Mapping and Pocketing Techniques for Laser Marking of 2D Shapes on 3D Curved Surfaces

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Abstract Laser marking has been used since the invention of lasers but it is only in the last decade that it started evolving into 3D surface marking. The problem of defining the toolpath for a 3 axis laser marking machine can seem to be the same as the definition of the toolpath for the CNC milling machines but this is not completely true. In the case of laser marking is not only the last pass that will affect surface finish but every pass made. This implies that to obtain the desired final effect on the material it is crucial to define different pocketing and filling patterns together with the laser parameters. Defining new patterns that meet the requirements for the laser marking on 3D curved surface is a non-trivial problem; the toolpaths, depending on the application, may need to have different properties such as constant distance or density between path lines, non-crossing of path lines or defined angle of intersection. When trying to mark non flat surfaces with 2D images or paths, in certain cases, distortion of the 2D space cannot be avoided. This paper will analyze different proposed techniques for mapping and marking 3D solids with a 3 axes, mirror based, laser marking CNC machine analyzing advantages and disadvantages of each one from the software development point of view.

Keywords Laser marking · Pocketing

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1 Introduction

Laser marking has been around since the invention of lasers in 1960; the amount of materials which can be worked is countless, metals, plastics and even transparent materials. On the other hand, only in the last decade, software for laser marking on curved and 3D surfaces started to be developed. Regardless of the type of laser marking machine, marking 3D surfaces require adoption of special focus lenses to change the focal point. Changing the focal point or changing distance of the emitter enables the laser to focus at different distances thus giving a third axis of control. The problem of defining the toolpath for a 3 axis laser marking machine can seem to be the same as the definition of the toolpath for the CNC milling machines but this is not completely true. Milling machines toolpaths have different requirements: Laser toolpath does not require checking for tool collision and the piece can be considered static since very little material is removed. In the case of milling, only the last pass will affect surface finish, while in laser marking every pass is important for the final result. This implies that, to obtain the desired final effect on the material, it is crucial to define different pocketing and filling patterns together with laser parameters. In the paper we will explore techniques and challenges faced during the development of a 3D marking software.

In Sect. 2, we give an overview of the issues and challenges encountered. In Sect. 3 we describe: (1) a mapping approach based on mesh description and UVW mapping; (2) a technique that allows the generation of the toolpath without the need of geometry data; (3) a technique that guarantees constant distance between toolpaths' lines which deeply affect marking results. Finally, in Sect. 4, we compare the surveyed techniques and explain when to use them based on toolpath requirement and available data.

2 Overview and Challenges

The process of defining a 3D laser toolpath can be summarized in two steps.

The first step is the definition of the mapping between the 2D marking and the 3D surface. This mapping will define the position, dimension and eventual distortion of the 2D shape on the 3D surface. The shape can be a simple contour that needs to be filled or a completely ready 2D toolpath. If the 2D toolpath does not need to be filled, only the transformation of the 2D coordinates to the 3D coordinates of the surface is required. In most cases the input to the marking software is a shape that needs to be filled.

Filling of the shape is the second step of the process. Filling or pocketing of the areas can be done in 2D or 3D dimensions. Filling or pocketing those areas in the

Fig. 1 2D cross filled text mapped on 3D surface

bidimensional rather than tridimensional space leads to different results and problems. For instance, Fig. 1 shows a preview of a toolpath generated from the text 'graphitech' on the Utah teapot.

Defining new patterns that meet the requirements for the laser marking on 3D curved surface is a non-trivial problem, the toolpaths, based on the application, must have different properties such as constant distance or density between path lines, non-crossing of path lines or defined angle of intersection.

Another problem which arises when trying to mark non flat surfaces with 2D images or paths is that in certain cases distortion of the 2D space cannot be avoided. When the solid, or the section of the solid being marked, is not unfoldable, the mapping between the 2D space and the 3D space will create a distortion which can be acceptable or not. It does not matter what technique is used to define the laser path, you will either have an already defined 3D path or you will need to define a transformation from a 2D path to the 3D surface.

3 Surveyed Techniques

The techniques described in this section have been designed during the development of commercial software for laser marking. Each technique addresses specific issues faced during practical use of laser marking machines.

3.1 Mesh-Based Surface Mapping

Mesh based surface mapping is a classic approach that defines the 2D to 3D transformation of the marking with a standard mesh UV mapping. This technique requires the 3D model of the physical object complete of a set of UV coordinates. The UV coordinates should be created for the specific purpose of mapping the area that will be marked. This approach requires good matching between the physical position of the real object and the position of the mesh in the virtual 3D space, failing to align the two reference frames will inevitably lead to areas where the laser will go out of focus. This is especially relevant when the area being marked has a high slope since a small lateral misalignment will lead to a greater vertical offset.

