Yueyang LUO, Xinmin ZHANG, Manabu KANO, Long DENG, Chunjie YANG, Zhihuan SONG, 2023. Data-driven soft sensors in blast furnace ironmaking: a survey. *Frontiers of Information Technology & Electronic Engineering*, 24(3):327-354. https://doi.org/10.1631/FITEE.2200366

Data-driven soft sensors in blast furnace ironmaking: a survey

Front Inform Technol Electron Eng

Key words: Soft sensors; Data-driven modeling; Machine learning; Deep learning; Blast furnace; Ironmaking process

Corresponding author: Xinmin ZHANG
E-mail: xinminzhang@zju.edu.cn
ORCID: https://orcid.org/0000-0002-4761-3969

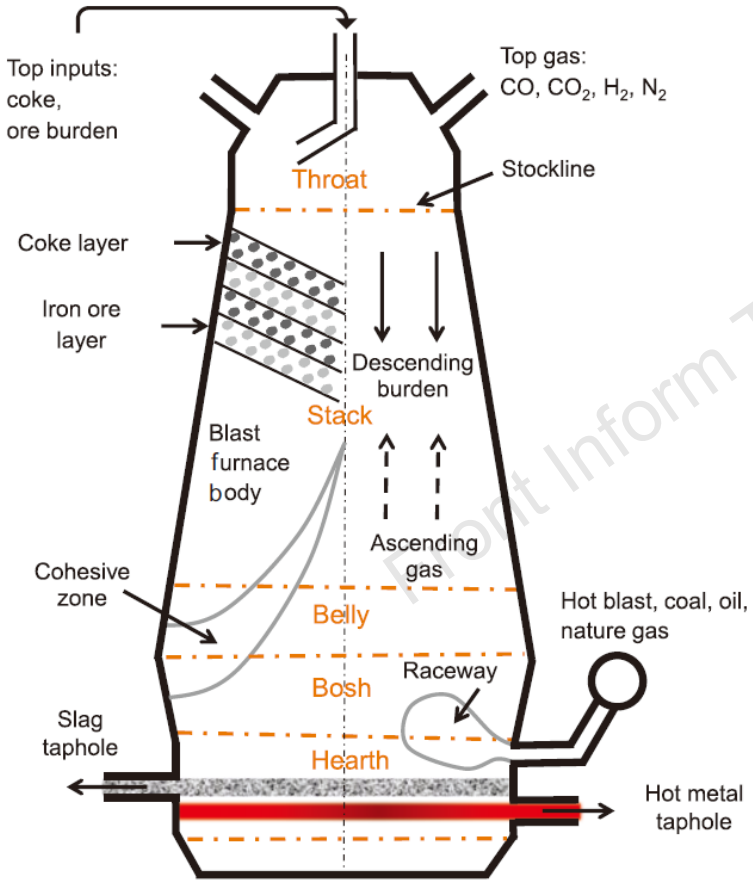
Motivation

- With the acceleration of the carbon neutrality target, green intelligent manufacturing has become an inevitable trend in the development of the manufacturing industry.
- Iron and steel manufacturing occupies a pivotal position in the industrial field, and blast furnace ironmaking is one of the most energy consuming processes in the iron and steel industry [1].
- Therefore, iron and steel enterprises urgently need stable and efficient intelligent operations in the ironmaking process to achieve the goal of producing better-quality, low-carbon, green, and sustainable products.

Front Inform Technol Electron Eng

Background

- The majority of the world's steel is extracted from iron ores, and blast furnace ironmaking is a key stage in the process [2]. The whole structure of the blast furnace is depicted as follows:

