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# ANALYSIS OF THE SAFETY OF MANIPULATORS USED IN INDUSTRIAL GAS FIRED FURNACES USING AN ONTOLOGY BASED HAZOP APPROACH

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**Abstract**
In modern industrial environments, ensuring the operational safety of manipulators used in gas-fired furnaces is a critical challenge due to complex thermal and mechanical interactions. This study presents an ontology-based HAZOP (Hazard and Operability) approach for systematic analysis and identification of potential risks in manipulator control systems operating under high-temperature conditions. The proposed method integrates semantic modeling with traditional HAZOP analysis to enhance decision-making and automate

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hazard detection. As a result, the ontology framework provides a unified knowledge base that improves safety assessment accuracy, reduces human error, and supports intelligent control of industrial furnace manipulators. This article proposes the integration of an ontology-based HAZOP (Hazard and Operability Analysis) approach to ensure the safe operation of controlled manipulators. The HAZOP method is widely used to identify hazards and malfunctions in technological systems, but its dependence on human factors makes the results ambiguous. The study recommends the development of an automated hazard analysis system based on an ontological knowledge base, causation models, and logical inference algorithms. The proposed system is justified to integrate with a neural network-controlled manipulator model in the MATLAB/Simulink environment, enabling the detection and evaluation of hazardous situations in real time.

**Keywords:** HAZOP, ontology, neural network, manipulator, hazard analysis, digital twin, automation.

## Introduction

In today's manufacturing industry, in the chemical, petrochemical, and food industries, the reliable and safe operation of manipulators is one of the key requirements of the industry. Especially in systems controlled by artificial intelligence and neural networks, failures or overloads can lead to unexpected situations. Therefore, it is necessary to create mechanisms for automatic analysis and early warning of hazardous situations in such systems.

The HAZOP (Hazard and Operability Analysis) method is used in the chemical, energy, and manufacturing sectors to identify hazardous scenarios. For this, hazardous situations are studied by qualified experts in a working group, and risk analyses are conducted. A sequence of measures is developed for possible hazardous situations. However, since it is a process involving the human factor,

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it requires a lot of time, and the subjectivity of the results is high. In recent years, ontology-based approaches have begun to be widely used in digitizing the HAZOP method. Ontologies express knowledge semantically and help identify logical connections between system components [1-2].

In this research, the ontological model of the HAZOP method is integrated into a manipulator system controlled by neural networks, and a real-time risk analysis system is proposed.

Traditional HAZOP methods are conducted by humans, and scenarios are identified based on team discussions. This process takes a long time, and the results depend on the experts' experience. In recent years, automated approaches have been developed to solve this problem, for example:

**Rule-based HAZOP** – analyzes cause-and-effect relationships based on predefined rules. This method is an expert system approach that relies on a set of predefined rules to detect hazardous states (deviations). Information about the process's operating mode (normal, deviation state) is obtained, and causes and effects are automatically determined through "If … then …" rules. As a result, HAZOP analysis is created without or with minimal human intervention. In general, this method primarily operates based on a knowledge base and a logical rules mechanism (inference engine). The advantages of this method are that it performs HAZOP analysis quickly without human intervention, provides results based on the same rules each time, not dependent on human opinion, analyzes hundreds of scenarios in a few seconds in large systems, allows conducting the HAZOP process in a uniform format, and is suitable for integration. The disadvantages are mainly related to the knowledge base; if the rules are incomplete, the system may not detect some hazardous states. It is not flexible, meaning the rules are strict, and if the system is new, it cannot adapt to unknown situations. There is a need for manually added rules, where experts must predefine each scenario. In complex and large systems, thousands of rules are required,

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resulting in slower analysis. It does not account for uncertainty; the ability to evaluate probabilities, uncertain states, or interactions is limited.
In general, this method is the first stage of automated risk analysis systems and is effective as an expert system operating based on precise rules. It is fast, standardized, and highly accurate, but limited in adaptability and knowledge updating. Some of these shortcomings can be supplemented with the Graph-based HAZOP method.

**Graph-based HAZOP** – This method analyzes connections in process diagrams in graph form, i.e., an approach that automatically performs HAZOP analysis based on the process schema using graph models (i.e., nodes and directed edges connecting them). In this method, elements in a technological system or mechatronic device (pump, pipe, valve, manipulator joints, etc.) are modeled in graph form, and fault propagation is observed along that graph. The main idea of Graph-based HAZOP is formulated as "If process components are interconnected in some way, the risk also propagates through those connections." That is, each component (pump, pipe, sensor, motor, joint, etc.) is designated as a node in the graph, and the information, energy, or material flow between them is connected through directed edges. For example, in a manipulator, a graph can be built from the manipulator motor to the end effector (Figure 1) [3-4].

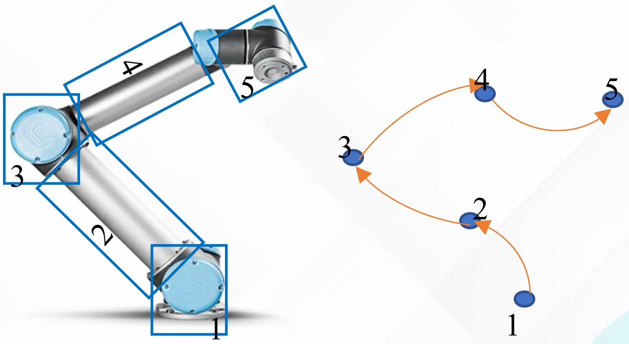


Figure 1. Graph constructed based on the Graph-based HAZOP method for the manipulator

