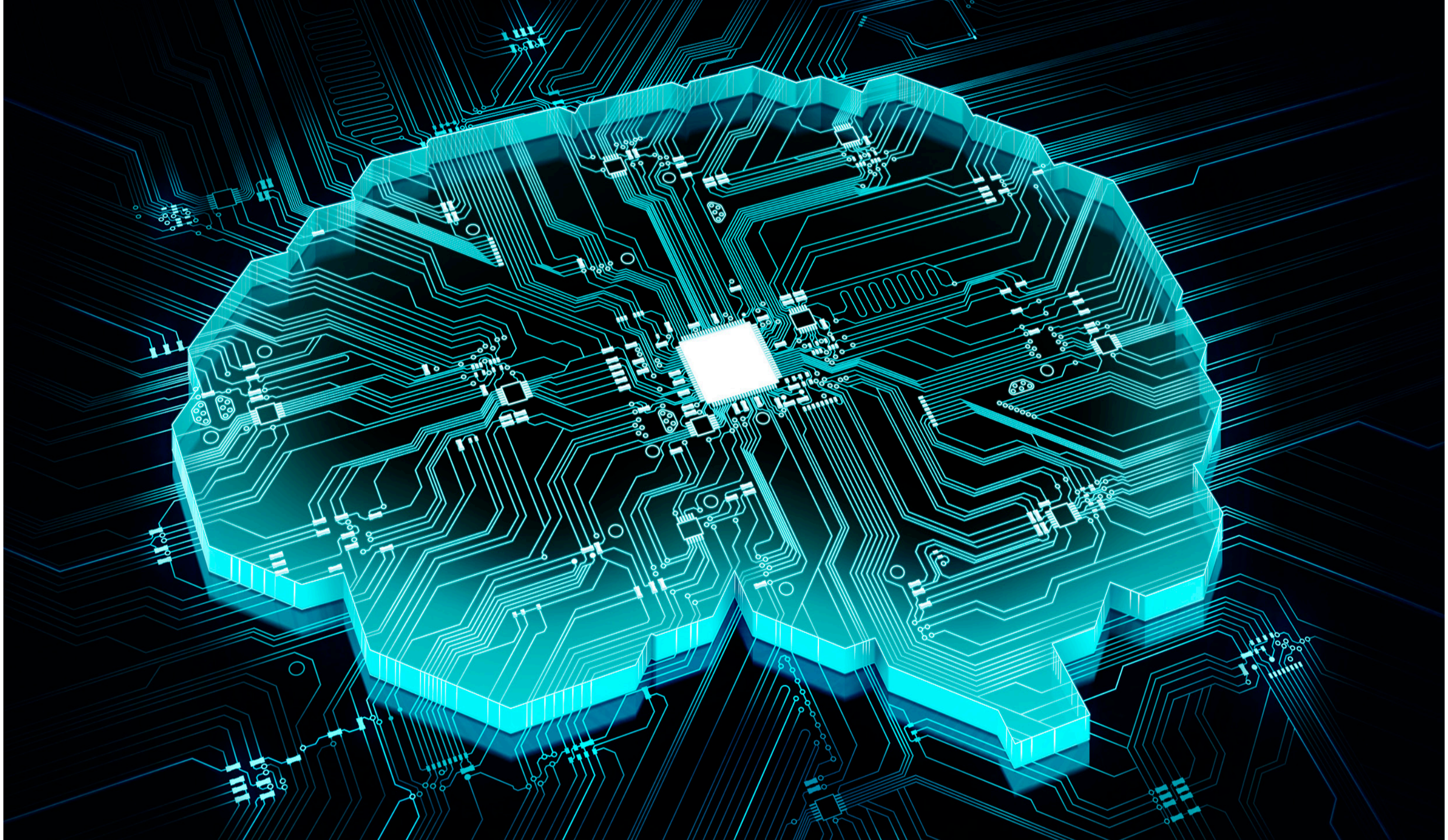
Petuum



AI POWERING THE FUTURE OF CEMENT

Henry Guo, Petuum, outlines how companies can adapt to Industry 4.0 and get to grips with AI in cement manufacturing.

Industry 4.0 is here and is driving the revolution of next generation manufacturing. AI is set to power the fourth industrial revolution and companies that can incorporate and adapt to Industry 4.0 components are likely to thrive and set the bar of accomplishments high. Yet hurdles such as the understanding of AI, how best to deploy and manage AI projects, and ultimately how to leverage AI, all pose significant barriers to its adoption. Petuum, a global AI start-up, hopes to help companies thrive and adapt to Industry 4.0.

