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Human-robot collaboration assembly line balancing considering cross-station tasks and the carbon emissions

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ABSTRACT

With the growth of industrialization, the global manufacturing industry is continually evolving and reforming in the direction of intelligence and green production. Industrial robots have replaced human workers because of the benefit of production efficiency. However, the large-scale application of robots requires a large amount of energy consumption and generates a large amount of CO_2, which will lead to energy waste and environmental pollution. In addition, in term of performing some particular tasks, current robot technology cannot achieve the same level of intelligence as human. Therefore, the design trend of assembly lines in industry has shifted from traditional configuration to human-robot collaboration to achieve higher productivity and flexibility. This paper investigates the human-robot collaboration (HRC) assembly line balancing problem, taking cycle time and carbon emission as primary and secondary objectives. A new mixed-integer programming model that features a cross-station design is formulated. A particle swarm algorithm (PSO) with two improvement rules is designed to solve the problems. The comparative experiments on ten benchmark datasets are conducted to assess the performance of the proposed algorithm. The experimental results indicate that the improved particle swarm algorithm is superior to the other two heuristics: simulated annealing (SA) and the late acceptance hill-climbing heuristic (LAHC).

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References

[1] Rubinovitz, J., Bukchin, J., Lenz, E. (1993). RALBP - A heuristic algorithm for design and balancing of robotic assembly lines, *CIRP Annals*, Vol. 42, No. 1, 497-500, doi: 10.1016/S0007-8506(07)62494-9.
[2] Yoosefelahi, A., Aminnayeri, M., Mosadegh, H., Davari Ardakani, H. (2012). Type II robotic assembly line balancing problem: An evolution strategies algorithm for a multi-objective model, *Journal of Manufacturing Systems*, Vol. 31, No. 2, 139-151, doi: 10.1016/j.jmsy.2011.10.002.
[3] Mukund Nilakantan, J., Ponnambalam, S.G. (2016). Robotic u-shaped assembly line balancing using particle swarm optimization, *Engineering Optimization*, Vol. 48, No. 2, 231-252, doi: 10.1080/0305215X.2014.998664.
[4] Wang, J.F., Kang, W.L., Zhao, J.L., Chu, K.Y. (2016). A simulation approach to the process planning problem using a modified particle swarm optimization, *Advances in Production Engineering & Management*, Vol. 11, No. 2, 77-92, doi: 10.14743/apem2016.2.211.
[5] Borba, L., Ritt, M., Miralles, C. (2018). Exact and heuristic methods for solving the robotic assembly line balancing problem, *European Journal of Operational Research*, Vol. 270, No. 1, 146-156, doi: 10.1016/j.ejor.2018.03.011.
[6] Li, Z., Janardhanan, M.N., Tang, Q.H., Ponnambalam, S.G. (2019). Model and metaheuristics for robotic two-sided assembly line balancing problems with setup times, *Swarm and Evolutionary Computation*, Vol. 50, Article No. 100567, doi: 10.1016/j.swevo.2019.100567.

