THESES OF THE DOCTORAL (PhD) DISSERTATION

Expert system support for the selection method of industrial mobile robots

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1 Introduction and research objectives

In manufacturing systems, the production of goods requires increased efficiency, while at the same time demand is shifting towards customized products, presenting two conflicting requirements for developers and operators of manufacturing systems. One of the central elements of Industry 4.0 and 5.0 is the industrial mobile robot, which is a manufacturing technology tool that supports the rapid and accurate production of objects while also enabling the creation of customized products. With my thesis, I aim to provide assistance in the first step of integrating such mobile robots into manufacturing systems by laying the foundations for an advanced decision support tool.

Mobile robots can be used for a variety of tasks, such as transporting raw materials, transporting finished products, transporting components, removing scrap, or even as an assembly platform. Accordingly, the mobile robot that is considered ideal for the task must be selected from among the robots available on the market.

2 Research activities

I simplified the manufacturing system models using mobile robots and wrote a new manufacturing system model in which I gave the mobile robot a central role, thus creating a "mobile robot-centric" manufacturing system model. I used the model to examine several transport tasks and also used it as an evaluation function for a genetic algorithm.

In another part of the research, I created a prototype expert system to test the knowledge base created from the mobile robot database. The knowledge base, which is a set of facts and rules, is highly scalable in terms of both the number of robots and the number of robot properties, as demonstrated by testing on 101 robots and 19 properties. I supplemented the objective knowledge relating only to robots with expert knowledge and the characteristics of the manufacturing system, which I made available in logical form in the expert system. The programs used were my own programs written in Python, Excel spreadsheets, and scripts written in the CLIPS expert system framework.

The novelty of my research consists in the fact that for the first time I developed a scalable decision support method based on an expert system for the integration of industrial mobile robots into manufacturing systems. The solution combines the technical parameters listed in the data sheets, human expert experience, and the complex requirements of the manufacturing environment, and then, based on these, provides a ranking based on multi-objective optimization. The system thus provides comprehensive and practical support to industrial decision-makers in selecting the most suitable mobile robot.

Based on the research achieved, decision support for integrating mobile robots into manufacturing systems is helpful for engineers designing new lines.

3 Theses

1. Thesis: I have developed a new modeling method that can manage the mobile robot independently of the production system. This model is a Petri net with 10 states and 8 transitions, which represents the necessary parts of the production system from the perspective of the mobile robot, as follows: where to pick up what (physical dimensions, weight, number of pieces) and where to deliver it, what route to take, which distance to travel, how the robot can pick up and put down the load, and how much the battery charge will decrease as a result of the transport task. The Petri net model is limited by battery capacity, all states are accessible, and there are no dead locks. The new method is called the mobile robot-centric manufacturing system model.

2. Thesis:

Part A of Thesis 2: Using the mobile robot-centric manufacturing system concept, I demonstrated that for a one-way transport task between two stations, the robot's battery capacity can be analyzed within theoretical limits covering two orders of magnitude, and the ideal size can be determined in a resource-efficient manner depending on the task, meaning that the method is highly scalable.

Part B of Thesis 2: I demonstrated that a computational model can be written using the mobile robot-centric manufacturing system model, which can be used as an evaluation function for higher-level optimization algorithms. In the case study, using genetic algorithms as a fitness function to evaluate individuals takes real manufacturing processes into account and thus provides a characteristic parameter, which therefore reached its optimal value in 10 generations based on the experiments.

3. Thesis: I have developed a decision support framework based on an expert system for integrating industrial mobile robots into manufacturing systems. The method combines formal parameters from robot data sheets, the practical knowledge of human experts, and operational characteristics from previous manufacturing systems.

The novelty of the method is that the selection of mobile robots is based not only on technical specifications, but also on empirical knowledge and expert knowledge of the manufacturing environment. The novelty of the method is that the selection of mobile robots is based not only on technical specifications, but also on empirical knowledge and expert knowledge of the manufacturing environment.

3.1. First sub thesis of the third thesis: I have created a knowledge base construction methodology that uses logical representation (propositional logic, fuzzy approach, CLIPS framework) to enable the alignment of mobile robot characteristics and manufacturing system requirements. The method is proven to be scalable: it is suitable for handling a large number (over 100) of robots and dozens of attributes, while being able to represent and process expert knowledge in an integrated form.

3.2. Second sub thesis of the third thesis: I have combined the decision results of the expert system with multi-objective optimization (VIKOR method), which provides a ranking among the alternatives selected during the preliminary ranking. The research confirmed that the combined method is capable of establishing an objective and feasible ranking among mobile robots, while also allowing for expert correction. Thus, the system provides reliable and practical decision support for robot integration in manufacturing systems.

Publications related to the topic of the doctoral thesis

M. Boleraczki és D. Dr. Fodor, „Robotmegfogó szerkezet optimális kialakítása additív gyártáshoz”, SzámOkt 2020 – 30th International Conference on Computers and Education, o. 53–56, okt. 2020.

M. Boleraczki, I. G. Gyurika, és D. Fodor, „Gripper Finger Design for Special Purpose Applications”, Hung. J. Ind. Chem., köt. 49, sz. 2, o. 91–95, 2021, doi: 10.33927/hjic-2021-28.

M. Boleraczki, C. Sik-Lanyi, Z. Zsák, és T. Papp, „DEVELOPING THE SUPPORT FRAMEWORK SYSTEM OF SPECIAL PURPOSE MACHINES DESIGNING”, IOP Conf. Ser.: Mater. Sci. Eng., köt. 448, o. 012029, nov. 2018, doi: 10.1088/1757-899X/448/1/012029.

M. Boleraczki és I. G. Gyurika, „Mobile robot models for manufacturing systems”, előadás 6th World Congress on Mechanical, Chemical, and Material Engineering, aug. 2020. doi: 10.11159/icmie20.135.

M. Boleraczki, „Development of a knowledge base for an expert system supporting the decision of industrial mobile robot selection”, J. Phys.: Conf. Ser., köt. 2714, sz. 1, o. 012004, febr. 2024, doi: 10.1088/1742-6596/2714/1/012004.

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M. Boleraczi, I. G. Gyurika: Data-Centric Engineering: Industrial mobile robot-based manufacturing system modelling potential