

LLM-Based Querying and Prognostic Evaluation in Industrial Control Systems*

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Abstract

Traditional industrial control systems often rely on predefined, rule-based logic to manage and regulate processes. While these systems are robust and predictable, they can be inflexible in dynamic or complex environments where unforeseen situations require adaptive responses. Recent advances in artificial intelligence, particularly in large language models (LLMs), have demonstrated promising capabilities in understanding context, performing reasoning, and making decisions based on natural language instructions. This paper investigates the potential of using those models as a substitute for rule-based controllers in industrial settings.

We have implemented a system in which a transformer-based model interacts with a simulated industrial system, receiving real-time state queries and responding with control decisions. The study evaluates the model's ability to retrieve current and predicted system states, formulate appropriate control actions, and maintain process stability. Through a series of controlled experiments, we compare the performance of the LLM-driven approach against traditional rule-based controllers across various scenarios, including normal operation, fault conditions, and unexpected inputs.

The results suggest that such a generative language model can not only emulate certain rule-based behaviors but also generalize beyond predefined rules, offering potential for more adaptive and intelligent control mechanisms. However, limitations in real-time responsiveness, safety assurance, and interpretability pose challenges for deployment in safety-critical environments.

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Introduction

Industrial control systems have long relied on rule-based controllers, which operate using predefined logical rules or decision trees that explicitly map input conditions to control actions. These systems are typically implemented using finite state machines, ladder logic, or structured control code in programmable logic controllers (PLCs) and distributed control systems (DCSs). Their popularity stems from several key advantages: they offer high reliability, deterministic behavior, and transparency, making them suitable for safety-critical environments and easy to validate and maintain in regulated industries [5].

However, the rigid, handcrafted nature of these systems also imposes significant limitations. Rule-based controllers lack adaptability and struggle to respond to unforeseen events or context-dependent variations in system behavior. As processes grow in complexity or require greater flexibility, the number of rules and exceptions grows rapidly, leading to brittle logic and high maintenance overhead [6]. Moreover, updating the control logic often demands expert intervention and downtime, which is costly in industrial environments.

In recent years, large language models such as GPT [1], PaLM [3], and LLaMA [9] have demonstrated potential capabilities in interpreting and generating human-like text. These models are trained on massive corpora of natural language and code, allowing them to reason over structured and unstructured prompts, answer complex queries, and even perform chain-of-thought reasoning. Their ability to generalize across tasks without explicit retraining has enabled breakthroughs in areas such as code generation [2], strategic planning and tool use [7], and interactive decision-making in simulation environments [4]. Early explorations into human-computer interaction and autonomous agents powered by LLMs have shown that these models can follow multi-step instructions, interact with virtual environments, and make decisions based on evolving context [8]. Such versatility raises the question of whether LLMs can move beyond text-based tasks and be deployed in real-time, decision-critical environments such as industrial control systems.

Research gap

Despite the rapid advancements and broad applicability of large language models, their use as direct replacements for rule-based industrial controllers has not yet been systematically studied. While LLMs have shown strong performance in high-level reasoning and decision-making tasks, the domain of industrial control introduces a unique set of challenges. Controllers in industrial systems must operate with high precision, often within strict real-time constraints, and must uphold rigorous safety and reliability standards. These requirements leave little room for ambiguity or delay that are not inherently guaranteed by AI model-based reasoning. Furthermore, the black-box nature of an autonomous reasoning system, combined with their probabilistic outputs, contrasts sharply with the deterministic and verifiable logic that rule-based controllers offer. As such, exploring the feasibility of substituting traditional logic with a generative language-driven control policies is a non-trivial

task. It requires careful investigation into the trade-offs, potential failure modes, and integration strategies necessary for safe and reliable deployment in industrial environments.

Focus of the study

This paper investigates how Large Language Models can replicate the decision-making behavior of rule-based industrial controllers by interpreting system state information and generating appropriate control actions, while maintaining acceptable performance in terms of accuracy, response time, and reliability within simulated industrial environments.

