Title:

On line CAM for wire arc additive manufacturing

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Introduction:
Wire additive manufacturing [1] has the possibility to build structure in 3D space and obtain truss skeleton. This technique can be extended to Wire Arc Additive Manufacturing (WAAM) to build metallic structure.

WAAM system is based on welding process to deposit metallic material and a robot that moves the welding torch to add material at a given position. For skeleton structure, it was chosen to deposit material point by point. The use of a welding process can induce lot of uncertainties [2]. Two main features must be taken into account. First, monitoring of the process is necessary to achieve geometrical accuracy of produced parts [3]. Local control on the geometry used to reach the final shape. Secondly, some deposition strategies must be implemented to manage branch intersections. An adaptive and modular slicer and a process manager have been developed in order to implement this control. It allows us, if an error occurs during the deposition, to correct the position of the effector. The CAM software have to be able to, (i) do a slicing during the additive process of the part with a variable deposit height in order to take into account variation of the deposition process and then to obtain the desired geometry and (ii) manage the deposition strategy at intersection to output the position of the torch.

CAM geometry description:
Figure 1 devises the flow of informations. CAD can be any type of geometry that can be converted to lines. It can even be a .STL that can be skeletonized. This geometry can be converted into a list of points and then to a list of segments ; this is called a polyline. The geometry is defined as a list of polylines. An example is given on figure 2

For a given curvi-linear abscissa, it is straightforward to compute the coordinates of the point and the normal vector associated to it and to control the position and orientation of the welding torch. Points are basic entities. The main property is to know if the point is shared by another polyline, in order to propagate the slicing between polylines.

Polylines have several properties that can vary during the slicing. Polylines have an indicator in order to know if they have priority over other polylines. The polyline has a boolean to know if it is under
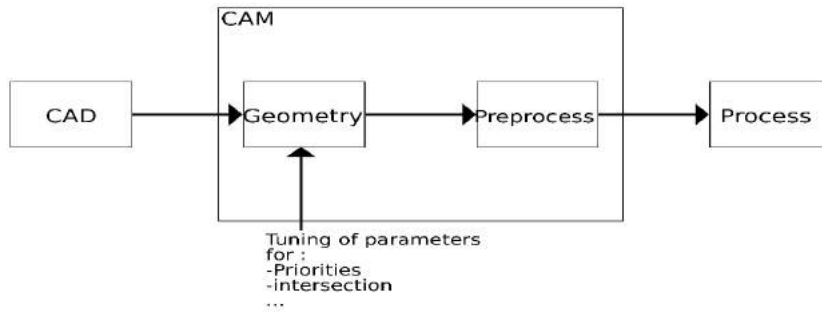
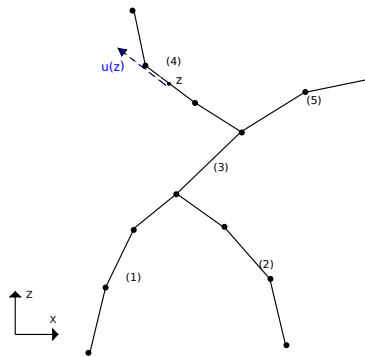Fig. 1: Numerical chain for additive manufacturing

Fig. 2: Example of a multi polylines shape in a XZ plan, with u a normal vector for a given point

construction. Finally, the polyline has a deposited radius property. It is assumed that the deposition can be represented by spherical cap.

To complete the CAM geometry, a starting plane and a building direction are defined.

Adaptative Slicer algorithm:

In classical slicing procedure, the slicer does the whole slicing on the base of the wanted geometry during the CAM. Data of trajectories is then stored and re-used without any modification. For welding point additive manufacturing, the slice must adapt the "step" because the height of the deposit can vary due to process problem or thermal modification during the process.