Assuming the real object is aligned with the virtual reference frame the computational steps required to achieve mapping are the following:

1. Define the position of the marking in UV space thus defining an actual 2D to 3D transformation.
2. Intersect marking lines with 2D UV mapping lines.
3. Project the intersected segments defined in 3D to obtain the toolpath.

Note that this process is valid both when the marking is only a contour that requires filling or pocketing or when the marking is a 2D toolpath complete of area fillings. In the case of area-only marking, filling can be done either on the 2D UV space as for classical laser marking and then transformed into 3D surface space or can be done directly in the 3D surface space as described in Sect. 3.

This technique presents advantages and disadvantages.

Among the advantages we can count the speed, the procedure does not, in fact, require a vast amount of time, even with complex meshes; it allows also to define precise pocketing paths, by specifying the line density and angle. This, as stated before, is of utmost importance when trying to create effects on the marked surface. The limitation of this approach is the unfolding of the object. In fact, not every object has a clear unfolding, or it may have a distorted one. Taking the sphere as an example, we know that it is not possible to unfold it in a plane without distorting it, the only thing that we can control is to choose where the unfolding will be less distorted.

The other problem of this technique is that usually, when an object is unfolded to create an uv map, some of the triangles of the map reference to more than one triangle in the object; thus trying to map a line from the 2D space to the 3D space will result in a duplicated line, and a wrong toolpath.

Clearly the advantages listed above are deeply related to the quality of the unfolding, while a good unfolding produces good and expected result, a bad one will reduce the quality of the toolpath caused by excessive avoidable distortion.

3.2 Depth-Based Surface Mapping

Depth based surface mapping approach is based on the idea that if the laser machine has a way to detect the objects in the marking area and pass this information to the control software, then the control software can use this information to modify and create the surface transformation required to place the marking image on top of the 3D model surface. To be able to detect the object on the laser work area any depth sensing technique can be used: photogrammetry, structured light, etc. One advantage of using depth based mapping, regardless of the technology used for the implementation is that the physical position of the object is intrinsically included in the detected depth information; this means that the user do not need to accurately place the object before marking [1]. Previously discussed techniques need both precise positioning and 3D information of the object including UV mapping of the surface. Even if 3D model of the marked object is available UV mapping is usually not and it requires specific knowledge to be created. On top of that when marking, only a specific part of the object needs to be mapped. This leads to the consideration that if the user were able to map in a simple and intuitive way the area to be marked, or even better to directly apply the image on the three-dimensional model without worrying about the coordinates, the ease of use of the marking software would increase significantly.

In the case of a mirror based laser CNC the origin of the marking laser is fixed and the field-of-view is constant so most of the mapping needs can be reduced to 2 fundamental cases. The mapping of nearly flat surfaces mapped with planar projection and mapping mapped curved surfaces with an appropriately distorted cylindrical projection. Any other cases with more complex surfaces, such as a sphere, no longer would benefit from special automatic mappings as there are no projections able to cancel the intrinsic distortion. This means that if we need to map a spherical object even if we use a spherical UV mapping the distortion would be the same as using a cylindrical mapping.

Regardless of the technology used; to implement this technique a depth sensor working in parallel with the laser machine is required. The 3D object surface data and position needs to be detected with enough accuracy to keep the laser focused on the surface of the object. The software should show the detected surface on a 3D view and the user should be able to place the 2D marking image on the detected surface abstracting mapping data.

3.3 3D Pocketing with Isolines

When the filling toolpath is calculated from the object unfolding, distortion problems can arise, causing a wide range of problems. Among them is the pocketing line distance, which varies depending on the distortion of the given area. In Fig. 2 we can see a visual representation of the spatial distortion between 2D and 3D of a

