Development of Reduced Glass Furnace Model to Optimize Process Operation

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HPC4 MANUFACTURING

Glass Production is Challenging

Production of glass is not only energy intensive but difficult to monitor due to the extreme environment. Computational models provide some insight into the molten flows but can often take too long to resolve the necessary details to make timely adjustments to the production line. A fast-running Reduced-Order Model can provide a “what-if” capability and an engine for control algorithms.

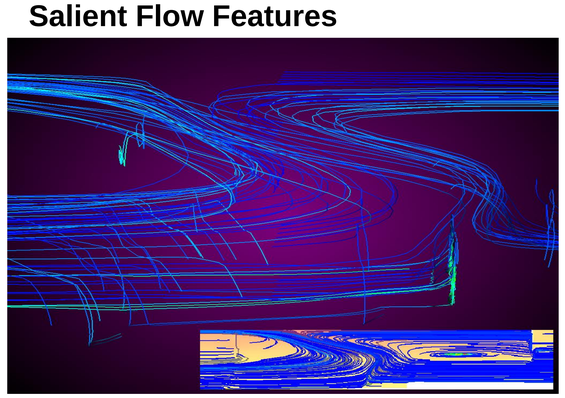
Approach

LLNL is using VisIT, the premier visualization and analysis tool for the HPC environment, along with machine learning methods to develop a reduced-order glass furnace model to enable engineers to make informed, real-time process adjustments.

Flow Features and Response Variables

Analysis scripts are used to explore the glass flows and quantify selected features. It is important to be able to consistently calculate a numerical value for each feature and assign a relative scale. Not all of these feature values will be used as responses … only those that distinguish flows and are relevant.

Salient Flow Features



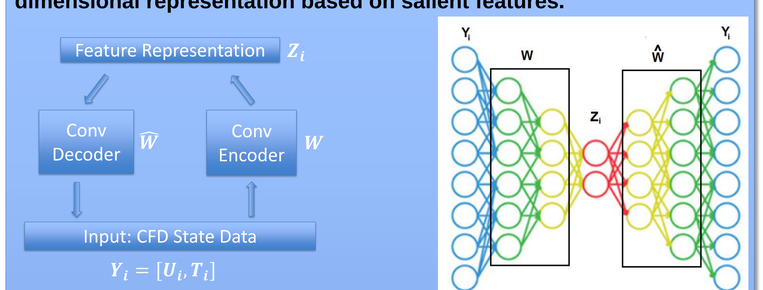
Stream lines display the interaction of the two main convective loops in the glass furnace forming the critical spring zone. The temperature and velocity profiles at the spring zone greatly influence the quality of the end product. The inset shows a larger area of the tank and the two main flow loops.

Classical and Modern Analysis

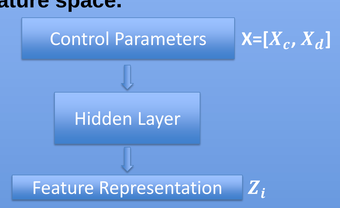
We are using a classic Central Composite experimental design to generate a baseline response model that relates the control variables to the flow features and other metrics. Deep Neural Networks are being developed to predict the flow field from the control parameters. Once trained, these networks can run quickly on a desktop computer.

Deep Neural Networks as a fast prediction tool

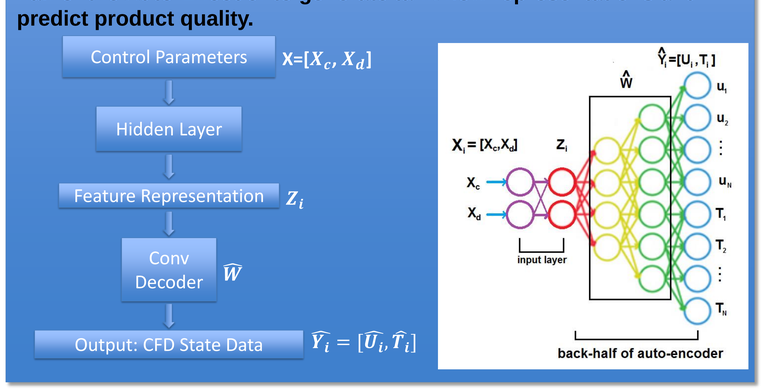
A Deep Convolution Auto-Encoding network will learn the best low-dimensional representation based on salient features.



Another Neural Network will be used to correlate Process Control variables X_c and tank design parameters X_d to the low dimensional feature space.



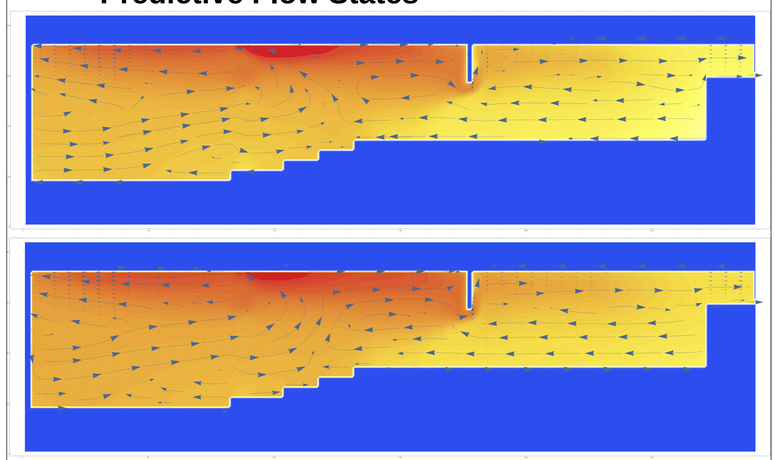
This Process Control network will be combined with the trained last half of the Auto-Encoder to generate tank flow representations and predict product quality.



Results

We have generated a large set of flow feature measuring routines and have collected information on a significant range of flows. We are also wrapping up the experiment set and are starting to develop the auto-encoder. The prototype visualization tool shows promise as a real-time visual process tool to help predict product quality.

Predictive Flow States



Prototype visualization of CFD States, $\widehat{Y_i}$, can quickly show the process engineer important flow features and predictions of other product quality metrics. This will run on a desktop computer

Benefits

This fast-running prediction tool can save roughly two weeks of production per year per furnace and increase productivity by 2%. Extrapolating that improvement to the entire U.S. glass manufacturing industry suggests 2.5 TBTUs of energy and 130,000 metric tons of carbon dioxide emissions could be saved.

This research was supported by the High-Performance Computing for Manufacturing Project Program (HPC4Mfg), managed by the U.S. Department of Energy Advanced Manufacturing Office within the Energy Efficiency and Renewable Energy Office. It was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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LLNL-POST-724919

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