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Seamless integration of AM Digital Twin with CAD/CAM software for large-format 3D printing of metals

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Decentralized manufacturing, closer to the point of use, requires tight integration of the process workflow, from part design, optimization, simulation, to manufacturing. Such demand is particularly clear in Laser Aided Additive Manufacturing (LAAM) of large-format components such as propellers and other parts for the maritime & offshore industry. A key component of modern workflow is the Digital Twin (DT), which informs the part and process developer of thermal history, microstructure, mechanical properties, and distortion of the part by doing process modeling simulation. While achieving a DT of LAAM is a complex task on its own, successful deployment of the workflow is even a more ambitious task because it requires integration between the DT with the design tool which generates the part and robot toolpath. Here, we demonstrate direct integration of a CAD/CAM software developed at SIMTech with the LAAM DT developed at IHPC. We prove this integration by designing an airfoil component together with its gcode, and transferring the data from one platform to the other. The direct inspection of thermal history at part scale supports the CAD/CAM user in selecting part design and robot code for optimal printing quality.

1. Introduction

Metal Laser-Aided Additive Manufacturing (LAAM) is an advanced manufacturing method whereby a robot arm is instructed to deposit material following a precise path. This way, a component is built as a sequence of robot moves across multiple layers [1]. LAAM has clear value capture when printing large-format components, for example in the shipbuilding and offshore sector, where the short lead time and point-of-manufacturing capabilities of LAAM make it economically attractive compared to traditional manufacturing routes [2] [3].

To reduce trial-and-error in developing the process for a new material or a new component, modeling and simulation offers the opportunity to perform such development digitally rather than experimentally, thus reducing costs. To achieve this grand vision, two main components are necessary. The first component is a CAD/CAM software which is capable of generating the component shape together with the robot code. The second component is a process simulator, for example a design digital twin [4], which takes component shape and robot code as input, and computes key quantities such as temperature distribution, phase evolution, and distortion.

The combination of these two tools provide a powerful workflow to achieve our grand vision. However, traditionally, these capabilities are separated and hard to integrate together. Early work by Kao *et al.* developed a CAD/CAM system where multiple users could collaborate together with capabilities in surface modelling, simulation of milling toolpath, and post-processing [2]. For the case of additive manufacturing, Popov *et al.* developed a CAD/CAM capability which used only the function representation of the geometry, which allowed to incorporate topology optimization capabilities [3]. With the goal of improving accuracy of material deposition and integrating the calculation of support structures, Silva *et al.* developed a CAD/CAM platform specific to ceramic deposition for dental crowns [4]. In terms of process modeling, Knapp *et al.* identified the key building blocks for a process digital twin [4]. For the case of Ti6Al4V, Heigel *et al.* developed a thermomechanical model which elucidated residual stress and distortion based on the thermal history [5]. This brief literature review already suggests that, while extensive work has been done in the fields of CAD/CAM and process modeling individually, to the best of our knowledge, little has been done to attempt a stronger integration between them. In this paper, we demonstrate seamless integration of CAD/CAM capabilities developed at SIMTech with process modeling capabilities developed at IHPC, using an airfoil as a demonstrator. Our integration contributes to the vision of an end-to-end digital workflow for LAAM and support industries to adopt this technology and leverage on its business case.

2. Integration of CAD/CAM software with Digital Twin process modeling software

2.1 CAD/CAM

A computer-aided manufacturing (CAM) software was developed in-house to generate the LAAM process code based on digital CAD models and simulate the robotic motions during the process. The 3D CAD slicing, toolpath planning, and robot kinematics algorithms were coded in Python. The GUI was created using PySide, the official Python binding of the Qt framework. Snapshots of the software are shown in Figure 1 below. A button was created at the menu bar to open the digital twin GUI directly from the CAM software. More details of the digital twin itself is described in the following sections.

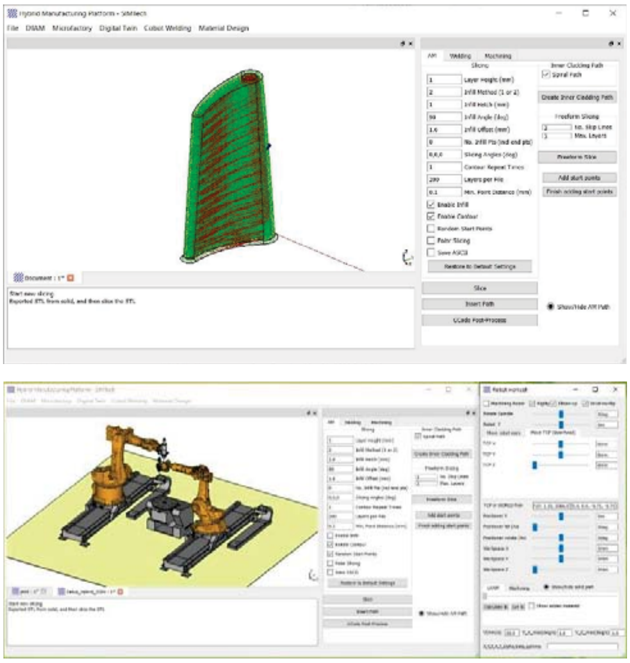

Figure 1. The in-house developed CAM software for LAAM toolpath planning (top) and robotic system simulation (bottom)

2.2 Digital twin process modeling

In terms of process modeling, software development was done to prepare a graphical user interface (GUI) which could serve as the end-point for the CAD/CAM software. The GUI was coded in C++ language using the Qt5 framework for user interaction and asynchronous event handling. Rendering was accomplished using the Visualization Toolkit (VTK). A screenshot of the GUI, as started by the user, is shown in Figure 1.