To be adaptive, the new way of slicing must be done by propagating the different points during the manufacturing. After a point is built, the slicer propagates it into a next one by adding the step increment for the last one. This new point is pushed in a list of points that would be built. When the new point reach an ended point, it is pushed to adjacent polylines. With this way of slicing, the increment height between each point can be changed before the propagation. The other major feature is the management of intersection. Figure 3 shows a skeleton structure which will be built along $\vec{z}$ building direction. This structure has convergent and divergent intersection. In figure 3 b), a divergent intersection is shown. This
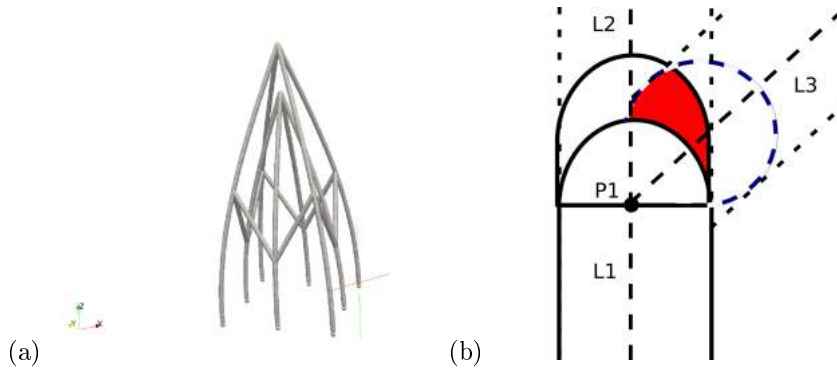
Fig. 3: (a) : A complex shape with many intersections; (b) : Example of overlapping material during a divergence
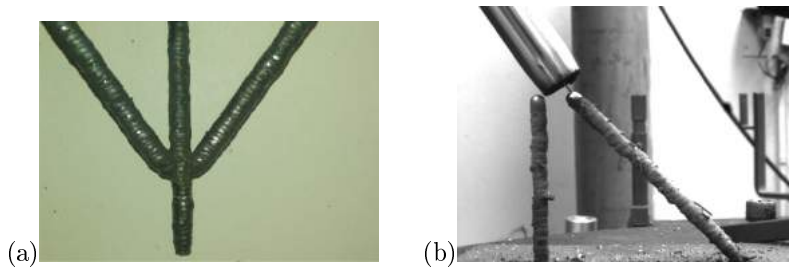

Fig. 4: (a) : Example of two divergent intersections polylines; (b) : Risk of collision during an experiment

is an intersection between 3 polylines (L1,L2,L3) at a point P1. The strategy chosen is to build L1 and L2 which have high priority and then to build L3. Because some material is already deposited, the quantity of material have to be decreased.

A module was developed to calculate this volume of intersection, and the slicer compute a new welding time in order to deposit less material. Indeed, the quantity of material brought to the system can be approximated as :

$$V_w = \frac{\pi . d_w^2}{4} . WFR . T_w$$

This approximation is true under the hypothesis that there is no loss of material by projection and that the WFR (wire feeding rate) value is accurate. With this, it is therefore possible to tune the welding time T_w. The calculation of the ratio is done with the formula : $NewT_w = AverageT_w * (1 - overlapping_\%)$ with : $AverageT_w$ the average value for welding time used in non-critical areas and $overlapping_\%$ the percentage of overlapping volume for the next deposition. The management of the ratio given a geometrical overlapping is then linear between 0 (no material deposited) and 1 (full sphere of material deposited). A result is shown in figure 4

The second type of intersection is convergent Fig.5 a). Due to priority of L1 it is not possible to add material on L2. The torch orientation has to be modified.

With all these properties, the slicer algorithm can be presented :

1. Initialization : first points are detected and push in points_to_build list
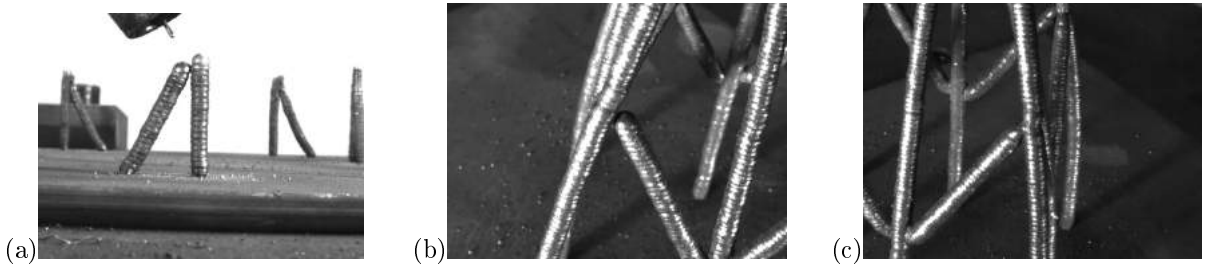
Fig. 5: (a): Strategy implemented to avoid intersection errors for deposition ; (b) : Intersection with a bad deposition (lack of material) ; (c): Intersection with a better filling