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As can be seen from this figure, using graph algorithms, it is possible to determine how the risk in the system propagates along the "flow." In general, the advantages of this method can be explained by its organic connection with the process schema, meaning that the HAZOP analysis can be read directly from the Simulink model, hazardous states can be observed in the graph, its convenience for complex interconnected objects such as manipulators, chemical, and energy systems, the ability to visualize risk propagation graphically, and the ease of adding new components or sensors. As disadvantages, it can be noted that it only works with structure, meaning the graph does not understand the meaning (semantics) of the connections, it only shows dependencies, lack of rules and context, the graph can become very large in complex processes and as a result, visual analysis becomes difficult in systems with many nodes, and it does not account for time delays in the simulation process or feedback loops.
Ontology-based HAZOP – This method expresses semantic relationships between system components, performs automatic risk analysis, and can fully eliminate the shortcomings indicated in the above methods. A number of mature scientists have worked on the development of this method, including the ontology-based HAZOP automation method developed by Johannes-Imanuel Single [1-2], which provided the opportunity to analyze process safety using a digital knowledge base. The adapted version of this approach for manipulator systems constitutes the main objective of this article.

## Proposed Ontological HAZOP Model

In the proposed system, the mechanical, electrical, and control components of the manipulator are represented in an ontological knowledge base. The following main classes are defined in the ontology:

- Equipment: manipulator joints, motors, sensors, actuators;
- Function: functions such as movement, rotation, gripping, shifting;

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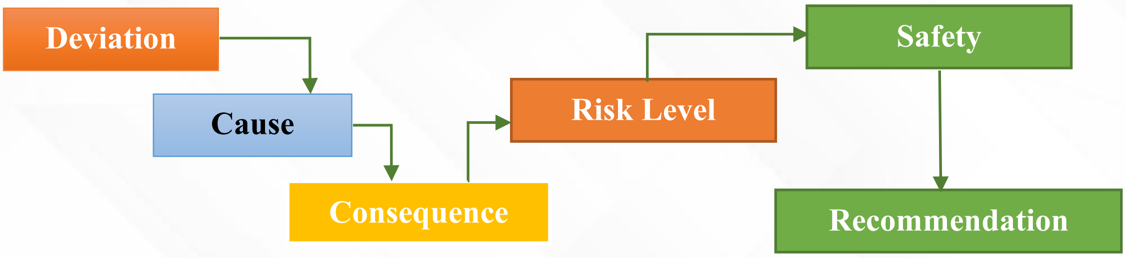
- Deviation: deviation from normal operating state (for example, excessive torque, reverse direction, incorrect signal from sensor);
- Cause: causes of failures (mechanical friction, overload, signal interruption);
- Consequence: consequences (collision, overheating, movement restriction);
- Safety: protective measures (torque limiter, emergency stop, cooling system).

The HAZOP process is expressed in ontological language as follows:




The ontology is created in OWL (Web Ontology Language) format, and logical inferences are drawn using the HermiT reasoner. The manipulator control model based on neural networks is developed in the MATLAB/Simulink environment. The model outputs — position, velocity, torque, temperature, and voltage values — are transmitted in real time to the ontological analysis system. Subsequently, the ontological HAZOP system analyzes this data and determines the risk level. For example, if the torque exceeds 5 N·m and the temperature approaches 80°C, the system automatically generates the following recommendation:
Hazardous state: Excessive torque and temperature.
Cause: Load has exceeded the limit.
Recommendations: Reduce movement speed, activate the cooling system.
The proposed ontological system enables automatic risk analysis without human intervention, significantly accelerating the safety assessment of the manipulator. In addition, this system lays the foundation for real-time monitoring within a Digital Twin platform [5-6].

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## Conclusion

The ontology-based HAZOP approach has been adapted for the automatic safety analysis of manipulators controlled by neural networks. The proposed system integrates cause-effect analysis, semantic logical inference, and risk assessment mechanisms.

The results demonstrate (detailed analyses and models will be presented more comprehensively in subsequent articles) that the ontological HAZOP exhibits high efficiency in ensuring the stable operation of the manipulator, early detection of faults, and protection of the control system. In the future, the system can be integrated with artificial intelligence-based digital twins and applied for proactive safety monitoring in manufacturing environments.

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## References

1. Single, J. I. (2022). Automation of the Hazard and Operability Method Using Ontology-Based Scenario Causation Models [Doctoral dissertation, Technische Universität Kaiserslautern].
2. International Electrotechnical Commission. (2016). IEC 61882:2016 – Hazard and Operability Studies (HAZOP) – Application Guide. Geneva, Switzerland: IEC.
3. Chung, W. J., Chung, W. K., & Youm, Y. (1991). Inverse kinematics of planar redundant manipulators using virtual links and displacement distribution schemes. In Proceedings of the 1991 IEEE International

Eureka Journal of Artificial Intelligence and Data Innovation (EJAIDI)
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https://eurekaoa.com/index.php/11

Conference on Robotics and Automation (pp. 926–932). IEEE. https://doi.org/10.1109/ROBOT.1991.131636
4. Angeles, J. (2003). Fundamentals of Robotic Mechanical Systems: Theory, Methods, and Algorithms. New York: Springer-Verlag. https://doi.org/10.1007/978-1-4615-0443-3
5. Юревич, Е. И., Каляев, И. А., Лохин, В. М., Макаров, И. М., Манько, С. В., & Романов, М. П. (2007). Интеллектуальные роботы: пособие для вузов. Москва: Машиностроение.
6. Koker, R., Oz, C., Cakar, T., & Ekiz, H. (2004). A study of neural network-based inverse kinematics solution for a three-joint robot. Robotics and Autonomous Systems, 49(3–4), 227–234. https://doi.org/10.1016/j.robot.2004.09.002.