Undergraduate Research Program

Department of Manufacturing Systems Engineering and Management

Research Duration: Summer 2024 (June – August 2024)

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Title of Project: A data-driven framework for automated classification of machining manufacturing processes

Goals and Objectives of the Project, Expectations and Outcomes

This project aims to classify traditional manufacturing processes like turning and/or milling based on part quality and geometry using data-driven techniques. It targets a fundamental yet timely issue relevant to producing modern performance-critical parts in sectors such as bio-medical, naval/marine, and aerospace. These parts rely on specific geometries, quality, and microstructures to fulfill functions like light-weighting, strength, and biocompatibility (Fig. 1). The research will be conducted by a team of undergraduate students, leveraging a large repository of information on turned and/or milled part geometries and quality, particularly focusing on commercially pure Cu. The project's innovation lies in its approach to encode part geometry and quality in a numerically tractable way whereas current manufacturability estimates focus on only one of these features (e.g. geometry alone), neglecting their interaction effects.

Fig. 1. Combination of light-weighting, strength, and biocompatibility as a result of designed geometries, quality and microstructure.

The potential of this project is significant, aiming to revolutionize manufacturing process classification for part fabrication, emphasizing achieving specific qualities, and geometries. It acknowledges the interdependence of these factors, which traditional approaches, focusing solely on geometry, fail to consider. The proposed approach, if successful, will enable such predictions, e.g., if it is possible to create certain quality and geometry combinations within such traditional manufacturing processes (e.g. turning and milling). Such priori knowledge can lead to significant cost reductions. A cloud of such frameworks can substantially reduce the time required to design and optimize manufacturing processes and show its predictive strength for use in Computer Aided Process Planning (CAPP) supporting the Industry 4.0 goals.

a. Expected Outcome

The scientific goal of this project is to delineate how traditional manufacturing processes—such as turning and milling—can be categorized by analyzing the interplay of part quality and geometry. The expected outcomes include: 1) An extensive dataset encompassing at least 200 parts, each uniquely defined by its quality and geometry attributes, and 2) A classification model capable of analyzing the dataset to determine the manufacturability of parts based on their attributes.

b. Methodology

The research team comprises 3 – 5 undergraduate students, led by PI with expertise in manufacturing processes and data analysis. The PI has recently submitted a paper on manufacturability classification based on part geometry which is a work of one undergraduate and one graduate student at CSUN supervised by the PI. The PI has the necessary qualifications to carry out this study. She holds a Ph.D. in Manufacturing and Materials Engineering with extensive experience in traditional manufacturing processes. She also teaches courses in manufacturing processes and part modeling, e.g. MSE 412/L and MSE 508/L in which the results from this project can help in preparing showcases of the courses.

The project consists of two primary tasks:

Task 1) Data Collection:

1-1) *Sourcing existing data:* The team will gather data from academic literature, industry databases, and online platforms such as GRABCAD and the Drexel University repository. This data will include geometries and quality indicators of parts made from pure copper. Our approach is predicated on the hypothesis that sufficient dataset can be assembled without the need for expensive physical experiments. The raw data will be prepared in Solidworks software, a software that CSUN has the license. All CAD models will be collected ensuring the comprehensiveness of the data sets. To do that, we will choose a variety of parts that covered the types of geometric shapes and features that are common in mechanical design, as described in the ISO 10303-224 standard and specifically its AP 204 protocol.

1-2) *Generating new data:* Where necessary, the team may produce additional samples in the lab (using the facilities in JD 1128) to fill data gaps not readily available in existing sources.

Task 2) Development of Classification Model:

2-1) *Model formulation development:* We will use the geometry features as well as material quality information in order to classify parts based on their manufacturability, considering the combined effects of part quality and geometry.

This involves developing a data-driven model that can predict the manufacturability of new parts based on the features of the dataset such as curvature and D2 distribution. This task will be accomplished by applying and possibly integrating various machine learning algorithms to analyze the dataset created in Task 1. Parts that indeed originate from the same source will exhibit similar patterns in their rotation invariant descriptors, which can indicate the similarity of their origins. We will first seek unsupervised machine learning (ML) algorithms to achieve this objective. Such algorithms can infer differences across complex data-sets without requiring human intervention. Herein, the ML technique called kernel principal component analysis (KPCA) can be utilized first to get a baseline metric of accuracy. The crux of the KPCA technique involves the projection of complex datasets onto spaces specifically constructed to accentuate the differences between different data within the set. It is hypothesized that this methodology can cluster similar parts (which comprise 'similar' geometries, and surface roughness – representing quality) into similar locations in this space. It is also hypothesized that this methodology can cluster parts with different manufacturing origins far away from each other. Such clustering can provide a qualitative sense of how easy it is to produce a part, based on whether similar parts that were previously produced using the same process cluster together, and dissimilar parts cluster separately. To develop the classification model, the project will also explore other data-driven approaches, such as neural networks.

2-2) *Model validation:* We will test the model's predictions against a set of novel parts and conducting cluster analysis to ensure accuracy and reliability of the model. Such cross-validation will be performed with a sufficient number of real case studies.

c. Potential Significance and student involvement

The proposed effort presents an innovative and potentially transformational solution to the challenges of Smart Manufacturing by integrating advanced data-driven techniques into Computer-aided process planning (CAPP). In the era of Smart Manufacturing, data is pivotal, and this project leverages data-driven methods such as AI to analyze part information for manufacturing process classification, exemplifying data-driven decision-making. This holistic approach, which considers combinations of part geometry and quality, to classify manufacturability in traditional manufacturing process within a unified data-driven framework, deviates from traditional isolated approaches, enhancing efficiency and automated CAPP. The project's potential impacts are far-reaching. It reduces manufacturing costs, boosts competitiveness, and drives economic growth by automating manufacturing process selection, considering geometry and quality. Automated CAPP, enhances efficiency, increasing production speed and productivity while aligning with Industry 4.0 objectives. It supports sustainability goals, fosters innovation, supports Smart Manufacturing workforce development, and encourages interdisciplinary collaboration. These improvements drive regional and national economic growth and address workforce diversity challenges. Educational enhancements include curriculum development, faculty training, and research integration, improving manufacturing-related programs. Furthermore, involving undergraduate students in research at CSUN as a Minority Serving Institution not only benefits the students themselves but also contributes to diversity and excellence in research, strengthens institutional reputations, and supports broader community and workforce development goals. It is a win-win situation for students, institutions, and the research community as a whole.

d. Plans for Dissemination

In the event of successful research outcomes, we plan to submit a paper and present our research findings from tasks 1 and 2 to showcase our work in a conference.