Geometry Processing for SLS/HIP

Ravi Venkataramani, Suman Das, Joseph J. Beaman
Laboratory for Freeform Fabrication
University of Texas at Austin

Abstract

SLS/HIP is a new net shape manufacturing method that combines the strengths of direct selective laser sintering and hot isostatic pressing. Direct selective laser sintering is a rapid manufacturing technique that can produce high density metal parts of complex geometry with an integral, gas impermeable skin. These parts can then be directly post-processed by containerless HIP. Sophisticated processing of the part geometry is required to facilitate the desired results from SLS/HIP. This paper presents geometry processing algorithms being developed for *in-situ* canning of SLS/HIP components. This research is funded by DARPA/ONR contract N00014-95-C-0139 titled "Low Cost Metal Processing Using SLS/HIP".

INTRODUCTION

Selective laser sintering (SLS) is a layered manufacturing technique that can produce freeform three-dimensional objects directly from their CAD models without part specific tooling or human intervention. Parts are built by selectively fusing layers of a powder material using a scanning laser beam. Details on this process are described elsewhere[1,2]. The next generation of selective laser sintering i.e. direct fabrication of functional metal and cermet components and tooling is under development at the University of Texas[3,4]. To produce full density metal parts having complex geometry, a novel net shape manufacturing technique called SLS/HIP[5,6] has been developed at the University of Texas. The idea is to consolidate the interior of a component to 80% or higher density and to fabricate an integral gas impermeable skin or "can" at the part boundary *in-situ*. Sophisticated geometry processing is required to obtain the desired results. It is proposed to develop parametric representations of the part contours at the slice level. These parametric curves will then be offset in a suitable direction, to grow or shrink the curves, to generate skins. This parametric representation will also enable local shape change to compensate for any changes in dimension or shape that might occur after HIP post-processing for a specific part. These parametric representations for each layer are then used as the contours for SLS processing. The SLS processed part can then be directly post-processed by containerless HIP to full density. The optimal thickness of the skin will depend on the HIP deformation model and the tolerance requirements. A final machining step will result in a part having the desired geometry, mechanical properties and tolerance.

BACKGROUND

In the SLS/HIP process (Figure 1), the component is produced by selectively consolidating a metal powder with a laser beam layer by layer. While producing each layer, a gas impermeable high-density skin (> 98% density) is formed at the boundaries of the part. The interior of the part is laser processed to a high density typically exceeding 80%. Thus, the part is shaped and canned *in-situ*. The encapsulated part is evacuated, sealed and post-processed by containerless HIP to full density. A final machining step may be applied if necessary.