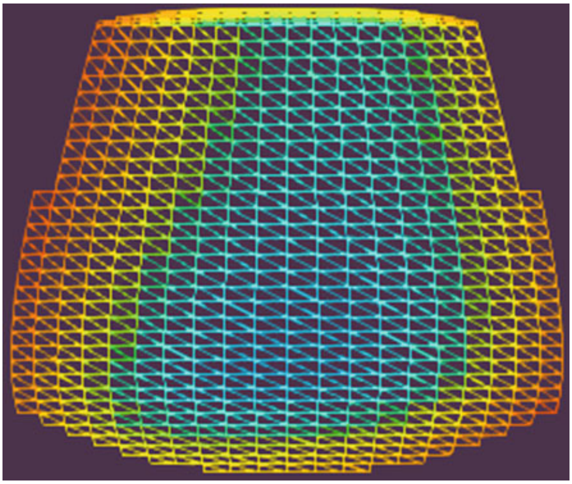

Fig. 2 Distortion in 2D to 3D mapping on a curved surface

curved surface (Utah teapot side). The distortion is one of the most concerning problems, because the line distance in the pocketing toolpath deeply affects the resulting marking.

To overcome this issue, it is possible to calculate the filling toolpaths with other techniques that do not require an UV map and work directly with the 3D shape. However, the technique does not remove the need of the unfolding because the image to be marked still needs to be mapped to the 3D surface.

One approach that allows computing pocketing toolpaths directly on the mesh consists in calculating the contour lines, that is, the set of points at a constant distance from a source on the object surface (isolines). Figure 3 shows an example of isolines calculated using the Saddle Vertex Graph algorithm. Calculating isolines of a discrete 3D mesh is a non-trivial task, and requires quite a lot of time. The discrete geodesic problem was successfully addressed for the first time in 1987 by Mitchell et al. [2]. They described an algorithm that allowed the computation of minimum shortest paths in a discrete 3D object. Recently, Xiang et al. [3] described how to reduce considerably computational time needed to calculate isolines by using a data structure called saddle vertex graph.

After having computed the isolines of a given object it is easy to create the output toolpath. First, the border of the image needs to be mapped from 2D to 3D, using its unfolding, and then the border is intersected with the isolines, only keeping the contour lines inside the image border.

The utilization of isolines open different possibilities regarding the patterns of the filling toolpaths, since it is possible to choose more than a vertex as source point it could be possible, for example, to highlight the features of the 3D object by choosing its edge as source points.

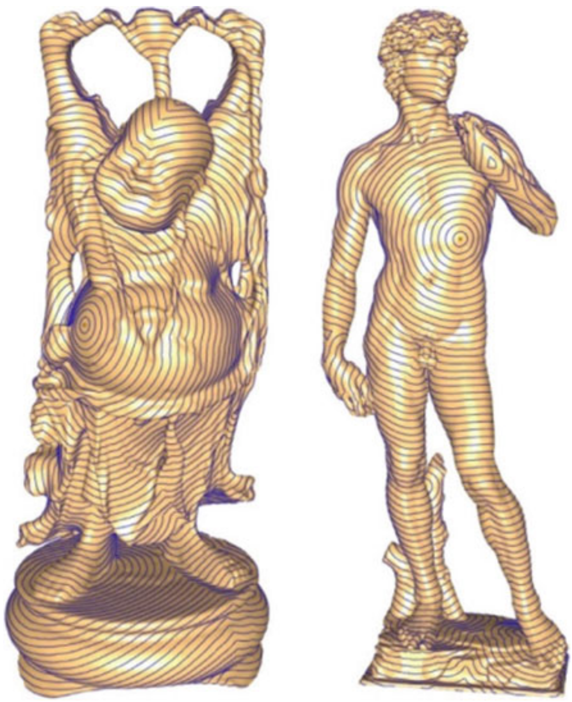

Fig. 3 Example of isolines on polyhedra meshes. Surazhsky et al. [4]

4 Conclusion and Techniques Comparison

To decide which technique use to generate the toolpaths for laser marking, it is essential to know the availability of the mesh's geometry and unfolding.

If it is difficult to obtain the unfolding or geometry of the object that needs to be marked, a depth based approach should be adopted, since this technique automatically obtains the data by analyzing the object itself. The downside of this approach is the extra hardware needed, which increases the cost and complexity of the laser marking machine.

As opposite, if the mesh's data is available, it is important to take in consideration the error of its unfolding. Since each mapping from 2D to 3D introduces a distortion, if the toolpaths need a very low tolerance, the right choice would be to adopt the isolines to calculate the pocketing, as this technique works directly on the mesh's surface, reducing considerably the error introduced.

In conclusion the mesh based approach should be followed when the mesh's unfolding is available and there are no particular requirements regarding the toolpath tolerance. This technique is useful because of its speed and straightforwardness.

A laser marking suite, which includes both software and hardware, should give the user the possibility to choose the most appropriate technique based on the specific requirements and data available for the given task.

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