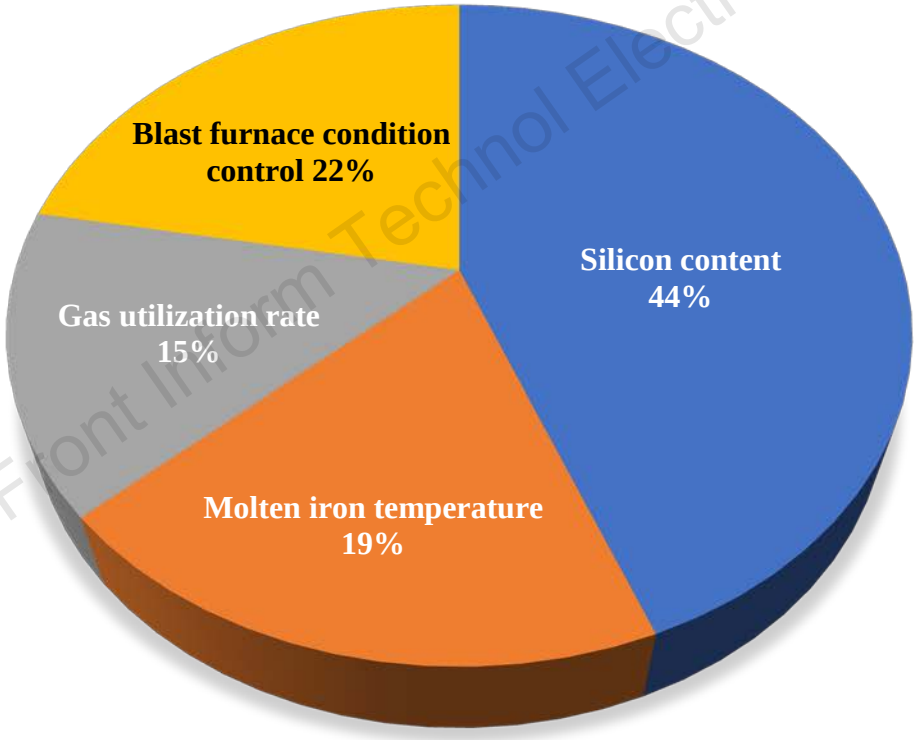




Front Inform Technol Electron Eng

Application areas

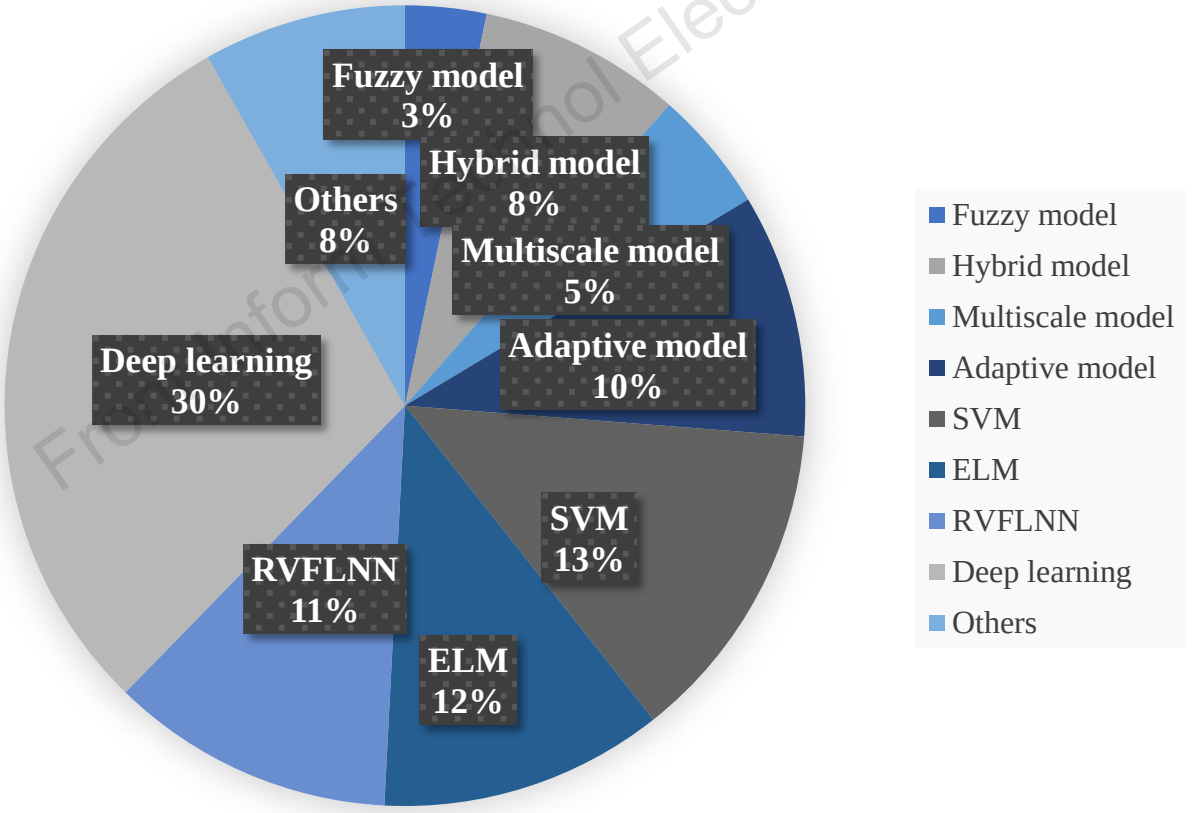
- Typical application areas of data-driven soft sensors in blast furnace ironmaking are classified as follows: silicon content prediction and tendency forecasting, molten iron temperature prediction, gas utilization rate (GUR) prediction, and control of the blast furnace condition.