References

- [1] T. BROWN, B. MANN, N. RYDER, M. SUBBIAH, J. D. KAPLAN, P. DHARIWAL, A. NEELAKANTAN, P. SHYAM, G. SASTRY, A. ASKELL, S. AGARWAL, A. HERBERT-VOSS, G. KRUEGER, T. HENIGHAN, R. CHILD, A. RAMESH, D. ZIEGLER, J. WU, C. WINTER, C. HESSE, M. CHEN, E. SIGLER, M. LITWIN, S. GRAY, B. CHESS, J. CLARK, C. BERNER, S. McCANDLISH, A. RADFORD, I. SUTSKEVER, D. AMODEI: *Language Models are Few-Shot Learners*, in: *Advances in Neural Information Processing Systems*, ed. by H. LAROCHELLE, M. RANZATO, R. HADSELL, M. BALCAN, H. LIN, vol. 33, Curran Associates, Inc., 2020, pp. 1877–1901, URL: https://proceedings.neurips.cc/paper_files/paper/2020/file/1457c0d6bfc4967418bfb8ac142f64a-Paper.pdf.
- [2] M. CHEN ET AL.: *Evaluating Large Language Models Trained on Code*, arXiv preprint (2021), eprint: [2107.03374](https://arxiv.org/abs/2107.03374).
- [3] A. CHOWDHURY, S. NARANG, J. DEVLIN, M. BOSMA, G. MISHRA, A. ROBERTS, P. BARHAM, H. W. CHUNG, C. SUTTON, S. GEHRMANN, P. SCHUH, K. SHI, J. SORESENSEN, B. STEINER, Q. V. LE, Z. GHAHRAMANI, J. DEAN, S. PETROV: *PaLM: Scaling Language Modeling with Pathways*, arXiv preprint (2022), eprint: [2204.02311](https://arxiv.org/abs/2204.02311).
- [4] S. GAO, Y. YAO, T. WU, D. WELD, S. M. XIE, J. HEER: *PAL: Program-aided Language Models*, arXiv preprint (2022), eprint: [2211.10435](https://arxiv.org/abs/2211.10435).
- [5] D. HÄSTBACKA, T. VEPSÄLÄINEN, S. KUIKKA: *Model-driven development of industrial process control applications*, *Journal of Systems and Software* 84.7 (2011), pp. 1100–1113, ISSN: 0164-1212, DOI: <https://doi.org/10.1016/j.jss.2011.01.063>, URL: <https://www.sciencedirect.com/science/article/pii/S0164121211000458>.
- [6] J. LEE, H.-A. KAO, S. YANG: *Service Innovation and Smart Analytics for Industry 4.0 and Big Data Environment*, *Procedia CIRP* 16 (2014), pp. 3–8, DOI: [10.1016/j.procir.2014.02.001](https://doi.org/10.1016/j.procir.2014.02.001).
- [7] S. LI, X. PUIG, C. PAXTON, Y. DU, C. WANG, L. FAN, T. CHEN, D.-A. HUANG, E. AKYÜREK, A. ANANDKUMAR, ET AL.: *Pre-trained language models for interactive decision-making*, *Advances in Neural Information Processing Systems* 35 (2022), pp. 31199–31212.
- [8] J. PARK, J. O'BRIEN, C. CAI, M. TERRY, A. DOSOVITSKIY, O. BOUSQUET, M. TERRY: *Generative Agents: Interactive Simulacra of Human Behavior*, arXiv preprint (2023), eprint: [2304.03442](https://arxiv.org/abs/2304.03442).
- [9] H. TOUVRON, T. LAVRIL, G. IZACARD, X. MARTINET, M.-A. LACHAUX, T. LACROIX, B. ROZIÈRE, N. GOYAL, E. HAMBRO, F. AZHAR, A. RODRIGUEZ, A. JOULIN, E. GRAVE, G. LAMPLE: *LLaMA: Open and Efficient Foundation Language Models*, arXiv preprint (2023), eprint: [2302.13971](https://arxiv.org/abs/2302.13971).