[7] Raatz, A., Blankemeyer, S., Recker, T., Pischke, D., Nyhuis, P. (2020). Task scheduling method for HRC workplaces based on capabilities and execution time assumptions for robots, *CIRP Annals*, Vol. 69, No. 1, 13-16, doi: 10.1016/j.cirp.2020.04.030.
[8] Jiang, L., Duan, J.J., Zheng, R.P., Shen, H.N., Li, H., Xu, J. (2023). Optimization and simulation of garment production line balance based on improved GA, *International Journal of Simulation Modelling*, Vol. 22, No. 2, 303-314, doi: 10.2507/IJSIMM22-2-CO6.
[9] Şahin, M.C., Tural, M.K. (2023). Robotic stochastic assembly line balancing, *Flexible Services and Manufacturing Journal*, Vol. 35, No. 4, 1076-1115, doi: 10.1007/s10696-023-09494-x.
[10] Yu, B., Wu, E., Chen, C., Yang, Y., Yao, B.Z., Lin, Q. (2017). A general approach to optimize disassembly sequence planning based on disassembly network: A case study from automotive industry, *Advances in Production Engineering & Management*, Vol. 12, No. 4, 305-320, doi: 10.14743/apem2017.4.260.
[11] Wang, Y.J., Wang, N.D., Cheng, S.M., Zhang, X.C., Liu, H.Y., Shi, J.L., Ma, Q.Y., Zhou, M.J. (2021). Optimization of disassembly line balancing using an improved multi-objective Genetic Algorithm, *Advances in Production Engineering & Management*, Vol. 16, No. 2, 240-252, doi: 10.14743/apem2021.2.397.
[12] Ding, H., Schipper, M., Matthias, B. (2014). Optimized task distribution for industrial assembly in mixed human-robot environments - Case study on IO module assembly, In: *Proceedings of 2014 IEEE International Conference on Automation Science and Engineering (CASE)*, New Taipei, Taiwan, 19-24, doi: 10.1109/CoASE.2014.6899298.
[13] Nikolakis, N., Kousi, N., Michalos, G., Makris, S. (2018). Dynamic scheduling of shared human-robot manufacturing operations, *Procedia CIRP*, Vol. 72, 9-14, doi: 10.1016/j.procir.2018.04.007.
[14] Dalle Mura, M., Dini, G. (2019). Designing assembly lines with humans and collaborative robots: A genetic approach, *CIRP Annals*, Vol. 68, No. 1, 1-4, doi: 10.1016/j.cirp.2019.04.006.
[15] Zanchettin, A.M., Casalino, A., Piroddi, L., Rocco, P. (2019). Prediction of human activity patterns for human-robot collaborative assembly tasks, *IEEE Transactions on Industrial Informatics*, Vol. 15, No. 7, 3934-3942, doi: 10.1109/TII.2018.2882741.
[16] Vieira, M., Moniz, S., Gonçalves, B.S., Pinto-Varela, T., Barbosa-Póvoa, A.P., Neto, P. (2022). A two-level optimisation-simulation method for production planning and scheduling: The industrial case of a human-robot collaborative assembly line, *International Journal of Production Research*, Vol. 60, No. 9, 2942-2962, doi: 10.1080/00207543.2021.1906461.
[17] Aljinovic, A., Gjeldum, N, Bilic, B, Mladineo, M. (2022). Optimization of industry 4.0 implementation selection process towards enhancement of a manual assembly line, *Energies*, Vol. 15, No. 1, Article No. 30, doi: 10.3390/en15010030.
[18] Riedel, A., Gerlach, J., Dietsch, M., Herbst, S., Engelmann, F., Brehm, N., Pfeifroth, T. (2021). A deep learning-based worker assistance system for error prevention: Case study in a real-world manual assembly, *Advances in Production Engineering & Management*, Vol. 16, No. 4, 393-404, doi: 10.14743/apem2021.4.408.
[19] Nourmohammadi, A., Fathi, M., Ng, A.H.C. (2022). Balancing and scheduling assembly lines with human-robot collaboration tasks, *Computers & Operations Research,* Vol. 140, Article No.105674, doi: 10.1016/j.cor.2021.105674.
[20] Lin, W., Yu, D.Y., Zhang, C., Liu, X., Zhang, S., Tian, Y., Liu, S., Xie, Z. (2015). A multi-objective teaching–learning-based optimization algorithm to scheduling in turning processes for minimizing makespan and carbon footprint, *Journal of Cleaner Production*, Vol. 101, 337-347, doi: 10.1016/j.jclepro.2015.03.099.
[21] Li, Z., Tang, Q., Zhang, L.P. (2016). Minimizing energy consumption and cycle time in two-sided robotic assembly line systems using restarted simulated annealing algorithm, *Journal of Cleaner Production*, Vol. 135, 508-522, doi: 10.1016/j.jclepro.2016.06.131.
[22] Nilakantan, J.M., Li, Z., Tang, Q., Nielsen, P. (2017). Multi-objective co-operative co-evolutionary algorithm for minimizing carbon footprint and maximizing line efficiency in robotic assembly line systems, *Journal of Cleaner Production*, Vol. 156, 124-136, doi: 10.1016/j.jclepro.2017.04.032.
[23] Zhang, B., Xu, L., Zhang, J. (2020). A multi-objective cellular genetic algorithm for energy-oriented balancing and sequencing problem of mixed-model assembly line, *Journal of Cleaner Production*, Vol. 244, Article No. 118845, doi: 10.1016/j.jclepro.2019.118845.
[24] Sun, B.-Q., Wang, L., Peng, Z.-P. (2020). Bound-guided hybrid estimation of distribution algorithm for energy-efficient robotic assembly line balancing, *Computers & Industrial Engineering,* Vol. 146, Article No. 106604, doi: 10.1016/j.cie.2020.106604.
[25] Zhou, B., Wu, Q. (2020). Decomposition-based bi-objective optimization for sustainable robotic assembly line balancing problems, *Journal of Manufacturing Systems*, Vol. 55, 30-43, doi: 10.1016/j.jmsy.2020.02.005.
[26] Kennedy, J., Eberhart, R. (1995). Particle swarm optimization, In: *Proceedings of ICNN'95 - International Conference on Neural Networks,* Perth, Australia,1942-1948, doi: 10.1109/ICNN.1995.488968.
[27] Otto, A., Otto, C., Scholl, A. (2013). Systematic data generation and test design for solution algorithms on the example of SALBPGen for assembly line balancing, *European Journal of Operational Research*, Vol. 228, No. 1, 33-45, doi: 10.1016/j.ejor.2012.12.029.
[28] Yuan, B., Zhang, C., Shao, X. (2015). A late acceptance hill-climbing algorithm for balancing two-sided assembly lines with multiple constraints, *Journal of Intelligent Manufacturing*, Vol. 26, 159-168, doi: 10.1007/s10845-013-0770-x.
[29] Li, Y., Peng, R., Kucukkoc, I., Tang, X., Wei, F. (2020). System reliability optimization for an assembly line under uncertain random environment, *Computers & Industrial Engineering,* Vol. 146, Article No. 106540, doi: 10.1016/j.cie.2020.106540.

