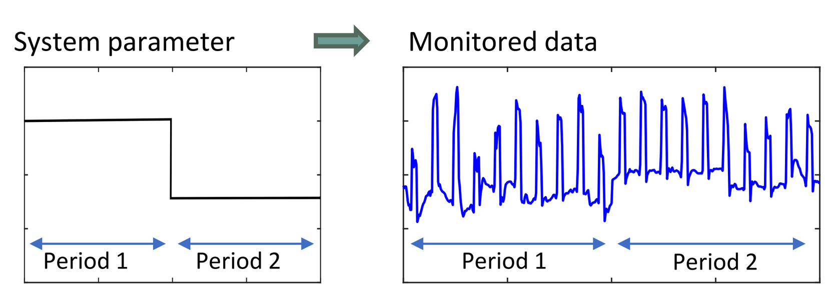
A digital twin in essence comprises a monitored system together with a computational model of the system which can simulate the system behaviour in context, giving a good agreement with the data. The computational model might be data-derived or, as is more usual in engineering systems, physics-based; the intention is that the computational model can give information that may not be easily accessible from the system directly and can be used to explore performance when it is impractical to run physical tests.



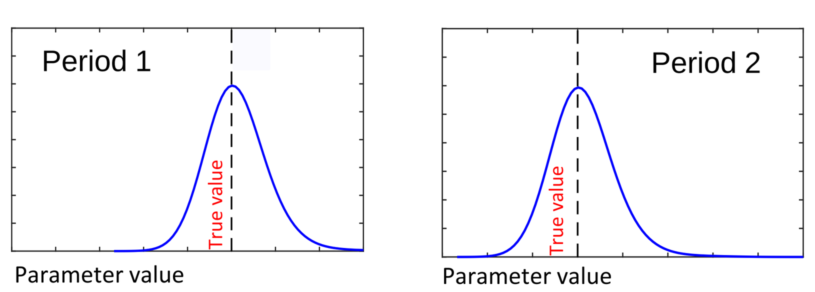
The problem …

How do we ensure continuing model fidelity if the system changes over time?

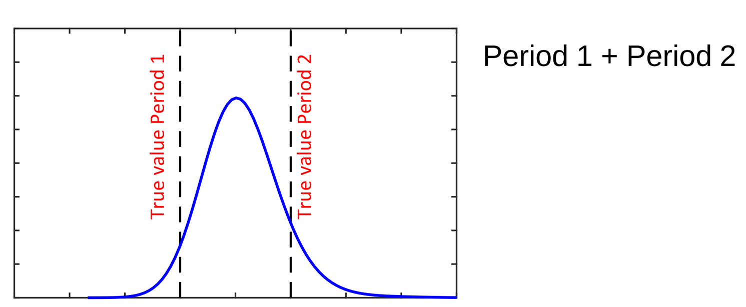
Suppose we have a system operation influenced by a parameter that cannot be measured directly but is known to have a step change in value. We can measure system output and calibrate a model:



Bayesian calibration over the two periods separately gives good estimates of parameter posterior distributions …



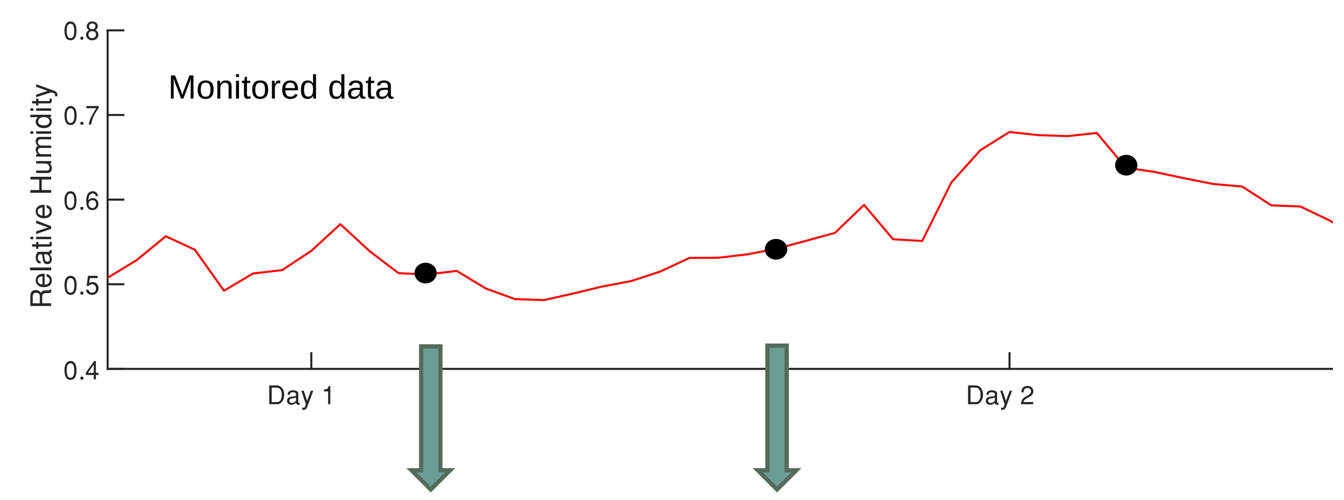
… but if calibrating over a period that includes the step change, Bayesian calibration can only give an average.



