Chapter 11
Sustainable Machining Process Optimization:
Predictive Modeling With Multi-Objective Ant Colony Algorithms

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ABSTRACT

Sustainable machining practices are essential for an effective machining process with minimum impact on the environment. In this respect, this chapter puts forward the utilization of multi-objective ACO techniques applied to predictive modeling on sustainable machining processes. In this research, ACO has been utilized to study the conflicting objectives of energy consumption, tool wear, surface quality, and production time to optimize the parameters for machining. Sustainably machining problems are discussed in detail and further go on to describe ACO algorithms: simulating foraging behavior of ants to identify good solutions. Then, case studies are presented, demonstrating how ACO can simultaneously minimize environmental impact while improving machining performance. The results underline potential resource-efficient manufacturing by way of minimization and decision making for waste with

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ACO-induced sustainable industrial processes.

INTRODUCTION

In the last few years, a growing emphasis on sustainability in almost all sectors of industries has generated huge interest within the manufacturing process optimization process. Machining, in particular, is one of the most energy- and resource-hungry processes in this sector. The decrease in energy consumption, material waste, and tool life with product quality renders it feasible to devise new sophisticated techniques to optimize the process. In such situations, the multi-objective optimization algorithms, known as ACO (Ant Colony Optimization), emerged as promising tools for battling conflicting objectives of sustainability and productivity (Jawahir et al., 2020).

Sustainable machining is the capability of machining processes to reduce impacts on the environment without compromising performance. Traditionally, machining operations involve high energy, serious wear in tools, and large material waste, with both occasions posing a challenge to issues on the cost of production and environmental damage. The problem of finding sustainable machining thus presents an opportunity for optimal adjustment of the cutting speed, feed rate, and depth of cut to ensure energy efficiency while maintaining quality results. However, getting the best compromise among them is not easy, as improvement in one characteristic, say energy consumption, may be at the cost of another characteristic, for example, surface finish or production time (Salem et al., 2021).

For ease of understanding, several optimization techniques have been developed to guide the decisions and process development. In multi-objective optimization, multiple conflicting objectives can simultaneously be optimized. Multiplicity in objective optimization tries to focus on optimizing a specific process in terms of one goal. What it does instead is look into the trade-off between several goals to offer a more integrated solution to the problem of optimizing the process. The machining targets may include maximizing energy efficiency and reducing the wear of the tools, improvement of the quality of the surface finish, among others, as well as a reduction of production time. The company can then better optimize its operations to be at once more environmentally friendly and more economical than otherwise possible for any one of these goals if they are considered in combination(Pimenov et al., 2022).

ACO, short for Ant Colony Optimization, is one of the most promising techniques in multi-objective optimization. This technique is inspired by the foraging behavior of ants in nature, simulating how ants find their shortest path from their nests to their food sources. Artificial agents, also called here "ants," search for potential solutions to a problem and deposit pheromone in promising areas for further guidance by other agents toward that region in the solution space. With time, the pheromone trail helps the algorithm converge toward a near-optimal solution. ACO has been applied very successfully to various complex optimization problems such as scheduling, routing, and resource allocation, among others, and is therefore ideal in sustainable machining process optimization (Salem et al., 2022).

The context where ACO is applied relates to machining while attempting to optimize a number of conflicting objectives by mimicking how ants work in search of the best combination of machining parameters. The algorithm seeks an array of different parameter combinations and tests them based on their ability to realize sustainability objectives, such as energy conservation and tool wear, while keeping surface quality intact. By doing so, ACO is able to find optimal trade-offs among such objectives. This, in turn, helps the manufacturers make progress toward more sustainable machining processes (Gajrani et al., 2022).

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