Front Inform Technol Electron Eng

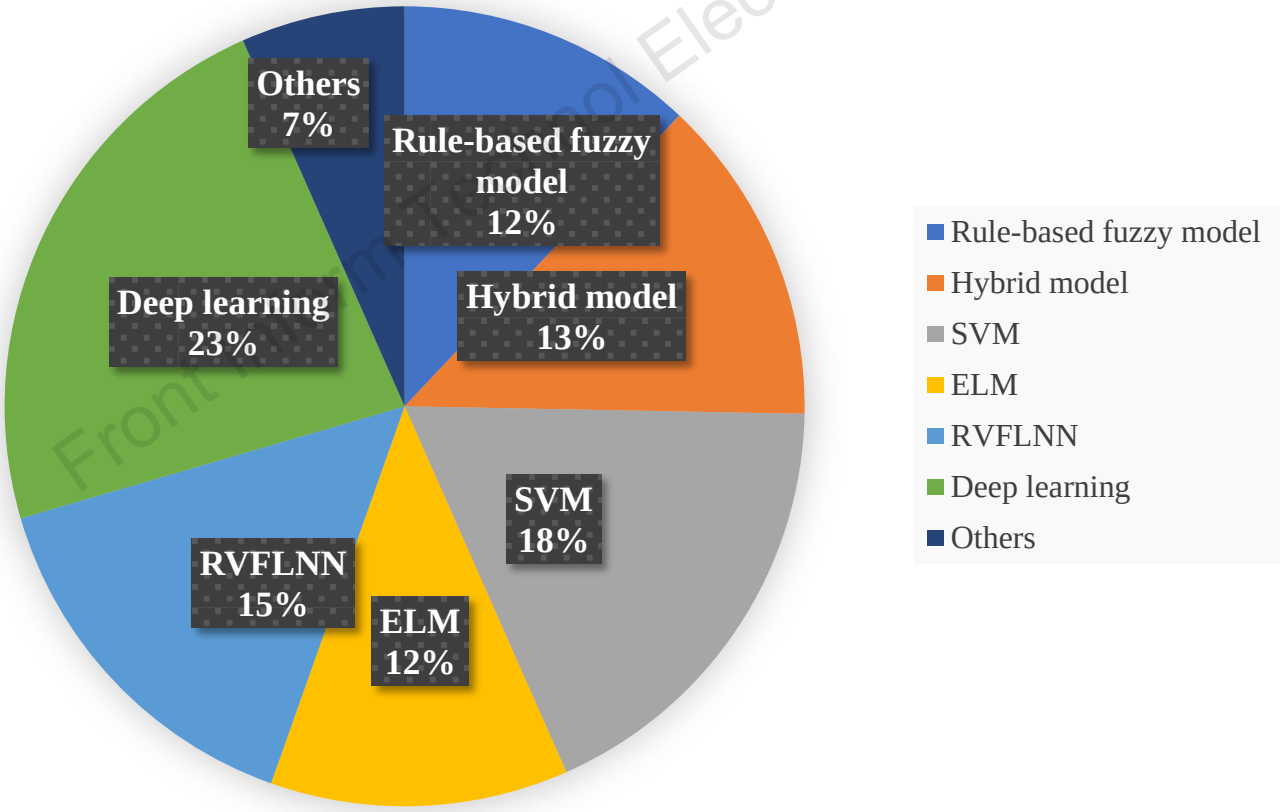
Application areas

- Silicon content is a key parameter in blast furnace ironmaking, serving as an essential indicator of the heat of the molten iron. Accurate prediction of silicon content can aid in optimizing the blast furnace process and achieving high-quality output, making it an important consideration for ironmaking operations [3].