2. While points_to_build is not empty:

    (a) Detect point that have to be built (last_point)
    (b) Detect if Last_point is near an intersection to modify orientation and compute new welding time
    (c) Propagate new point in points_to_build with the increment step
    (d) Go to last_point and build it

Experimentation:

When applying this slicer to a welding example case, the developed code can give first a virtual simulation of the WAAM process in order to verify and ensure the correction of all intersection and trajectories. First, the orientation of the torch for the intersection has been implemented. On figure 5 the change of angle on close points from an intersection is represented. If the torch is in the normal direction for this polyline, the deposition would be made on the other polyline instead of where it is intended to be. The influence of this strategy can be seen on the two other pictures. The first one is without the correction, and we can see a lack of material between the two polylines. They are not bound by metallic material. When the strategy is implemented in the control, we can see that this gap is filled with metal and the connection between the two polylines is good.
Then the possibility of changing the increment between each layer was tested. As shown on figure 6, the height between each point is different in the two first pictures. Fig.6(b) shows an example of the possibility to change this increment on line, during the manufacturing.

Conclusions:
The CAM software presented in this paper is therefore adaptive and modular. In order to do that, some strategies were developed for intersections, and a possibility of tuning the welding time. We succeed in improving the overall geometry in intersection areas with theses modules, and now we have a adaptable tool which can be employed to implement a closed loop with instrumentation for the system and to control the geometrical characteristics of a build part.

References:

[1] Mueller S, Im S, Gurevich S, Teibrich A, Pfisterer L, Guimbretiere F, Baudisch P (2014) WirePrint: 3D Printed Previews for Fast Prototyping, UIST'14 5-8, 2014. https://doi.org/10.1145/2642918.2647359 (document)
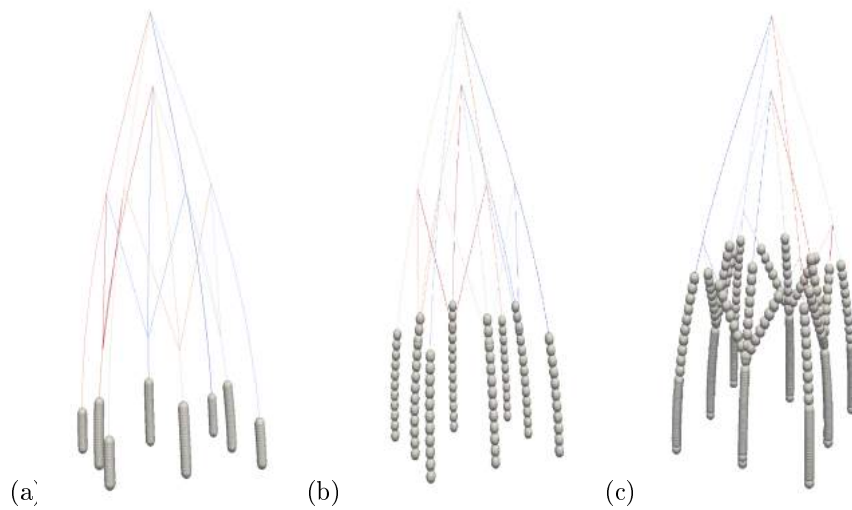
Fig. 6: Virtual model with : (a): Small increment ; (b) : High increment ; (c) : Variable increment

[2] Almeida,A.: Process control and development in wire and arc addictive manufacturing, Ph.D Thesis, Cranfield University, School Of Applied Sciences (2011-2012) (document)

[3] Heralic A, Christiansson AK, Lennartson B (2012) Height control of laser metal-wire deposition based on iterative learning control and 3D scanning, Optics and Lasers in Engineering 20 1230-1241 https://dx.doi.org/10.1016/j.optlaseng.2012.03.016
(document)