A SCALLOP-HEIGHT BASED ALGORITHM TO COMPUTE PARALLEL PATHS ON PARAMETRIC SURFACES

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Abstract. *The turbine blades are submitted a frequent erosion process called cavitation due to the action of water flow, its vortex, and the slow pressure created by the phenomena on blades surface. The cavitation are identified by a set of craters in the blades surface, generally mechanical damages that needs to be recovered, nowadays by a manual welding process. The ROBOTURB project is developing an automatized system, where a robot is used for recovery these damages, also by welding process. The recovery process requires material deposition by layers, and each layer are applied on the crater surface in accordance with welding parameters. The robot s end effector path must be gotten equally spaced, or mathematically parallel itself, in way to optimize the process related to the time and quality deposition. Considering that the eroded area and surface mathematically doesn't have a predefined shape, ones can use a freeform surface representation to represent it. From that local properties can be evaluated as well as to achieve the set of parallel paths on it. These paths are references to compute the robot inverse kinematics that will carry through the operation. This article presents a solution for the parallel path evaluation based in scallop height algorithms.. Also, through properties of the Bezier surfaces a solution for delimiting the erosion area is presented. All those parameter and algorithms variables are in accordance with parameters used on welding process.*

Keywords*: Parallel path planning, Differential geometry, Freeform surface, Bezier surface interpolation.*

1. INTRODUCTION

In general turbines blades have submitted an aggressive erosion due cavitation process created by interaction between water flow and surface blade. These aggressive mechanical damage process means that craters comes out and nowadays it has to be recovered by using manual welding process. The manual welding process consists in some steps like stop the turbines, preparing the area eroded and finally the recovery material is applied by layers. One layer is put on interposing the weld chord related with the former layers. It is a process performed in an unhealthful human workspace.

A proposal of using robot to replace human being operation was though to that recovery operation. It was called project ROBOTURB, where a robot was designed to operate in a confined workspace. Beside the robot design, two tasks needed to be planned to perform a damage recovery process on the blades: to measure the rotor blade eroded area, and after to plan and to perform the task to recover the eroded region by welding process.

As said before, the welding process is done by applying the material by layers, where each layer recovers all eroded surface in accordance with welding parameters (Bonacorso, 2004). The robot's end effector paths must be evaluated precisely meaning to be spaced equally on the surface, or in others words mathematically parallel (Sarma and Dutta, 1997) (Huang and Oliver, 1994). Like any manufacturing process it has to take in account the time optimization and quality of final surface recovering as goal in whole robot interaction process (Bobrow, 1985).

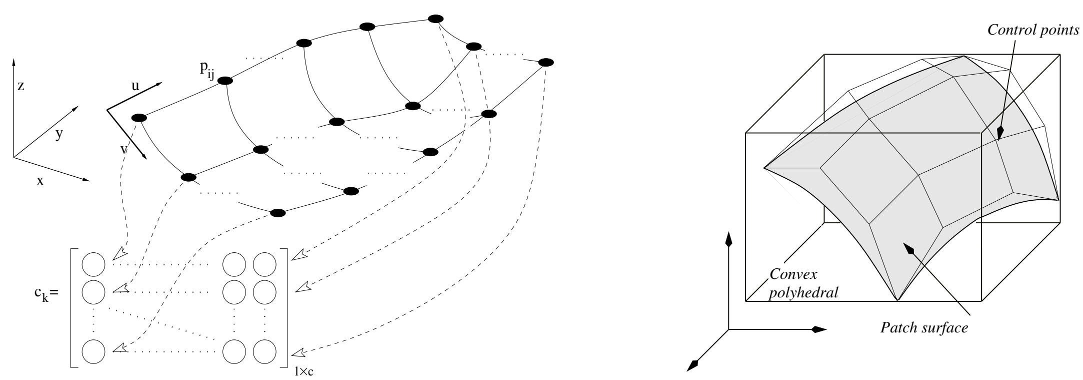
A first step is to evaluate the blade eroded surface and to compare it with the design surface. It is common to work with non documented design of those surfaces, because the turbine is very older or the drawing available are only in paper. So, the eroded surface doesn't have a mathematical defined shape explicitly, and some approximation method will be necessary to describe it. Thus, the first robot's task is to measure such surface that may be represented by a cloud of points. Such surface can be represented to task plan as wireframe shape by linking the points by lines, or yet as a set of triangle, or even by approximate as free form surface (Dragomatz and Mann, 1994, Tonetto, 2007). An approximate mathematical representation is a way to describe information about local properties on the surface point, and use them plan task thinking that the job has to be perform by a robot. In this research will be used a Bezier representation in order to describe the eroded surface and the steps necessary to recover it by welding process. Form path planning, end effector robot's trajectories can be obtained in order to its inverse kinematics.