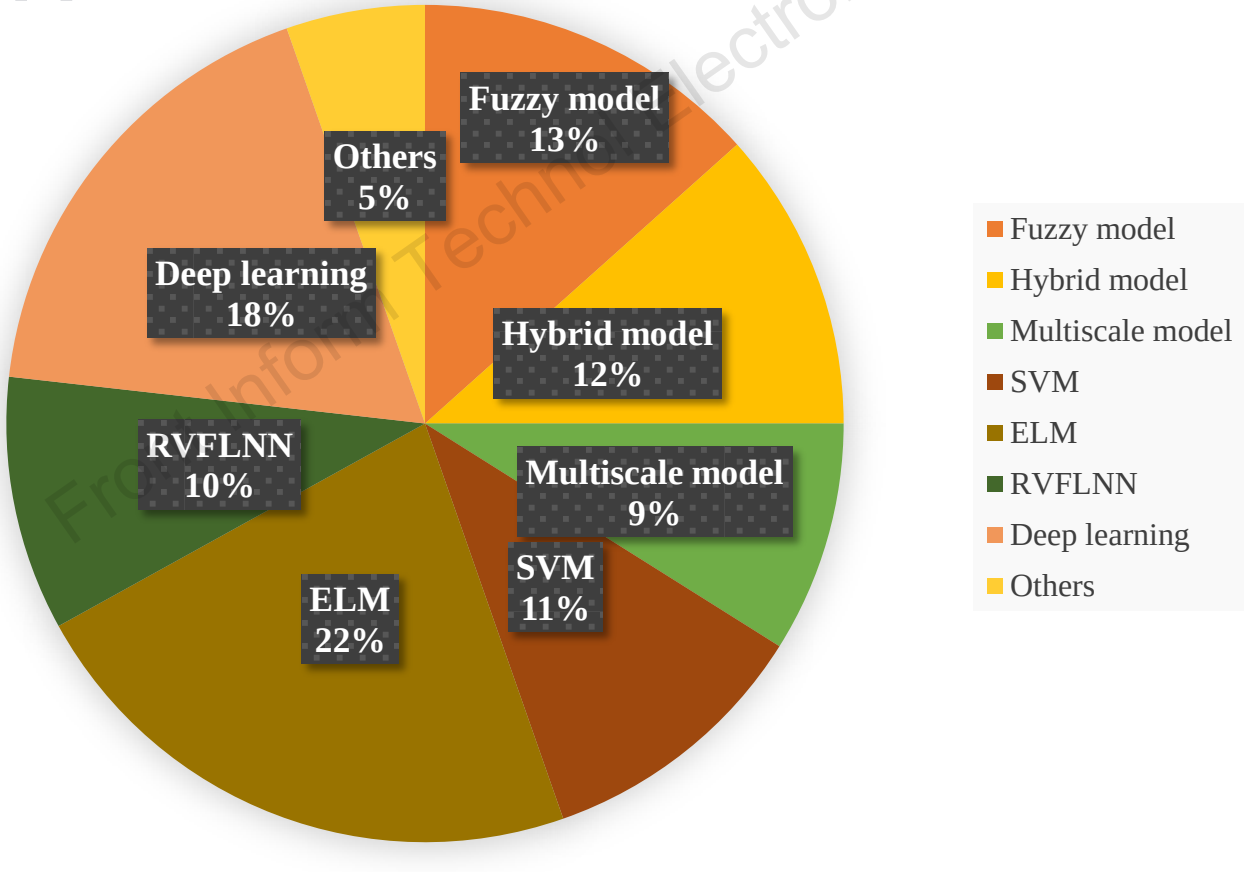
Application areas

- Temperature of molten iron is a critical parameter in blast furnace ironmaking, as it provides valuable insight into the thermal state of the blast furnace [4]. As such, accurate prediction and control of molten iron temperature is vital to ensure optimal conditions for the ironmaking process.