Tackling industrial manufacturing problems

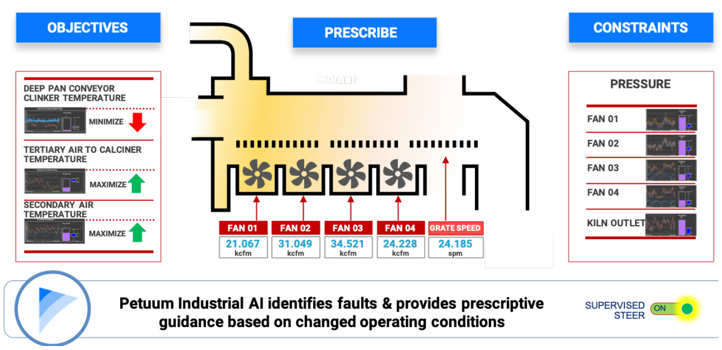
Petuum designed and created a line of industrial cement AI products to harness the power of AI in industrial manufacturing. Industrial AI can enable yield and energy savings, while reducing unplanned shutdowns and accidents.

The complexities of building AI for cement

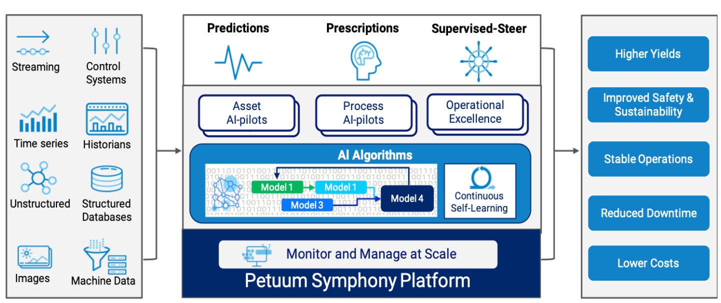
Cement manufacture is a complex process that involves many steps and specialised machinery assets. Cement manufacture takes in raw limestone, sand, iron ore and alumina as input materials, and then mixes them in the right proportions and heats them at an extreme temperature to produce cement. The majority of the heating to create cement is done through the kiln and preheater. The cement kiln is a huge rotational cylindrical vessel with its size (length and diameter) directly proportional to the factory capacity. Raw materials are introduced into the rotary kiln from the upper end (the kiln tail). At the lower end (the kiln head), the fuel, mainly coal powder from the coal injector, and the primary air from the air blower, are mixed into bi-phase fuel flow, which is sprayed into the kiln hood and combusts with the secondary air coming from the cooler. The heated gas is brought to the kiln tail by the induced draft fan, while the material moves to the kiln head via the rotation of the kiln and its own weight, in counter direction with the gas. After the material passes through the drying zone, pre-heating zone, decomposing zone, burning zone and cooling zone in sequence, clinker is generated as the product of the kiln process.

Cement AI in action

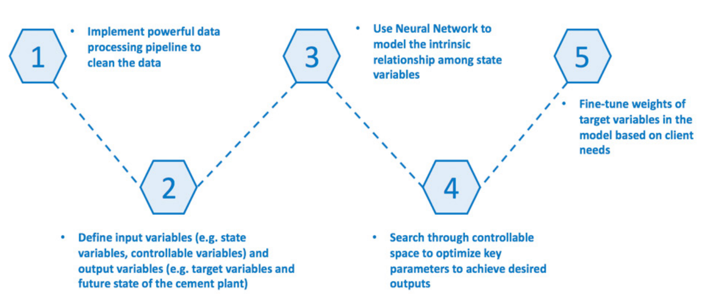
Petuum's AI model for cement adds AI powered smart factory manufacturing capabilities to each piece of the specialised cement manufacturing machinery, and optimises the whole manufacturing process. The AI for cement includes cooler AI, ball mill AI, vertical mill AI, and the complete pyro process which includes pre-heater, cooler, and kiln in an all-in-one package; it is able to optimise the whole cement manufacturing process by utilising multifactor AI capabilities to accurately predict, prescribe, and ultimately, autonomously run under supervised-steer mode cement manufacturing. The AI model learns the dynamics of each of the industrial assets (cooler, ball mill, vertical mill, pre-heater, and kiln) and processes from historical sensor data, creating prescriptions by searching for the optimal values of critical control parameters, and closing the loop by sending prescriptions back to assets and processes to be activated. This takes a step towards transforming traditional cement factories into Industrial 4.0 smart factories.