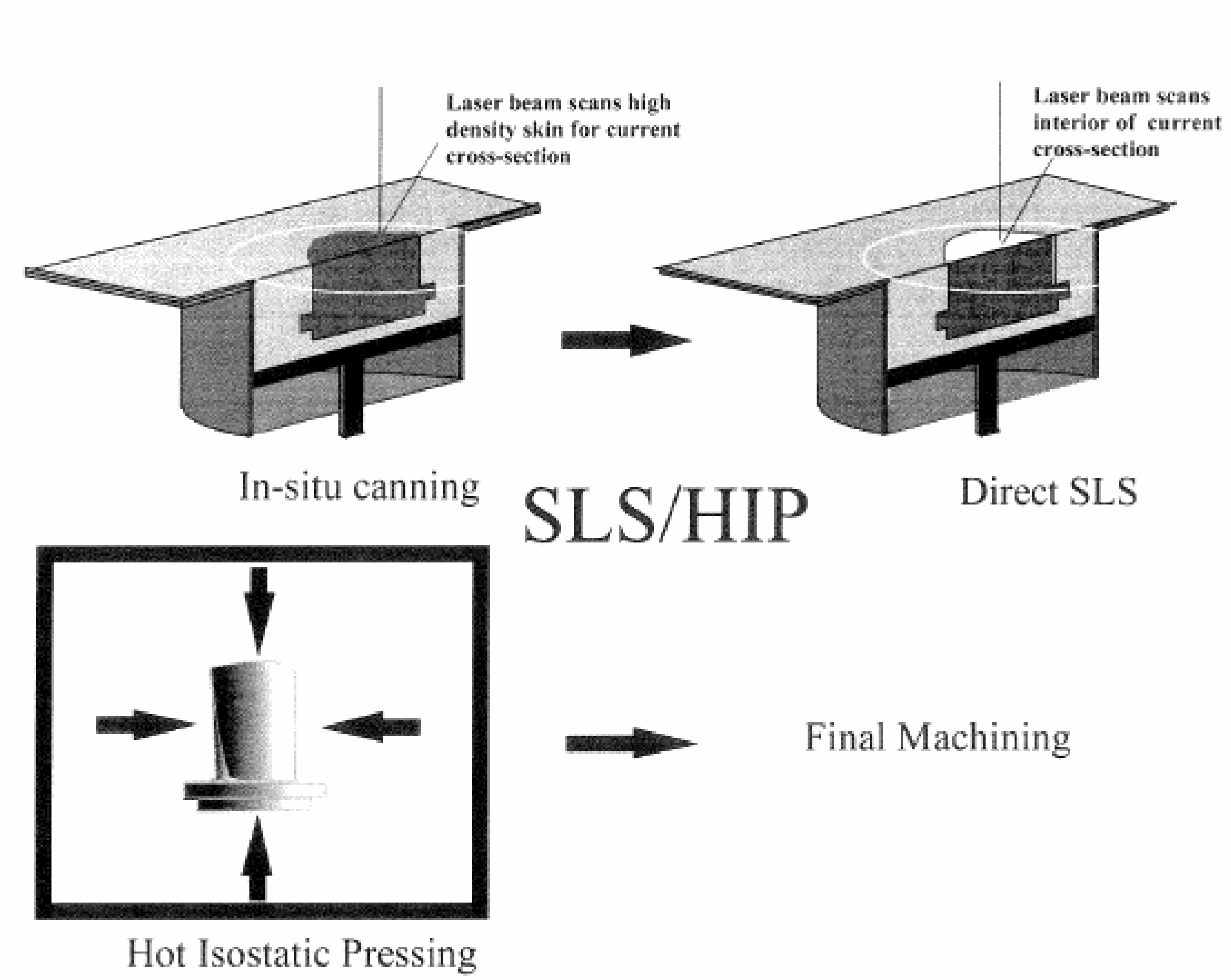

Figure 1 The SLS/HIP Process

Offset curves have been used in industry for a range of applications some of which are mold design, NC path planning, tolerance analysis and CAD in the automobile industry. An offset curve is a curve parallel to the original curve at some offset distance. Offsets can be generated for implicit curves as well as freeform curves. Offset techniques have been well established for a series of parametric curves like Hermite curves[7], B-splines[8], NURBS[9], Pythagorean Hodograph curves[10] etc. It is proposed to use B-splines and NURBS for the considered application.

B-splines have been chosen because they are used widely in industry and have been well documented. However they cannot represent regular or implicit curves like conics precisely. NURBS, being rational, are more versatile in representing both freeform and regular curves precisely. One of the drawbacks of using NURBS is that the offsets generated will not be rational requiring the use of special polynomial parametric curves like Pythagorean Hodograph curves, which surmount this problem.

GOALS

This research proposes to address the following issues:

Generation of skins for each slice contour data, modification of part geometry based on part-specific HIP deformation models, development of intelligent scan patterns to produce an integral, gas impermeable skin by SLS, and to incorporate the above in intelligent process control.

PROCEDURE

The sliced CAD data file of the component considered gives the contours along each layer. A B-spline or a NURB is fit to the slice data points. Details on the formulation of B-splines and NURBS can be found elsewhere[11,12]. This parametric curve is then used to generate the offset. Depending on the relative location of the part contours at the slice level it may be required to grow or shrink the curve, thus denoting a positive or negative offset respectively.

Offset Procedure

Let $(x(t), y(t))$ be a point on a parametric curve C. Then, the curve C_0 offset a distance $\pm d$ has points $(x_0(t), y_0(t))$ that satisfy the equations[13]

$$x_o(t) = x(t) \mp d \frac{\dot{y}(t)}{\sqrt{\dot{x}(t)^2 + \dot{y}(t)^2}}$$

$$y_o(t) = x(t) \pm d \frac{\dot{x}(t)}{\sqrt{\dot{x}(t)^2 + \dot{y}(t)^2}}$$

where $((x(t), y(t))$ is the tangent vector at $(x(t), y(t))$. This is illustrated in Figure 2.

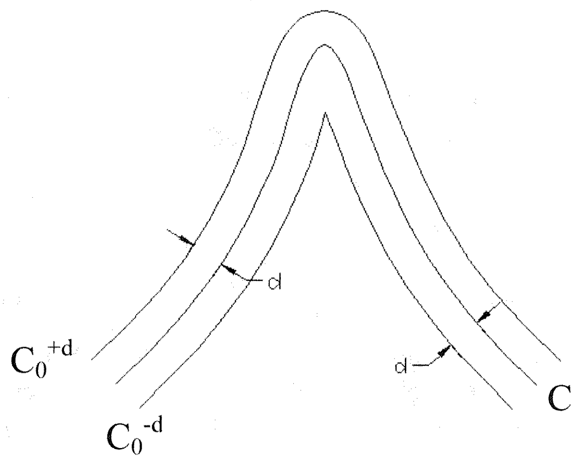

Figure 2 Offset Procedure

Some of these offset curves may have self-intersections forming loops as shown in Figure 3. These loops need to be removed to get an intersection-free contour, giving the offset.