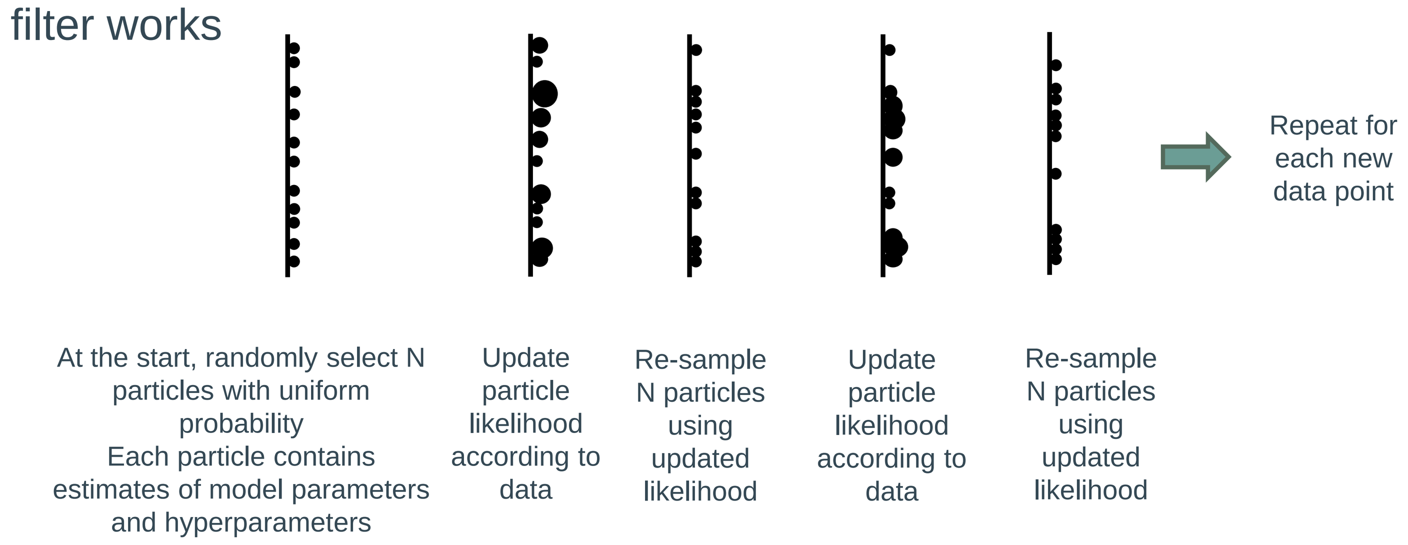
The proposed solution:

