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Paper title: The role of artificial intelligence-driven soft sensors in advanced sustainable process industries: A critical review

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Keywords specific to the paper: Soft sensor; virtual sensor; sustainable development; process monitoring; artificial intelligence; machine learning; process industry; data-driven modeling

Summary of the main contributions:

These past few years, focus on environmental issues has increased and sustainable development has become a subject of conversation in process industries. The predicted depletion of natural resources and environmental issues turned into an important focal point in organizations because global authorities have been imposing tighter environmental rules and regulations over the past decade. In fact, the big process industries take part in global warming by using excessive fossil fuels, producing material wastage and toxic gas. Hence, adopting sustainable development strategies in a company or an industry is now mandatory. This requirement impacted the importance of the process monitoring aspect in the business process management lifecycle of an organization. Normally, in order to assess and monitor the process industry, companies used hardware sensors at desired locations of the process so they can control material wastage, environmental pollution or energy consumption. But they observed that hard sensors are now not suitable or enough in processes to estimate 'hard-to-measure' quality parameters because they can't satisfy the end-desired product quality. It is also impossible to monitor and control the quality parameters in real-time when it comes to using hard sensors. Using soft sensors as a replacement for that model provided real-time predictions of the desired parameters but suffered from serious limitations.

Therefore, the paper addresses the limitations of using traditional modeling techniques in soft sensor applications and the foundation of their developments. Consequently, it aims to explore and study advanced AI-based algorithms in achieving sustainable development in process industries. Numerous advantages are cited. The ability to operate in harsh working environments, the ability to make accurate real-time estimations of the quality parameters without measurement delays, the ability to be implemented on existing hardware without any additional investments, the ability to replace expensive hardware sensors at a low-cost, and the ease of maintenance are some of the benefits of soft sensors compared to the traditional process monitoring techniques used in process industries. In the article, researchers are even illustrating soft sensors applications in multiple fields in the industries to showcase the importance of their usage and the specific benefits the companies can generate through them.

The paper mentions the evolution of the design of soft sensors using AI based algorithms such as neural networks models (ANN, LSTM, RNN, FIS, NFS) However, the article also identifies challenges (thanks to 5 case studies) encountered when developing soft sensors, such as missing data, varying sampling rates, small datasets, and model interpretability. The article proposes AI-based solutions to address these challenges that still exist. The paper highlights the importance of providing a critical review and study of the latest research and development on soft sensors based on AI algorithms, as much as their role in guiding process industries toward sustainable development. The results of the paper contribute to linking existing research gaps and provide directions for future researchers on soft sensors and AI models. The latest AI-based modeling techniques have the potential to enhance the prediction accuracy and the computational efficiency of soft sensors which enables accurate and continuous monitoring of industrial processes. Despite their advantages, the design, application, and maintenance of soft sensors present numerous challenges. All stages of soft sensor development, such as collection of process data, data

preprocessing, model selection and validation, and soft sensor maintenance are associated with various limitations and challenges which slows the growth of soft sensor applications. But to conclude, the paper points out the effectiveness of AI-based techniques in overcoming challenges and improving the performance of soft sensors, which is ultimately contributing to sustainable manufacturing strategies.

AI model used

- **Introducing the AI models**

A soft sensor is a technique of estimating 'hard-to-measure' quality related parameters in industrial processes according to the article. The paper discusses various AI models used in soft sensor applications, including deep neural networks (DNN), fuzzy logic, evolutionary algorithms, unsupervised and semi-supervised learning techniques, and spatio-temporal attention networks (STAN). These AI models are employed to address challenges in soft sensor design, such as handling missing data, improving predictive performance with small datasets, and extracting temporal and spatial features from process data. But using these algorithms permits us to effectively mimic the cognitive functions of humans, leading to excellent performance in a wide range of AI applications. However, to improve the AI models and enable its development for prediction, the study bases all research on multiple types of neural networks models or its sub models. One is called Graph mining, convolution, and explanation stacked target-related autoencoder (GMCE-STAE). In this approach a spatial self-attention mechanism was used to extract process knowledge based on available historical data. Then, the extracted knowledge along with the human experience was used to extract features. These extracted features were then input into the soft sensor model to predict missing data. Finally, a graph neural network was used to explain how the process knowledge was utilized by the model for prediction.

The enhanced performance of the soft sensors can be observed through reduced prediction errors. This has mainly been achieved by combining two or more AI-based algorithms together. Enhanced predictive performance is the key to accurately monitoring industrial processes in real-time which enables maintaining the process within desired limits.

- **How do they contribute the idea proposed by the paper?**

The study highlights the use of advanced AI algorithms/models to improve prediction accuracy and computational efficiency of soft sensors, to ultimately contribute to sustainable development in process industries. For example, deep neural networks are used to effectively mimic human cognitive functions, leading to excellent performance in soft sensor applications. Spatio-temporal attention networks are employed to extract temporal and spatial features, also improving the predictive performance of soft sensors. These AI algorithms enable the development of soft sensors with high prediction accuracy, which is crucial for real-time process monitoring and control, leading to reduced environmental risks for organizations. The key is to improve the prediction accuracy and the computational efficiency of these soft sensors by addressing the limitations of the models as time goes, or by forecasting predictions to assess the situations in advance. It helps the company's strategy. These algorithms are shown to be better than the traditional and machine learning-based models, particularly in the big process industries.

The AI models really do contribute by adopting different soft sensor applications toward sustainable manufacturing strategies, including material efficiency, resource efficiency, eco-efficiency, waste minimization. These would help in reducing waste generation, optimizing material and energy utilization, and reducing harmful emissions.

Supported by a software application?

Software applications are not explicitly mentioned, as no extensive example of implementation of the AI based solutions for soft sensor design and development were made in this article.