International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
www.ijarst.in
ISSN: 2457-0362

NOVEL APPROACH ON CONTINUOUS TOOL PATH GENERATION FOR WELD DEPOSITION BASED ADDITIVE MANUFACTURING

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Abstract:
Additive manufacturing sometimes referred as rapid prototyping or 3D printing is the growing disruptive technology that builds 3D objects by adding layer upon layer of material such as plastic, metal, concrete, etc. Weld deposition based additive manufacturing approach is one of the most significant and efficient processes. In that, wire and arc additive manufacturing process are controlled manually or automatically. The wire when melted is extruded in the form of beads on the substrate, a base plate. As the beads stick together, they create a layer of metal material. It is a generating process that is applied for surface finishing and fabricating functional metal parts layer by layer. Though automated welding deposition has overruled manual process, it has a few demerits apparently such as uneven weld bead with a lot of starts and stops. Focusing on this challenge, this project splits the automated deposition into three steps i.e., diving an arbitrary 2D geometry into convex polygons of known shapes such as square, rectangle and triangle; generating the tool path for each individual polygon with contour and zigzag patterns; and connecting all the individual paths to form a continuous tool path for deposition manufacturing. The project uses MATLAB programming software for generating the algorithms. The tool path generation approach accomplishes all the design applications and also improves the accuracy by reducing the number of starts and stops in the deposition process and gets rid of uneven weld bead geometry.
Keywords: additive manufacturing, weld deposition, tool path generation, weld bead geometry.

Introduction

Wire and Arc Additive Manufacturing (WAAM) is an effective additive manufacturing process which is widely used around the world in recent times. However, owing to a number of intrinsic technological problems, such as distortion and residual stress from high heat input and uneven weld bead geometry distribution across weld routes, a mature WAAM system (Nikola et al, 2019) is currently not commercially accessible to industry. The use of thermal tensioning technology or a low heat input method like Cold Metal Transfer might help to reduce distortion and residual stress (CMT). This project work focuses on improving the weld bead geometry and increasing the surface accuracy of the built parts through improved tool-path planning. After numerous layers of deposition, uneven weld bead shape may lead to the

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accumulation of defects in the vertical direction.

To overcome this issue of uneven surface induced by arc start and arc end procedures, a hybrid method (Ding et al, 2014*)* is proposed in this work to adjust the deposition parameters at the start and end positions of weld paths to flexibly control the weld bead geometry. However, the control procedures are empirical and time consuming. Hybrid layer manufacturing processes, which combine the means of both additive and subtractive manufacturing, have been recently developed. The hybrid process employs intermediate machining of the upper surface between successive layer depositions to overcome

the layer surface roughness and to avoid the cumulative deviations in build height. However, such cleaning steps increase the complexity of the system and reduce the productivity also.

RESEARCH METHODOLOGY

The algorithm firstly decomposes the geometry of each 2D slice into a set of convex polygons. Then for each convex polygon, the outlines are generated with a contour pattern and the interior area is filled with a zigzag pattern. The algorithm for identifying the optimal contour pattern for a convex polygon has been devised. The contour pattern and zigzag pattern are joined for each sub-polygon to create one closed curve, decreasing the number of too-path passes. The proposed continuous path generation method is implemented to each sub-polygon independently. Finally, all the sub-paths are linked together to form a single continuous path without any starting stopping sequences.

Stereo lithography is a commonly used file format for describing the 3D geometry of a component suitable for fabrication using AM. 2D slices may be easily created from this format. The decomposition of these 2D slices into simpler convex polygons will make the implementation of path generation much easier. Many approaches have been developed for decomposing polygons (Fenandez et al, 2000). After slicing the input 3D CAD model, 2D geometries are obtained. Polygons make up the sliced 2D geometry.

For a convex polygon, filling the interior area using a zigzag path (Rajan et al, 2019) is an efficient strategy. To improve the geometrical accuracy, the outline of the convex polygon is fabricated using the contour method. Since a better finish can be obtained if there are fewer welding passes, the interior zigzag pattern and external contour are connected to a continuous path without starting-stopping. To minimize the number of toolpath elements, an optimal fill direction of the zigzag pattern in the convex polygon must be identified. The algorithm for producing the offset curve (Jurusann et al, 2013) for a polygon has been developed in MATLAB programming software. The offset curve is nothing but the contour of the sides of a polygon. The code entered in MathWorks software is given in figure 1.

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A peer reviewed international journal www.ijarst.in
ISSN: 2457-0362

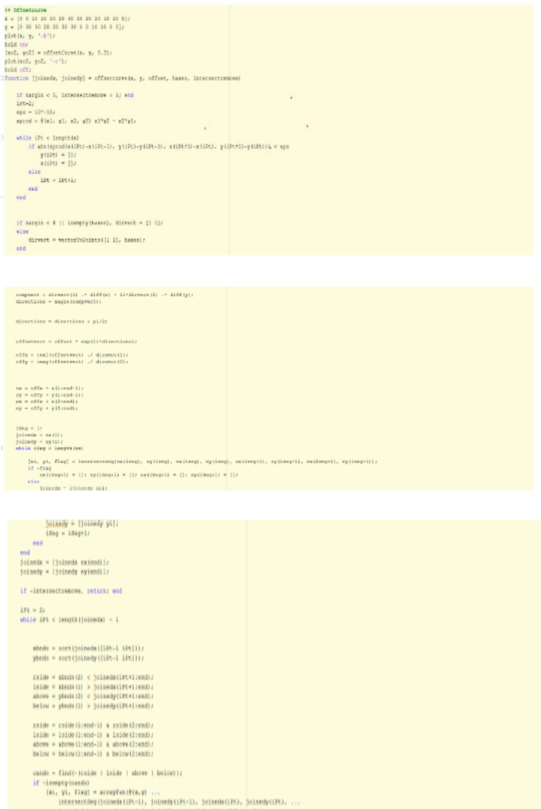

Fig. 1 MathWorks software coding.