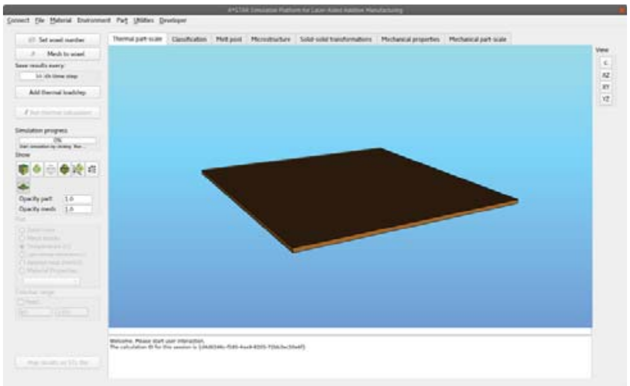

Figure 1. Graphical User Interface (GUI) of the process modeling digital twin.

Component loading is done by clicking the user menu “File” and then selecting “Load component (stl)”. Such operation opens a new window, where the user selects the stl file. Using the demo component, the GUI status is shown in Figure 2.

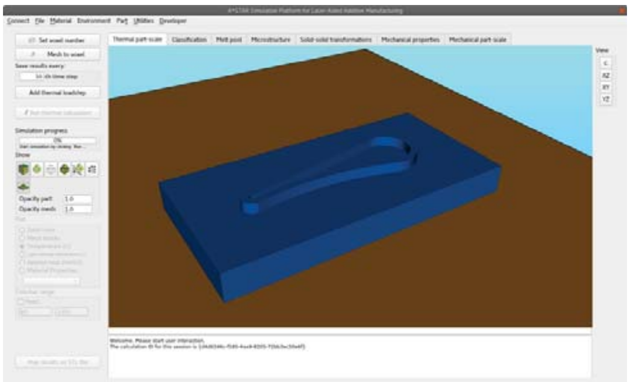

Figure 2. Status of GUI after loading the component, in the form of stl file.

After loading the component, the robot code is loaded. This procedure is accomplished by clicking the menu “File” followed by “Load g-code”. Then, the GUI reads the gcode line by line, and converts it in VTK format for rendering. As a result, the situation in Figure 3 is obtained. In this figure, we can see the user can inspect each robot move and assess printing sequence. Of note, the gcode lines are colored according to laser power. In the figure, we can the paths where laser is on, at power 600W, are colored in red, while the paths when the laser is off are colored in blue.

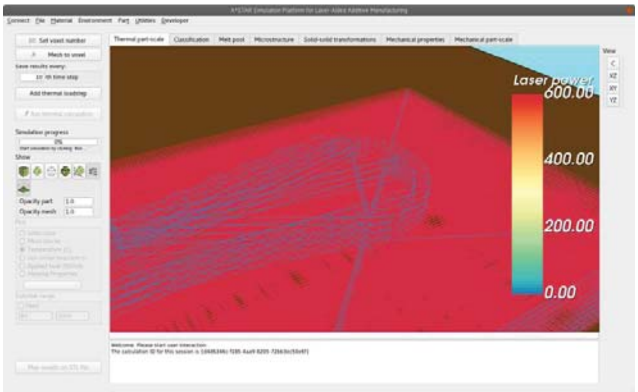

Figure 3. Status of GUI after loading the robot code (g-code).

Finally, the GUI allows the superimposition of part and gcode, to let the user have an overall assessment of the printing job. The corresponding status of the GUI is shown in Figure 4.

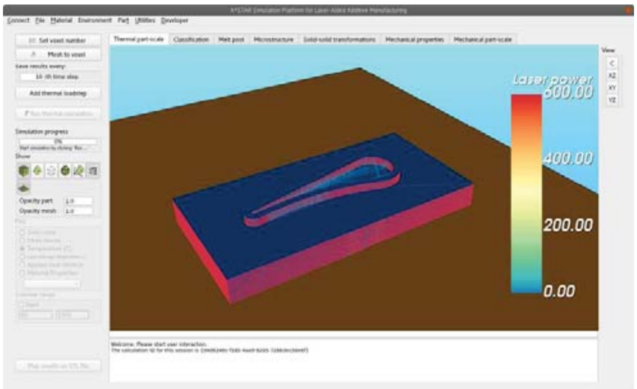

Figure 4. Status of GUI after loading both component and stl files generated by the CAD/CAM application.

In order to load the input files directly from the CAD/CAM software, coding was done to pass them as parameters at executable invocation from command line. In particular, the following command configures the GUI as shown in Figure 4 without user interaction:

```
/path/to/gui/bin/digitalTwinGUILaam
        <stl file> <gcode file>
```

thus achieving the intended goal of integration between platforms.

3. Conclusions

In conclusion, we have briefly presented the integration between CAD/CAM software developed at SIMTech with the process modeling digital twin developed at IHPC. Such development and integration was possible because both platform were written in-house, thus allowing customization to this specific need. The integration enables an holistic view of digital manufacturing by progressing towards the complete end-to-end digital workflow.

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