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ProMED: Production Optimization for Additive Manufacturing of Medical Devices

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Abstract

In metal 3D printing, and in particular in the production of dental implants and prosthodontics, a careful geometric analysis of the parts is key to maximize the overall throughput and minimize fabrication costs. Herewith we describe the main results obtained within the European Project DIGITBrain/ProMED, whose objective is to optimize the production of customized metal medical devices. ProMED delivers a digital twin of an existing production pipeline and allows for the quick simulation of a large number of fabrication scenarios. This is achieved thanks to a clever geometric analysis driving the optimal orientation of the part in the platform combined with a geometry-based process simulator that makes it possible to estimate fabrication time, material consumption, human labour, and other useful information that greatly supports users in the task of optimizing the overall fabrication performances from many meaningful points of view. Compared to standard simulation software provided by printer vendors, our approach can be orders of magnitude faster: this makes it possible to analyze and compare a great number of scenarios to support companies in their day-by-day decisions for real productions.

CCS Concepts
• ***Computing methodologies*** $\rightarrow$ ***Robotic planning;***

1. Introduction

In digital dentistry the production pipeline of dental implants and prosthodontics (e.g. crowns, bridges, frameworks) consists of scanning, computer aided design (CAD) and manufacturing (CAM). Manufacturing in the last decades was carried out primarily by CNC milling. In the last few years 3D Printing (3DP - AM) has progressively started to take its place since it allows producing dentures more quickly and economically, and even enables the production of complex parts not possible with CNC milling (e.g. sheets, CMF and subperiosteal implants).

In metal 3D printing, generally, several parts can be placed on a single platform and produced together. In addition, the parts to be printed in case of medical devices are always different (even if they are within certain categories). The overall objective is to make production in an optimal way [LEM*]. However, optimums – at a given time, and for a given product or a set of products – can be completely different (see Fig. 1). Optimum might be linked to: priority to produce a given product (e.g. urgent order); production time; production cost; product quality; mechanical properties; request for manual work.

The main objective in ProMED is to optimize the overall process according to one (or a combination) of the aforementioned measures, and to effectively predict them for different scenarios and configurations. This would make it possible to make faster and more precise quotes for clients. Since real 3D printing is an extremely slow and expensive process, having an appropriate tool that quickly simulates the process is extremely important.

Figure 1: *Based on the list of orders and their priorities, the same building platform may be filled differently. On the left, the denture (sheet) is an urget order, hence it is placed horizontally for fast production. On the right, the same part is placed vertically so that more parts can be produced in the same overnight session.*

2. Design specifications and implementation

Our solution is a digital twin of an existing fabrication pipeline, which allows finding the optimal orientation, simulating the pro-

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cess, and calculating the global results. The digital twin infrastructure includes the following four functional modules, namely Graphical User Interface (GUI), Orientation Optimization (OO), Process Simulator (PS) and Machine Learning tool (ML).

Graphical Interface It is the entry point for the users to interact with the system. Fig. 2 shows the main window, from where the user can upload a model, set up the optimization parameters (e.g. some goals to be reached), and start the optimization process. At the end of the optimization process, the user will see that the model has been oriented according to the optimal rotation, and a feedback window will give insights on the results. Furthermore, it's possible to download the oriented model.

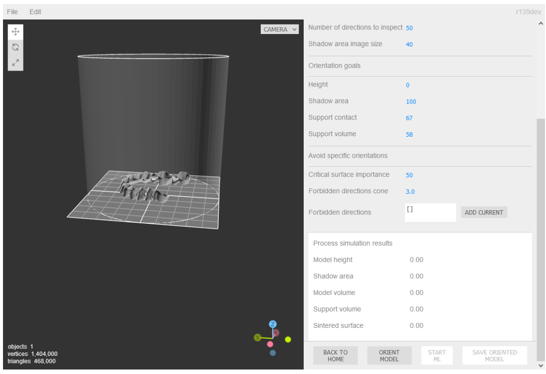

Figure 2: *Main window of the graphical user interface.*

Orientation Optimization module Based on a set of user-controllable objectives, this module calculates the optimal object orientation in the building chamber. The algorithm can minimize any weighted combination of the following measures:

- Object height: roughly proportional to fabrication time;
- Shadow area (i.e. area of the object projection on the building platform): smaller area leaves more space for other objects on the platform;
- Support contact area (i.e. percentage of the object surface which will be attached to support structures): smaller area corresponds to less imperfections and need for human labour to remove the structures;
- Support volume: roughly proportional to material consumption.