Petuum Industrial AI optimises cement manufacturing.



Petuum's Symphony platform.



Industrialised cement AI in 5 steps.

Pyro process (includes pre-heater, kiln, and cooler) with primary emissions

Key control factors

- Kiln feed.
- Fan speeds.
- Main fuel to main burner variables.
- Alternative fuel to main burner variables.
- Main fuel to calciner.
- Alternative fuel to calciner.

AI solution

- Optimising kiln and preheater which can be done by increasing production capacity through minimising fuel usage, and stabilising key kiln parameters.
- Optimising the pryo process to meet the objectives of energy savings and increased throughput with safe and stable operations.
- Includes kiln primary emissions measurements to control pollutants by optimising key control parameters.
- Includes cooler to control fan flow and undergrate pressure.
- The cooler transfers the heat from clinker to combustion air to increase

heat recovery and maximise clinker potential strength through rapid cooling.

Key benefits

- Pyro operations stabilisation improvement – reduction of standard deviation for kiln amps, burning zone temperature, feed and fuel rates.
- Improves the safety of the kiln and preheater operations.
- Increase in production rate.
- Reduction in specific heat consumption.
- Reduction of primary emissions.
- Cooler operations stabilisation improvement – reduction in standard deviation for undergrate pressure, cooler speed and increasing energy recovery by increasing secondary and tertiary air temperature.
- Improving the safety of the cooler operation.
- Increase in energy recovery of secondary/tertiary air temperature.
- Reducing clinker temperature variation.

AI handles complexity simply

The AI model looks to optimise heat in order to ensure the highest level of production, while reducing wear-and-tear to the system. Traditionally, these operational goals are achieved by manually adjusting the tunable parameters in a control system. Anywhere from thousands to tens of thousands of sensors are installed in the large and complex manufacturing facilities to monitor operational status. Operators analyse the values of a limited subset of sensors and change the control parameters accordingly to optimise the operational goals. Due to the complicated dynamics between the control parameters and goals, this tuning process is often ad-hoc, and highly variable among different operators, thus potentially being time-consuming and less effective.

The company's AI provides a data-driven optimal-control mechanism which automatically discovers the complex, nonlinear dynamics between control parameters and operational objectives from a large volume of complicated sensor data. It then searches for the optimal parameters that yield the best objectives, by solving multi-objective constrained nonlinear optimisation problems defined upon the learned dynamics.

Self-learning improvements

The company's AI model is able to handle a number of different input data types, ranging from internet of things (IoT) streaming data to high-speed camera images in both structured and unstructured formats. Petuum's AI platform, Symphony, identifies and removes irrelevant and unneeded attributes from data with the aim of minimising their effect on the accuracy of predictive models. For cement manufacturing, Symphony ingests the streaming IoT data, and then constructs training and serving graphs to run the AI models that power cement AI. This allows for rapid model and iterative training as more streaming data is processed, and new sources of data are added to further drive self-learning and improvements over time.

Industrialised cement AI in 5 steps

Step 1

The first component is data processing and representation learning. The company connects to existing instrumentation, then ingests and cleans the vast amount of data from a diverse set of sources. Petuum's data processing pipeline is powered by a collection of transformation modules that perform missing value imputation, data normalisation, feature selection, feature engineering and representation learning, which convert the original, often irregular, sensor data into readily actionable feature representations.

Steps 2 – 3

Once the multi-modal and vast sets of industrial manufacturing data are cleaned and AI-ready, the model will use the cleaned data to construct and improve upon nonlinear hierarchical models to capture the complex dynamics of the assets and processes, especially how the operational objectives change with the control parameters. These models detect the long-range temporal patterns of the streaming sensor data, capture the high-order correlations between a large number of sensors, learn a hierarchy of low-level, middle-level, and high-level representations of the data, and discover the nonlinear and complex functional mapping from the control parameters to the objectives.

