Adaptive Digital Twins of combustion systems using sparse sensing strategies

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This work proposes to implement a sparse sensing framework to build a hybrid numerical-experimental Digital Twin of a practical combustion system. The goal is to find the optimal sensor placement that minimizes the prediction error, and to predict the distribution of reacting scalars using few measurements.

Three-dimensional CFD simulations with detailed chemistry were used to build the design space by varying the fuel composition (from pure methane to pure hydrogen), the equivalence ratio (from 0.7 to 1) and the air velocity. The Proper Orthogonal Decomposition (POD) was applied to the numerical data to find a tailored basis for dimensionality reduction. Then, the QR decomposition with column pivoting was applied to the tailored basis to find the optimal sensor placement. This technique allows to determine both the optimal sensor placement and which feature has to be sampled in each position. Finally, the model was employed to predict the three-dimensional temperature distribution in the unexplored part of the design space, using the experimental samples as input.

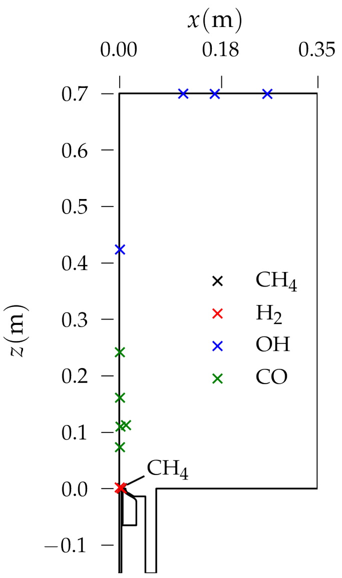

Figure 1: Optimal sensor placement inside the furnace.

The optimal placement of the 14 sensor is reported in Fig. 1. The results show that 14 sensors are enough to predict the entire state of the system with good accuracy. This finding also carries valuable information on which are the key positions and features required for the optimal reconstruction of the state of the system. This knowledge could be very important in the design of a reactor network as a simplified CFD model, among other uses.

The reconstruction and prediction accuracy of the DT was first tested by employing the CFD temperature sampled in the positions corresponding to the experimental temperature measures. The results show that even if the placement of the experimental measurements was not optimized, the model is still able to reach a very good level of accuracy both in the reconstruction and the prediction of the three-dimensional temperature distribution.

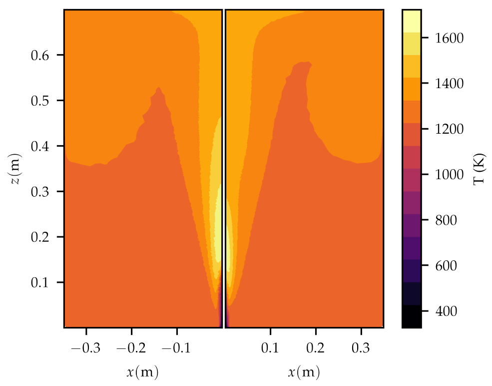

Figure 2: (*left*) Numerical distribution of the temperature for case 1. (*right*) Predicted temperature field using few experimental temperature samples.

Finally, the DT was tested by feeding the model with the experimental temperature measurements. The results show that the model produced a temperature field which is consistent with the corresponding numerical simulation, both for known and unknown operating conditions, as shown in Fig 2. Moreover, the hybrid DT was able to generate an adjusted temperature distribution which reduced the error with the experimental measurements, when compared to the CFD results. The temperature distribution is plotted in Fig. 3.

This work demonstrates how a sparse sensing framework can be applied successfully to the development of hybrid DTs to build soft sensors, and to control and optimize the operation of complex combustion systems.

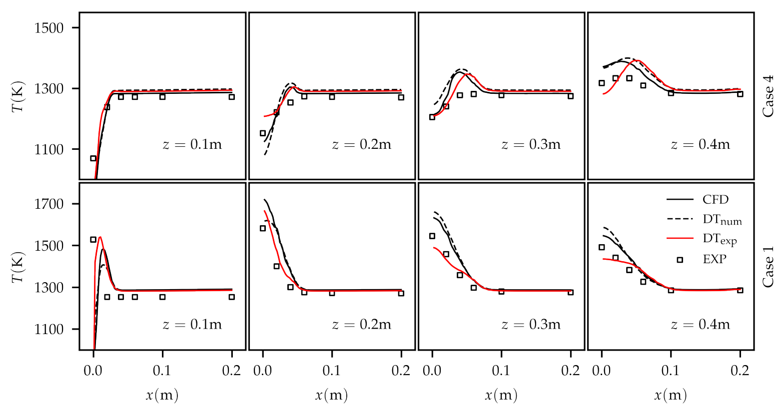

Figure 3: Temperature distribution for case 1 and case 4 at different positions along the axis. The averaged experimental uncertainty is 10 K.