The above coding creates an offset for the sides of a polygon. Now for the generated contour patterns, a zigzag path has to be created. To generate the zigzag pattern, a suitable method is proposed to easily implement any form of polygon. A zigzag pattern can be created in an empty space and the polygon can be inserted in the given space of patterns. Now the generated pattern intersects the polygon at several points. Those points can now be collected and arranged in a manner that generates a zigzag path in the polygon. Thus finally, a zigzag path is obtained in the given contour. A sample algorithm has been developed for a square polygon as shown in figure 2.

Fig. 2 Algorithm for a square polygon

```
clc
clear all
clear figure
clear
axis equal
hold on
x0 = [3 8 8 3 3];
y0 = [3 3 8 8 3];
plot(x0,y0);

x = [1 1 2 3 1 1 4 5 1 1 6 7 1 1 8 9 1 1 10 11 1 1 12 13 1 1 14 15 1 1 16 17 1 1];
y = [1 2 1 1 3 4 1 1 5 6 1 1 7 8 1 1 9 10 1 1 11 12 1 1 13 14 1 1 15 16 1 1 17 18];
mapshow(x,y,'Marker','+')
[xc,yc] = polyxpoly(x0,y0,x,y);
mapshow(xc,yc,'DisplayType','point','Marker','o')
```

Above code generates zigzag pattern inside a square polygon. Now the intersection points are collected and some modifications in the zigzag pattern are done to generate the zigzag path. The final step is to connect the sub-path of each polygon into a closed curve. To improve the surface quality, the connecting points between two polygons are set on the outlines of the geometry. During the decomposition of 2D geometries, the partition lines are used to generate the sub-polygons.

The performance of the proposed route planning strategy can be compared to the hybrid method on four sample geometries, it is possible to compare the number of tools passes and the number of path elements for the two methods and demonstrate that the proposed method is very effective and efficient. The proposed tool-path planning strategy is capable of generating a continuous tool-path pattern, while the number of tool path passes using the hybrid method is more. Therefore, the surface finish of the part fabricated with the proposed method is expected to be better than the hybrid method.

RESULTS AND ANALYSIS

The variation between the heights after several layers of deposition can be

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ISSN: 2457-0362

significantly reduced using the proposed method since arc starting and stopping has a large influence on the surface variation for the hybrid method. Initially a 2D surface can be decomposed into simple polygons using various methods which are available already. Now each polygon should be generated with an offset curve so that the zigzag curve can be made easily. Generation of the offset for a sample polygon has been programmed in MATLAB and the output is shown in figure 3.

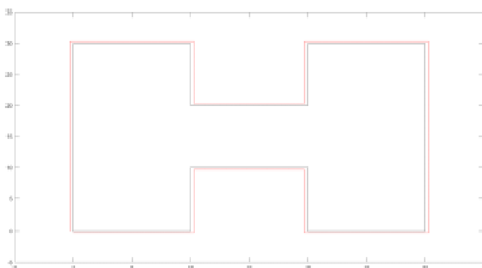

Fig. 3 MATLAB output of a polygon

Now this offset curve can be fed into to make a zigzag pattern as discussed above. A sample square polygon is taken and the zigzag path has been generated for it as shown in figure 4.

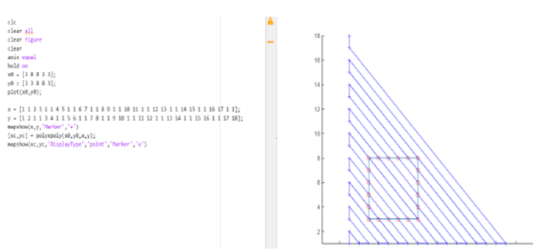

Fig. 4 MATLAB code and output for optimized path for square polygon

Now the intersecting points are collected and an appropriate zigzag pattern is generated inside the polygon. The result is shown in figure 5.

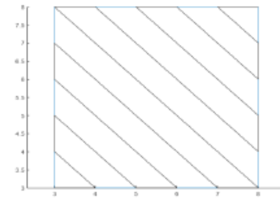

Fig. 5 Optimized path inside the polygon

FUTURE OBJECTIVE OF WORK

In the proposed work, the algorithm to optimize the tool path generation has been developed only for sample square polygon, due to time constraints. Also, offset curve for a single polygon has been developed separately. However, the same should be combined and similar approach has to be extended for other complex polygons. Also, the process of connecting all the optimized paths of all polygons is also required to be done in the future work.

CONCLUSION

The generation of the toolpath is a fundamental step for a practical WAAM system. A novel tool-path generation strategy has been developed and tested using MATLAB. The algorithm firstly decomposes 2D sliced geometry into a set of convex polygons. Then for each convex polygon, the contour pattern and zigzag pattern are implemented and connected to produce one closed curve, reducing the number of tool-path passes. All sub-paths are finally linked together to form a single continuous path passes without any starting-stopping sequences for fabricating each 2D slice or layer. Both tool-path passes and path elements have been reduced by the proposed method when compared to the existing hybrid method. The proposed path planning

International Journal For Advanced Research In Science & Technology
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ISSN: 2457-0362

strategy combines the advantages of both zigzag and contour tool-path generation strategies. The effectiveness of the proposed algorithm can be tested in experimental trials of WAAM process, which is the further scope of this research work.

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