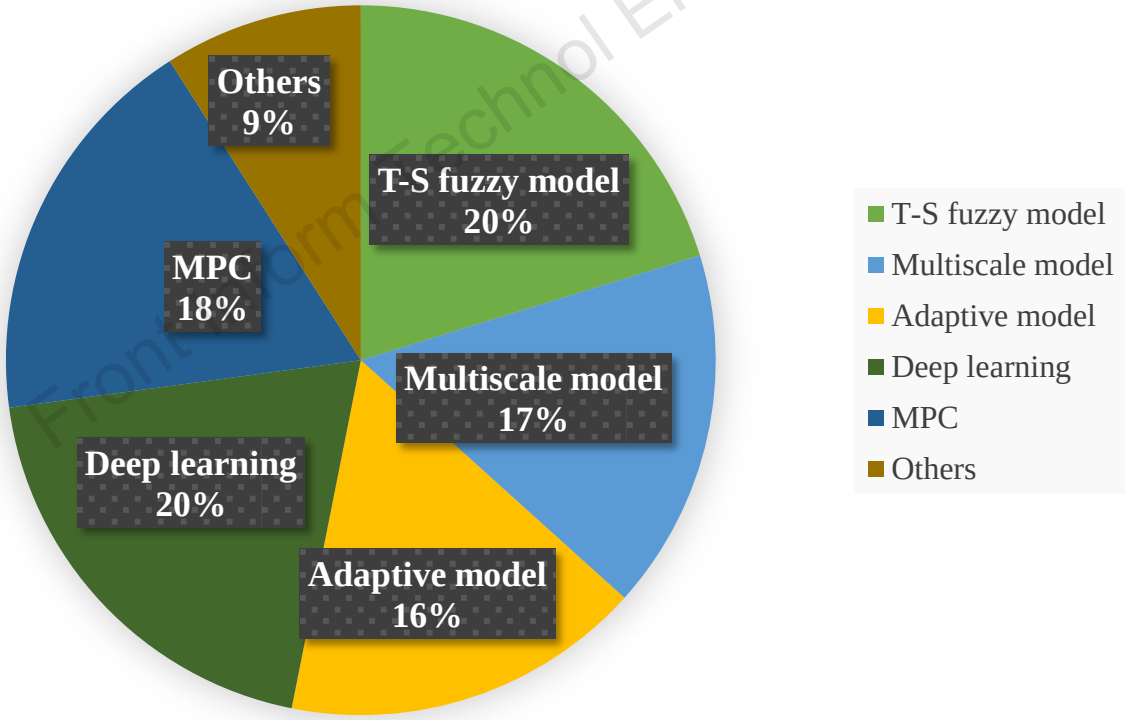
Application areas

- GUR is the ratio of the carbon dioxide content to the total carbon monoxide and carbon dioxide content in the top gas flow. A high GUR is indicative of adequate coal burning and reduced consumption, which is crucial for achieving optimal blast furnace performance [5].



Application areas

- Blast furnace condition control is a critical aspect of blast furnace ironmaking, typically focused on ensuring that the final molten iron quality (MIQ) meets the desired specifications [6]. Achieving optimal MIQ requires careful monitoring and control of various parameters, such as temperature, chemistry, and gas flow, throughout the ironmaking process.



Front Inform Technol Electron Eng

Prospects

- Multi-source data fusion [7]
- Digital twin modeling [8]
- Parallel and distributed modeling
- Carbon neutrality





Summary

- This paper aims to provide an overview of data-driven soft sensing techniques for blast furnace ironmaking. By reviewing the state-of-the-art data-driven soft sensing algorithms in blast furnace ironmaking, it can be confirmed that data-driven soft sensors have great potential for academic research and industrial applications.
- This survey will motivate more researchers to strive to overcome the above challenges of soft sensing technology for blast furnace ironmaking. In the next decade and beyond, it is expected that more innovative ideas and more advanced soft sensing technologies will be developed and applied to solve various problems in blast furnace ironmaking.

Front Inform Technol Electron Eng

References

[1] Yu X, Tan C, 2022. China's pathway to carbon neutrality for the iron and steel industry. *Glob Environ Change*, 76:102574.

[2] Geerdes M, Chaigneau R, Lingiardi O, 2020. Modern Blast Furnace Ironmaking: an Introduction (4th Ed.). IOS Press, Amsterdan, the Netherlands.