Sequential calibration using a particle filter …

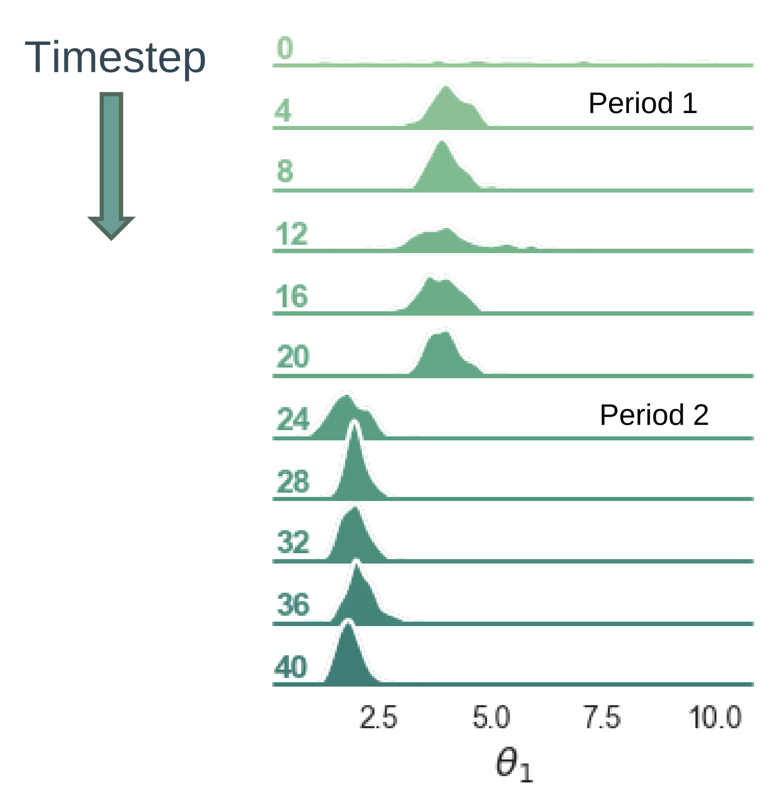
The particle filtering approach works sequentially by using the posterior distributions from one timestep as the prior distributions for the next, thereby updating estimates for each parameter based on the observations given. A shift in the posterior range of the parameter can be detected because the likelihoods of the particles are updated accordingly.



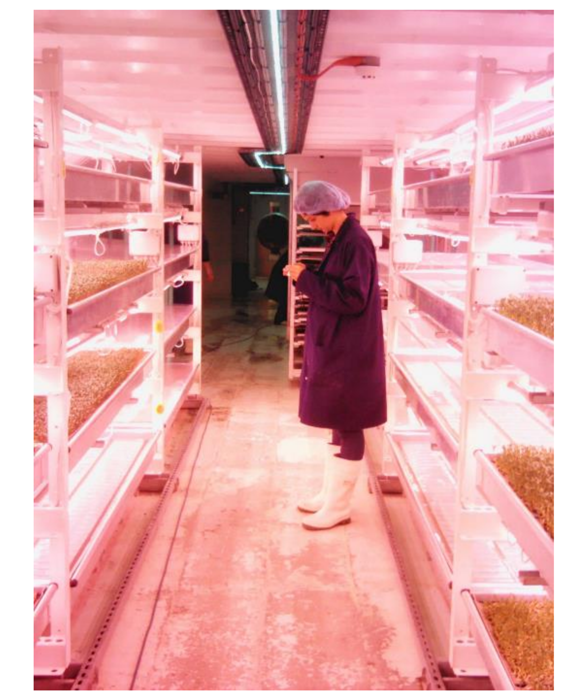
How the particle filter works

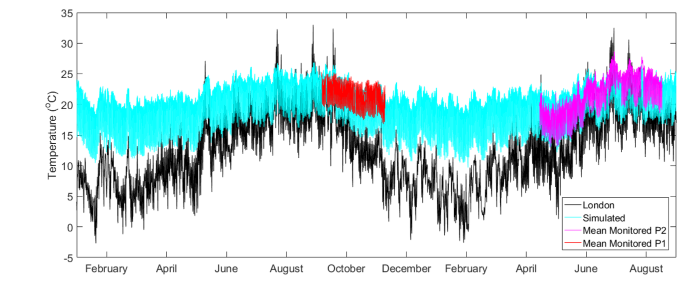


The results: model parameter probability distribution evolution in time and identification of step changes in parameter values

