

EARLY STUDENT ENGAGEMENT IN THE DEVELOPMENT OF PROCESS MONITORING TOOLS FOR ADDITIVE MANUFACTURING

Sim-AM 2019

MICHAEL J. MOECKEL

University of Applied Sciences Aschaffenburg, Faculty for Engineering,
Wuerzburger Str. 45, 63743 Aschaffenburg, Germany
e-mail: Michael.Moeckel@th-ab.de, web page: <http://www.th-ab.de>

Key words: Additive Manufacturing, Selective Laser Melting, Process Monitoring, Data Analysis, Software Engineering, Education

Abstract. Project work accompanying an undergraduate course on software engineering has been re-designed to provide early student exposure to data analysis for process monitoring in additive manufacturing. For original data from a local research group active in selective laser melting (SLM) process development, i.e. for sensor measurements and control flags, a set of established mathematical and statistical routines were made conveniently available by developing scientific software tools. Standardized procedures for software engineering were taught and applied. Students experienced challenges and professional approaches involved in collaborative software development, implemented project management ideas and delivered a working software tool together with proper documentation. Gain in domain knowledge on process monitoring for additive manufacturing supported the activity as a motivating factor.

1 INTRODUCTION

The development of advanced physics-based simulations techniques and data-driven process monitoring tools is required to improve process control in additive manufacturing, in particular for 3D printing of metals, alloys and oxides. For this purpose, a substantial number of qualified experts will be required both in industry and academic research groups. To allow prospective PhD students to quickly enter productive research, early training of students on mathematical techniques as well as familiarity with real experimental data is highly desirable. For this purpose, exposure to current research activities in additive manufacturing has been provided for undergraduate students (4th semester) by re-defining project work accompanying a taught course on software engineering in the programme “Electrical Engineering and Information Technologies” at the University of Applied Sciences Aschaffenburg, Germany.

While the university already offers a well-established research group on experimental additive manufacturing techniques and process development led by Prof Ralf Hellmann [1], questions related to simulation and process monitoring will gain additional relevance in the near future [2,3]. Such approaches require competences in mathematical algorithm development as well as software implementation. Therefore, a specific concept addressing these needs has been

developed by combining elements of a mathematical seminar on statistical data analysis for additive manufacturing with project work required for software engineering. The programme is part of training on professional scientific and technical software development.

2 GOALS

The following objectives had been defined:

- Familiarity of students with the basic usage of mathematical concepts for process monitoring, e.g. descriptive statistics, sliding averages, Fourier transform and filtering, principle component analysis (PCA)
- Developing critical thinking for testing, assessment and integration of existing libraries containing mathematical routines
- Working with real data, including pre-processing steps and understanding the basic aspects of data acquisition during a selective laser melting (SLM) process
- Systematic approach towards software development based on: setting up software requirement specifications, choosing a suitable analysis model, defining software design specifications, implementing those following a project management plan and, finally, a clear documentation of all functionalities in a user guide.
- Stimulating a collaborative team effort to develop and test a problem-specific software tool using an integrated development environment (IDE, e.g. MS Visual Studio or Eclipse) and source control manager (GIT archive provided).
- Producing a configurable software tool which allows for a straightforward and convenient visualization and first inspection of process data collected from a SLM process.

3 SETUP

3.1 Educational environment

The course was organized as a lecture on models, methods and standards in Software Engineering (90 min per week) and an accompanying team project. The team project was supervised weekly for twelve weeks. Students were free to develop their own approaches within the set tasks. External resources had to be tested and cited before inclusion in the project. Python was used as programming language. A working software tool and a use case scenario had to be presented as part of an oral examination.

To illustrate project management techniques, intermediate deliverables had been defined as milestones of the project: A presentation of the software architecture and interfaces was expected four weeks after starting the project, a first working prototype of the software with reduced functionalities had to be presented after eight weeks. While full functioning was not expected, awareness for inconsistent definitions and outstanding contributions was raised. Moreover, the need to contribute to the project continuously was stressed. Three working days

before the examination the final result had to be submitted by upload.

3.2 Data

Sensor and image data from real selective laser melting building processes performed on a DMG MORI Lasertech 30 printing machine was kindly provided by Prof Ralf Hellmann's group. The data consisted of more than 70 data outputs which were collected continuously during previous building processes. Sensor measurements included, for instance, temperatures taken at various points, oxygen concentration, Ar gas pressure and flow in the building chamber, some laser characteristics (laser power, backreflection, etc.) and powder properties. A number of control and action variables, first of all the platform position and the powder level, as well as error flags were recorded. Thus, a high dimensional data set was available. Some data pre-processing was needed to ensure data consistency.