Loop Removal

In order to remove loop that may occur in the offset generated the following sequence of operations may be performed

1) Analyze the offset for self-intersections[13]. Self-intersections define multiple closed loops[14].
2) If the direction of rotation of such a loop is inconsistent with the direction of rotation of the original contour, it is removed.
3) For loops whose direction of rotation is consistent, check the span of the remaining part of the offset.
4) If the span of the remainder is greater, discard the loop.
5) If the span of the loop is greater, keep the loop and discard the rest of the offset.

The result of the given set of operations on an offset curve with self-intersections is shown in Figure 4.

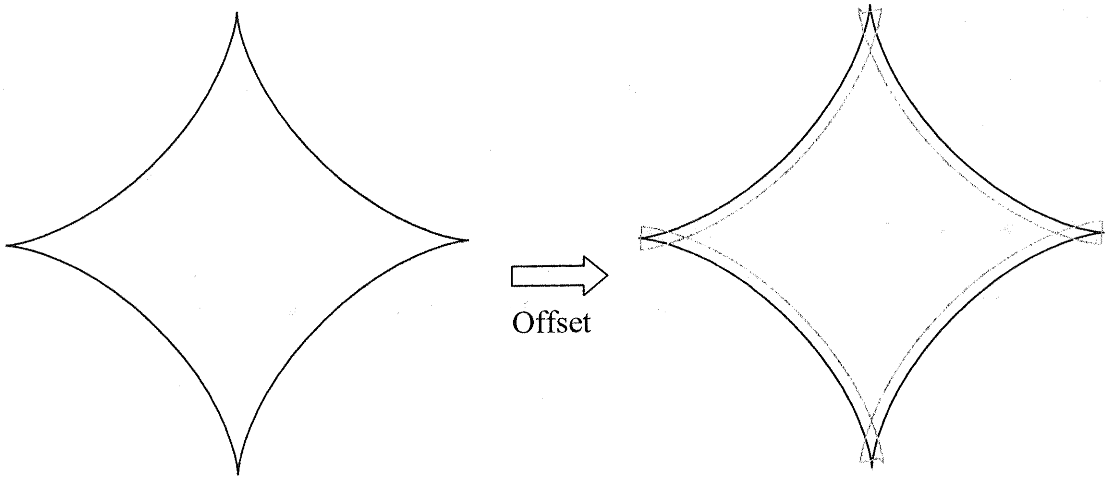

Figure 3 Offset with loops

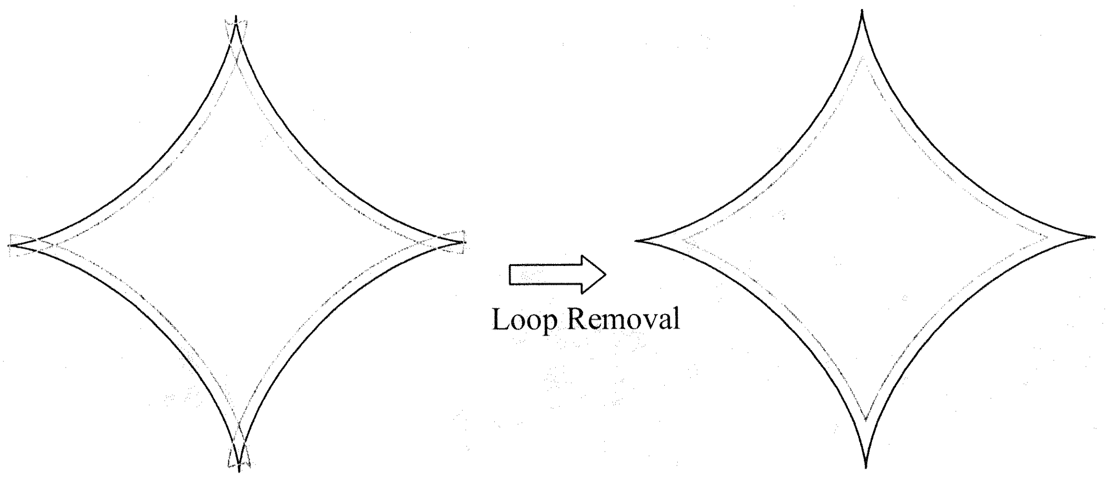

Figure 4 Loop Removal

RESULTS

Two test cases were considered to validate the algorithm, one for a freeform contour and the other for a regular or implicit contour.