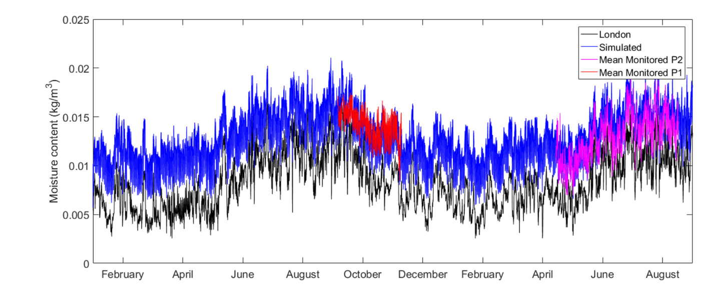


Result: evolution of model parameters in time





Comparison of simulated air temperature against monitored data

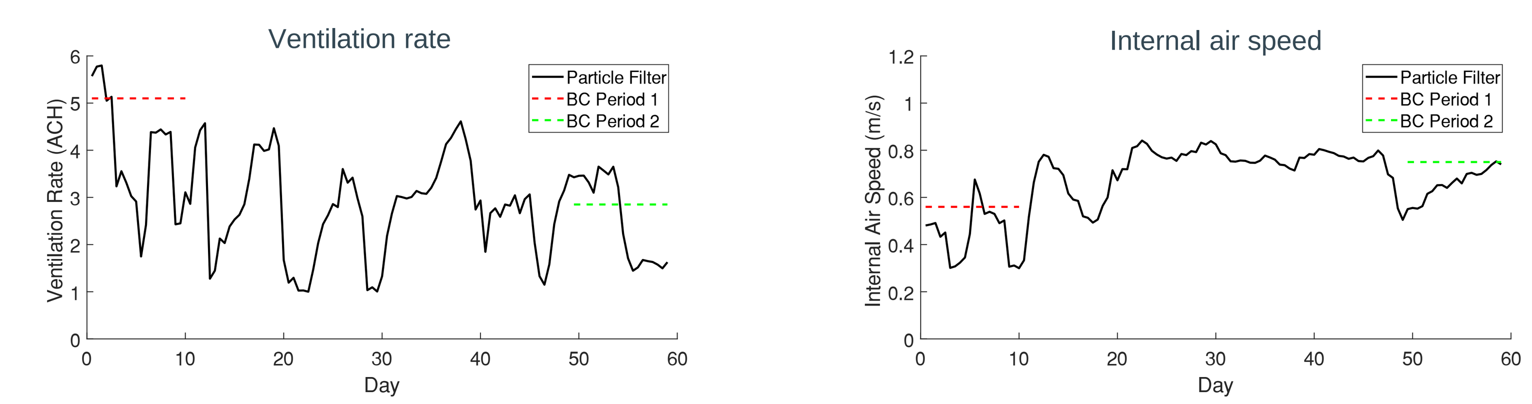


Comparison of simulated air moisture content against monitored data

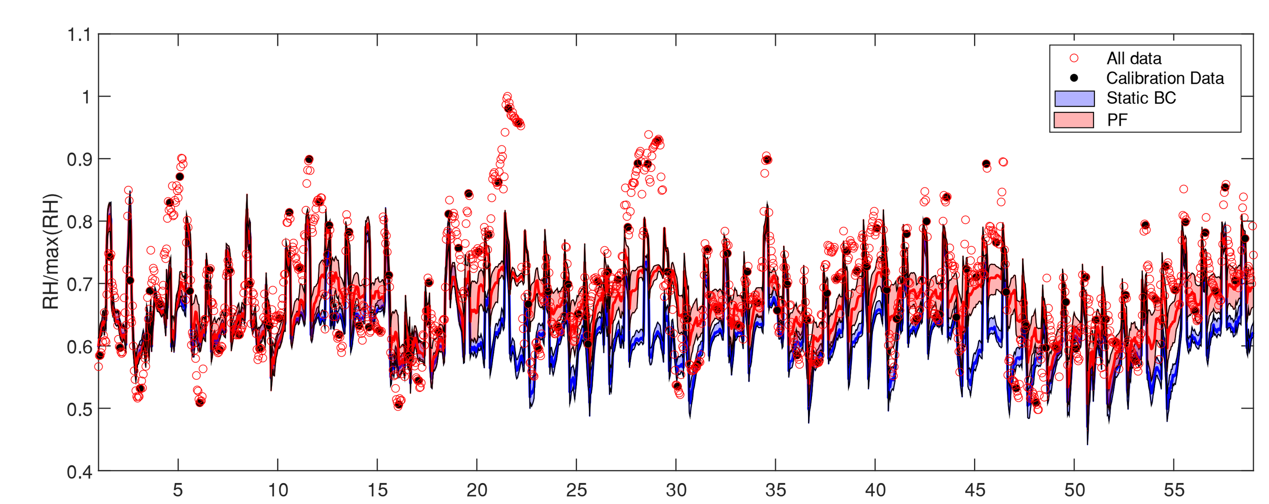
Case study: the underground farm

Physics-based simulation model of a hydroponic farm in a disused underground tunnel

The important parameters for crop growth are air temperature and relative humidity, which are directly affected by the tunnel ventilation rate and internal air speed. Using data consisting of monitored relative humidity with the particle filter approach allows us to track the values of ventilation rate and internal air speed that give the best agreement of the model with the data.



We then use the time varying parameters as inputs to the physics-based model. The model output shows a better agreement with the monitored data than results based on a static Bayesian calibration



Comparison of simulated Relative Humidity against monitored data using parameter values derived from the particle filter approach (red) and the a static Bayesian calibration (blue)

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