Moreover, photographic images of the powder bed were taken each 50 μm . Images are greyscale, consist of 1280 x 960 pixels at 24 bit and picture the building chamber as well as the surrounding box. Their size is roughly 1 MB each. The resolution is suitable to detect the built objects and to observe macroscopic inhomogeneity in the powder distribution like stripes or holes. It is not sufficient for an inspection of finer details directly.

Data sets were taken from correctly terminated as well as from early abandoned building processes. In the later cases, problems in the powder preparation caused fatal outcomes.

3.3 Student teams

Two student teams were formed consisting of five members each. Each team member was assigned responsibility for a particular mathematical routine, its software implementation, and a document describing some aspect of the software engineering process. Responsibility for the software architecture, the definition of interfaces and the final integration of subroutines as well as systematic testing was shared among all team members.

While one student team (team A) focussed on the time series analysis of physical sensor data (temperatures, etc.), the other team (team B) was involved in image processing. Two independent solutions have been developed and presented.

One of the teams (team A) quickly started productive activities and a well-balanced collaborative working habit and continued until the software tool had been developed. However, the other team (team B) struggled to organize itself already in the beginning. Despite of regular supervisions, early student disengagement could not be avoided: Three students continued to form a hard working core of the team, one student cancelled his participation early, still trying to minimize damage to the team, while another student continuously reduced involvement and, despite ongoing encouragement, did not contribute to the project outcome. This required some late stage interventions to ensure that a working software tool with reduced functionalities could be presented by the remaining team members. Reasons for this outcome cannot be clearly specified. They are not primarily linked to the abilities of the students since all tasks were designed to work on various levels of engagement and ability. For instance, a graphic user interface (GUI) could be built in a very elementary form by essentially copying textbook examples or including specific features and advanced

design. Dropout was, in particular, not linked to the kind of -and the challenges of- the mathematical routine chosen.

4 RESULTS & OBSERVATIONS

4.1 Selective Laser Melting Process and Data Analysis Methods

Participating students got in contact with current research activities in the field of additive manufacturing. They learned about the basic aspects of the selective laser melting process and are able to link relevant sensor parameters to steps and particular features of the process. They reviewed previous knowledge on signal processing, e.g. based on Fourier transforms, and extended their mathematical knowledge slightly beyond eigenvalue problems by making the principal component analysis available for the given data set. Working with real data generated at their home university and contributing at least a tiny step to research activities was for many a motivating experience.

4.2 Scientific software development

The main focus, however, was the development of a software tool for scientific purpose. As a result, two independent programmes were specifically designed for first inspection of data sets from a particular selective laser melting process performed by a research group. Simple time series analysis of historic data can be rather conveniently performed with the tool. Data visualization was performed wherever appropriate to support the growth of data and process intuition.

Team A developed a user-friendly graphical user interface (GUI) suitable for a quick search for dominant correlations between various data traces. Team B suffered an unexpected shortage of manpower and designed a command line control approach as a backup solution. Both teams developed concepts to make observations reproducible by logging configuration and input parameters and, partly, storing intermediate results.

Documentation reached a satisfactory standard to allow future thesis students to use this tool for a first analysis of similar data and to add own contributions, e.g. additional mathematical routines, within the given framework. A bit of further software development would be needed to integrate both programmes into a joint tool.

Performance analytics was conducted by both groups as part of the final testing to benchmark the programme developed. It clearly shows room for further improvements.

4.3 Perspectives

The chosen approach motivates the development of new and specific educational programmes at the intersection of mathematics, software engineering and process analytics. While traditional mathematical seminars constrain themselves to purely theoretical analysis, practical software engineering projects often approach problems based on advanced high-level frameworks; those may completely disguise mathematical content. Scientific software

development requires the ability to combine both, using efficient numerical core routines while making slight adaptations to overall mathematical implementations where needed.

Further work could involve the combination of a seminar on higher machine learning techniques with a direct development of code aimed at addressing specific research tasks. Natural candidates are tools for error detection or state prognostics.

5 ACKNOWLEDGEMENTS

The data used for the student projects had been collected independently by Prof Ralf Hellmann and his group. It was provided free of charge for educational purposes. In particular, the author thanks Jakob Feldmann for supporting the project by annotating and explaining some of the sensor data labels.

The lecturer of the course *Software Engineering*, Prof Konrad Doll, provided the opportunity to complement existing software engineering projects by reaching out to joint data analysis and software development for additive manufacturing.

Furthermore, the author gratefully acknowledges funding provided by the State Government of Bavaria under the project PromoAdd^{3D}.

REFERENCES

- [1] Hellmann, R. <http://www.alp-aschaffenburg.de> (downloaded 11th of July 2019)
- [2] Tapia, G. and Elwany, A. *A Review on Process Monitoring and Control in Metal-Based Additive Manufacturing*, J of Manufac Science and Engineering (2014) **136**:060801.
- [3] *Measurement Science Roadmap for Metal-Based Additive Manufacturing*, NIST (2013)