Case 1 : Slice Contour of a Stator Vane

This is one of the candidate components chosen to demonstrate the capabilities of SLS/HIP.

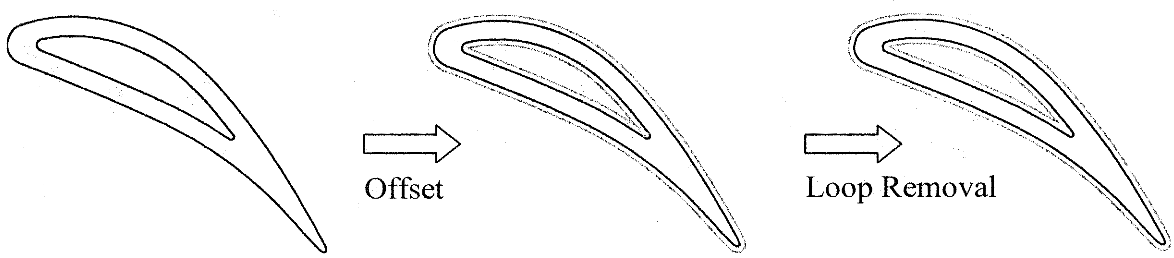

Figure 5 Growing of the Stator Vane

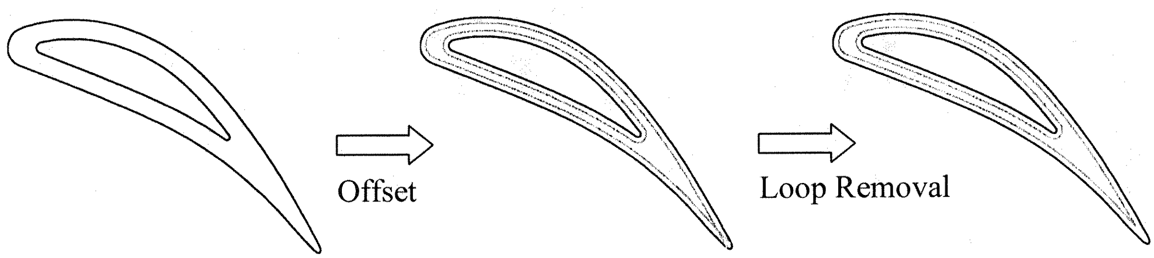

Figure 6 Shrinking of the Stator Vane

Case 2 : Curve with Convexities

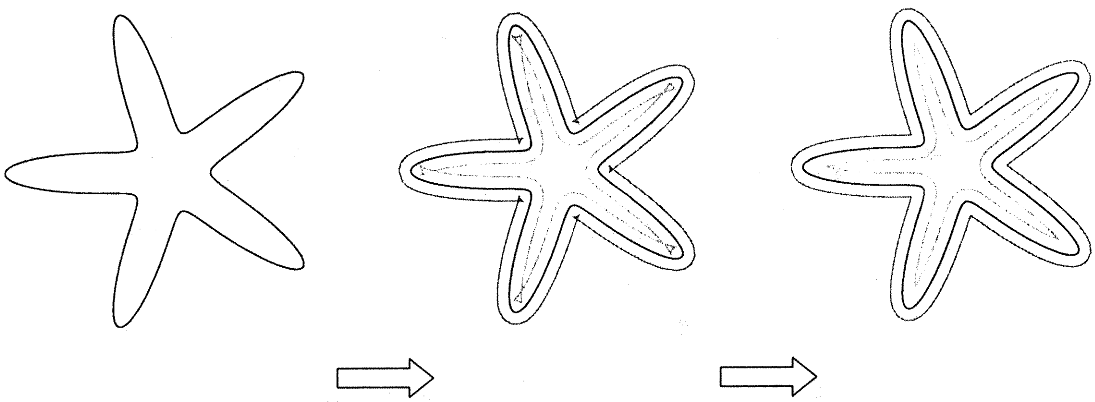

Figure 7 Offset of an Implicit Curve

The polar form of the curve of Figure 7 is given by

$$\rho = \frac{p}{1 + \epsilon \cos(m\varphi)}$$

$$p > 0, \quad 0 < \epsilon < 1, \quad m \in \mathbf{N}, m > 1$$

SUMMARY

An offset technique for B-splines was developed and tested for a series of curves. This technique will be validated by producing an SLS/HIP component. A similar technique for NURBS should be developed to optimize contour specific processing. Part geometry re-engineering will be performed based on HIP deformation models.

ACKNOWLEDGEMENTS

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