[3] Waller M, Saxén H, 2003. Time-varying event-internal trends in predictive modeling methods with applications to ladlewise analyses of hot metal silicon content. *Ind Eng Chem Res*, 42(1):85-89.

[4] Zhou B, Ye H, Zhang H, et al., 2016. Process monitoring of iron-making process in a blast furnace with PCA-based methods. *Contr Eng Pract*, 47:1-14.

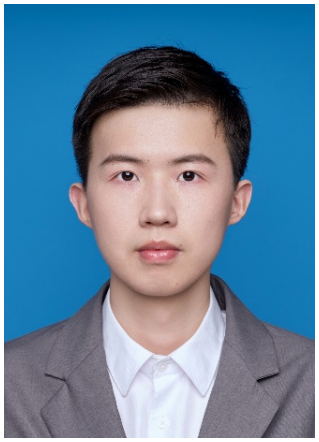
[5] Liu Y, Fan Y, Chen JH, 2017. Flame images for oxygen content prediction of combustion systems using DBN. *Energy Fuels*, 31(8):8776-8783.

[6] Hashimoto Y, Okamoto Y, Kaise T, et al., 2019b. Practical operation guidance on thermal control of blast furnace. *ISIJ Int*, 59(9):1573-1581.

[7] An JQ, Wu M, He Y, 2013. A temperature field detection system for blast furnace based on multi-source information fusion. *Intell Autom Soft Comput*, 19(4):625-634.

[8] Glaessgen E, Stargel D, 2012. The digital twin paradigm for future NASA and U.S. air force vehicles. Proc 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conf, p.1818.

Front Inform Technol Electron Eng



Yueyang LUO received his BE degree in automation from School of Mechanical Engineering and Automation, Beihang University, Beijing, China in 2021. He is currently working toward his ME degree in electronic information engineering in College of Control Science and Engineering, Zhejiang University, China.
His research interests include time series prediction, deep learning, and soft sensor.



Xinmin ZHANG, corresponding author of this invited paper, received his PhD degree in systems science from Kyoto University, Japan in 2019. From April to December 2019, he was a post-doctoral research fellow in Department of Systems Science, Kyoto University, Japan. Currently, he is an associate professor with the State Key Laboratory of Industrial Control Technology, College of Control Science and Engineering, Zhejiang University, China. His research interests include industrial big data modeling and analysis, process control, fault diagnosis, soft-sensor, and machine learning and deep learning with applications to industrial processes.

Front Inform Technol Electron Eng



Manabu KANO received his BS, MS, and PhD degrees from Department of Chemical Engineering at Kyoto University in 1992, 1994, and 1999, respectively. He has been an instructor at Kyoto University since 1994. From 1999 to 2000, he was a visiting scholar at Ohio State University, USA. Since 2012, he has been a professor of systems science, Kyoto University. He has conducted research in collaboration with various industries, such as semiconductor, chemical, steel, and pharmaceutical. His research interests focus on process data analysis for quality improvement, process monitoring, and process control.



Long DENG is a senior engineer with the Central Research Institute of Baoshan Iron & Steel Co., Ltd., Shanghai, China. His research interests include automation and intelligent control of key processes, such as steelmaking, continuous casting, heating, and heat treatment.

Front Inform Technol Electron Eng



Chunjie YANG received his BS degree in machine design, MS degree in fluid transmission and control, and PhD degree in industrial automation from Zhejiang University, China in 1992, 1995, and 1998, respectively. In 2009, he was a visiting scholar at Florida State University, USA. He is currently a professor in College of Control Science and Engineering, and a Qiushi Distinguished Professor of Zhejiang University, China. His current research interests include industrial big data, process monitoring, soft-sensor, and fault diagnosis.



Zhihuan SONG received his BE and ME degrees in industrial automation from Hefei University of Technology, China in 1983 and 1986, respectively, and his PhD degree in industrial automation from Zhejiang University, China in 1997. Since 1997, he has been in College of Control Science and Engineering, Zhejiang University, where he was first a postdoctoral research fellow, then an associate professor, and is currently a full professor. His research interests include modeling and fault diagnosis of industrial processes, analytics and applications of industrial big data, and advanced process control technologies.

Front Inform Technol Electron Eng