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Izvirni znanstveni članek

Uravnoteženje sodelovalne montažne linije človek-robot ob upoštevanju izvedbe naloge na več postajah in emisij ogljika

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POVZETEK

Z rastjo industrializacije se svetovna proizvodna industrija nenehno razvija in preoblikuje v smeri inteligentne in zelene proizvodnje. Industrijski roboti so nadomestili človeške delavce zaradi učinkovitosti proizvodnje. Vendar pa obsežna uporaba robotov zahteva veliko porabo energije in ustvarja veliko količino emisij CO_2, kar vodi v izgubo energije in onesnaževanje okolja. Poleg tega trenutna tehnologija robotov pri izvajanju nekaterih posebnih nalog ne more doseči enake ravni inteligence kot človek. Zato se je trend oblikovanja montažnih linij v industriji premaknil od tradicionalne konfiguracije k sodelovanju med človekom in robotom, da bi dosegli večjo produktivnost in prilagodljivost. Ta članek raziskuje problem uravnoteženja sodelovalne montažne linije človek-robot (HRC), pri čemer sta primarni in sekundarni cilj čas cikla in emisije ogljika. Oblikovan je nov model mešanega celoštevilskega programiranja, ki vključuje zasnovo izvedbe naloge na več postajah. Za reševanje problema je zasnovan algoritem z rojem delcev (PSO) z dvema praviloma za izboljšanje. Za oceno uspešnosti predlaganega algoritma so izvedeni primerjalni testi na desetih primerjalnih naborih podatkov. Rezultati kažejo, da je izboljšani algoritem roja delcev boljši od drugih dveh hierarhičnih metod: simuliranega žarjenja in hevristične metode LAHC (angl. late acceptance hill-climbing heuristic).

PODATKI O ČLANKU

Ključne besede:
Problem uravnoteženja montažne linije;
Sodelovanje med človekom in robotom;
Izvedba naloge na več postajah;
Emisije ogljika;
Sodelujoči robot (kobot);
Algoritem roja delcev (PSO)

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