Based on [Liv19; ALC22], the algorithm tests n orientations uniformly distributed using Poisson disk sampling and, for each orientation, evaluates the weighted combination based on user-provided weights. The optimal orientation is chosen as the global minimum. It is returned as a vector pointing in the direction of the optimal building direction. The number of test directions n is provided by the user to trade efficiency for accuracy.

Process Simulation module The goal of this module is to simulate the fabrication process and return useful information to help operators in the difficult task of setting an optimal configuration before starting the real production.

Based on a given orientation, this module virtually slices the object and calculates the following measures:

- Part and support volume;
- Height (i.e. num. slices);
- Part surface area;
- Supports contact area;
- Supports shadow area.

The machine process parameters (i.e. laser speed, recoating time, ...) and the current material costs per unit are used to estimate the printing times and printing costs.

The printing time, for example, is calculated by dividing the part and support volume by laser speed, layer thickness and hatching distance, and by adding the recoating time between each layer. This calculation is live updated when the user changes the oriented object at hand and/or the machine and material parameters, making the process of planning a 3D printing batch more straightforward.

Machine Learning module This module helps the user in the task of selecting the proper configurations for the other modules by exploiting past configurations for similar objects. At the time of writing, objects are categorized into five families which make sense in digital dentistry. For each family, Machine Learning is used to collect all the configurations set by the user during all the sessions, and to return similar configurations in the future. The ML model chosen is a simple MLP (Multi-Layer Perceptron) for regression and has been trained to predict some values (e.g. the weights used by the orientation optimizer) starting only from the name of the object family provided in input by the operator.

3. System Evaluation

The final evaluation was conducted by an usability expert and by a company operating in a Manufacturing-as-a-Service context for the production of custom products designed by dental technicians. The usability evaluation method was mostly heuristic: a usability expert observed the demonstration of the application, provided recommendations for improvement, and evaluated the system again after requirements were met. The company could evaluate the system for its day-by-day production, and provided useful feedback that allowed us to fine tune the application.

4. Conclusions

The most significant progress beyond the state of the art provided by ProMED is the possibility to simulate a 3D printing process as efficiently as needed. With respect to existing algorithms distributed by printer producers, the simulation delivered by ProMED is at least one order of magnitude faster, and the tradeoff between efficiency and accuracy can be controlled by the user depending on the needs. In particular, such an efficiency enables a completely new process planning strategy based on a quantitative comparison of costs and times needed to produce the same set of goods while changing the production settings. As a future improvement, we plan to replace the request to indicate an object family with an automatic object recognition algorithm in the ML module.

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References

[ALC22] ATTENE, M., LIVESU, M., and CABIDDU, D. *CAxLib - A Process Planning Framework for Additive Manufacturing Applications*. Version 0.20.2. Sept. 13, 2022. URL: https://github.com/CAxMan/CAxLib 2.

[LEM*] LIVESU, MARCO, ELLERO, STEFANO, MARTÍNEZ, JONAS, et al. "From 3D models to 3D prints: an overview of the processing pipeline". *Computer Graphics Forum* 36.2 () 1.

[Liv19] LIVESU, MARCO. "cinolib: a generic programming header only C++ library for processing polygonal and polyhedral meshes". *Transactions on Computational Science XXXIV*. Lecture Notes in Computer Science (2019). Ed. by SPRINGER. https://github.com/mlivesu/cinolib/. DOI: 10.1007/978-3-662-59958-7_4 2.

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