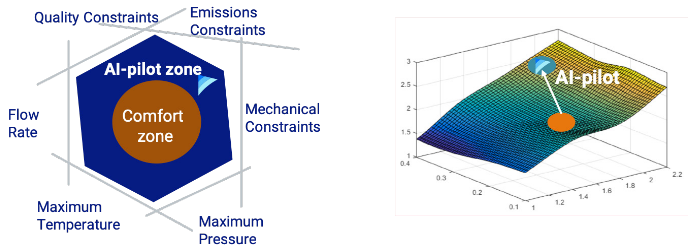
Steps 4 – 5

When the operational dynamics are learned, the product performs effective multi-objective optimal control. It defines a constrained nonlinear mathematical optimisation problem based on the learned dynamics and solves this problem to identify the optimal control parameters that yield the best objective values. The AI's cement knowledge base uses input from operators and other key subject matter experts to collect domain knowledge, such as equipment, safe operating ranges and peripheries, and environmental requirements, and incorporates such knowledge into the optimisation of problems to ensure operational safety and productivity.

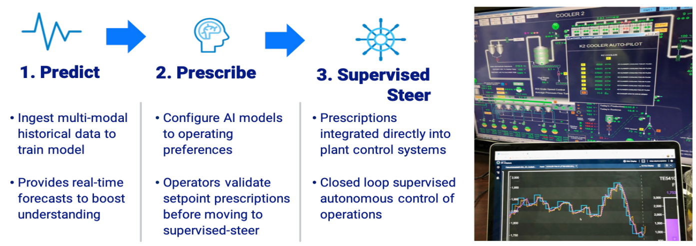
After these steps, the model is trained, ready to be put into production, and deployed in any on-premise data centre or cloud-based environment.

Fully optimised AI in action

The AI model allows operators to operate safely and consistently beyond what is available today, by incorporating AI to predict, prescribe, and autonomously run in supervised-steer mode, while adhering to boundary constraints as dictated by operators. It incorporates quality constraints,



Safe and consistent cement manufacture.



Industrial AI in action.

emissions constraints, mechanical stability constraints, flow rate, maximum allowable temperature, and pressure constraints for cement manufacturing. Once operators feel comfortable and validate setpoint prescriptions, Petuum Industrial AI is able connect to any number of control systems to write back and autonomously steer manufacturing in a supervised-steer mode. The model enables operators to be in control to configure cement AI to operate at their preference level.

The company incorporated the dynamics of cement manufacturing by using machine learning and deep learning techniques that optimise operations based on the learned dynamics. The control space is multi-dimensional and non-smooth. The AI model incorporates advanced searching algorithms to search optimal solutions across many different factors and the algorithms incorporate the feature importance during the search process, thus producing the best possible solution by considering the weights among features. The system is designed to adapt to such dynamic changes in real-time operations, even when sensors are faulty or not available. Industrial AI is able to make optimal operation suggestions while keeping operation in safe zone by leveraging the learned knowledge of the relationships among faulty and healthy sensors. The model also incorporates online learning within the system so that it can adapt to concept drift and stabilise the autonomously run cement operations iteratively.

Measures of success

The company's AI model for cement can achieve about 2 – 5% savings in energy costs and over 2% in higher overall yield. This translates to yield and energy improvements in the range of 2 – 7% when the supervised-steer model is turned on for all Petuum Industrial cement AI products within a smart factory. The AI model can achieve these results by leveraging the power of AI to better increase and optimise cement manufacturing and emissions throughout the process. The company's model increases the ratio of alternative fuels (including biowaste and tires) to Petroleum coke, while optimising the pyro operation, the core process of cement production that includes the preheater, kiln, and cooler. The product can also reduce the emission of gases such as NOx, SOx, and heavy metals, mercury and lead, by recuperating temperature from the cooler to the kiln and pre-calciner, thus reducing the need to burn additional fuels. On average, Industrial AI has observed a reduction of CO_2 emissions by over 3000 kg/hr or up to 28 000 tpy from a single AI powered cooler alone, when running Petuum Industrial AI.

Conclusion

AI can predict, prescribe, and autonomously control cement manufacturing in a supervised-steer mode by ingesting streams of IoT data from thousands of sensors. Once Petuum Industrial AI is up and running, it is hoped to further improve over time by adapting and self-learning from more data, and new data sources. The model is designed to optimise across secondary air temperature, tertiary air temperature, clinker temperature, kiln pressure, stability, and operational safety. Air temperatures were optimised to be as high as realistically possible, and to safely and securely have high heat recovery and good combustion efficiency. ■

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About the author

Henry Guo leads product marketing at Petuum, an artificial intelligence (AI) start-up company backed by tier 1 venture capital firms. Henry has an extensive background within the technology space that spans over 10 years across multiple high-tech companies, and has worked on a variety of sectors including artificial intelligence, cloud computing, virtual machines, and cyber security. He holds a M.S. in Computer Science and an MBA from top US institutions.