This article presents a proposal for compute parallel trajectories based in scallop height algorithms applied in manufacturing environment by machines tools. Also, it will present how to use approximate surfaces by Bezier representation to delimitate the eroded area. The computation is done by using parameters in accordance with welding process operation.

2. SURFACE PATCH AND DATA POINTS ARRANGEMENT

The path planning operation takes in account that the paths to be followed by the robot's end-effector should be parallel themselves in the work space. So, the first step is to identify the eroded area contour from the data points set got by the measurement process. The measurement procedure gives a set of data points that may need to be ordered in order to be used to rebuild the blades surface.

In this research the set points data are organized in a matrix arrangement. The main strategy is to use each four data points from the matrix to model a surface patch. So, to implement a algorithm to simulate a surface rebuilding the matrix arrangement seems more appropriate at first, although other data set arrangement can be proposed (Tonetto, 2007). In this way, the original rotor blade surface will be represented by a set of patches organized in the matrix form. A patch of surface is given by four points. Each points has x, y and z coordinates on the Cartesian workspace. Thus, each point in a matrix is arranged in terms of matrix lines and columns indexes. And each element k on matrix c_k contains a vector representing a point data in terms of Cartesian coordinates. The net surface point and the coordinate matrix c_k. are depicted in the Fig. 1 (a).



(a) (b)

Figure 1. Net of points, its matrix arrangement and Bezier convexity property.

So, for each patch of surface is needed to defined a mathematical parametric representation. Among several different approaches, it was chosen one that provides the main property of convexity. The convexity property determines that all the Bezier curve, or Bezier surface, are contained in the its polygon or polyhedral formed by its control points, respectively, that are convex contours (Farin, 1992). In spatial curves, the convex contour is a closed polygon and in the patches of surface it is a polyhedral, also defined its control points. In the Fig.1 (b) depicted a Bezier patch inside of its polyhedral contour and showing the convexity property meaning (Qiulin and Davies, 1987; Farin, 1992).

In this research was selected Bezier patches to rebuild the surface, due to it has the convexity property appointed above and also, it approximates very well the erosion type and smooth shape commonly found in damaged rotor blades. However, other mathematical surface representation is also good to simulate this research goal.

The eroded area may be delimitate by a curve that can be computed by the intersection between two surfaces the reference (original surface) and the eroded surface. The reference surface is initially approximated by Coons surface (Farin,1992), which is given by a set of curves; the curves are computed from data points acquired in the measurement process. After, it is transformed in a Bezier representation in order to find and facilitated the intersection process developed in this research. The Bezier surface representation is also got by the set of points interpolated by using the Coons surface in the measurement methodology. From reference (original surface) and the eroded surface approximated surfaces a check method is used verify if both surfaces represent with fidelity surface shape, and so, certifying the measure process.

2.1. Defining eroded areas on the surface

The eroded area and the reference surface are rebuilt from set of data point, and now can be used to compute the curve limit between the damaged surface areas by erosion and not damaged are ones. The curve limit evaluation is an intersection problem among these surfaces. That curve will be used to limit the path to be followed by robot's end effector used to turn on and off the welding process, and also to compute precisely the length and distance between welding chord and layers to recovery the damaged area.

In this research is used a parametric bicubic surface representation to rebuild the surfaces from initial data point gets up as shown in the Fig. 1 (a) at beginning of this section. As said before, the surfaces are going to be rebuilt as a Bezier representation. A Bezier bicubic patch is used because it has mathematical properties assuring continuity C_0, C_1 and C_2 between two adjacent patches (Qiulin and Davies, 1987) (Zeid, 1991). These continuities are enough to compute precisely the parallel path on the surface from what the robot's trajectories are going to be evaluated.

The methodology to evaluate intersection between both surfaces explores the fact of each Bezier curves segment, and by extension the Bezier surfaces patch having the useful convexity property. It implies in to use the polyhedral that involves the surface to find where the intersection among the surfaces. So, the intersection problem will be computed iteratively by using Bezier surface subdivision and its respective polyhedral intersection.

Let's be S_{ua} and S_{ue} Bezier surfaces representation of reference and eroded surface. For each patch S_{ua} and S_{ue} a convex polyhedral is defined as result of the Bezier convexity property. So, instead of calculating directly the intersection between surface mathematically, here it will be used the convex polyhedral to detect intersection among the patches.

Let's be two polyhedral P_{aij} and P_{bsv} convex and belong to the patches *ij* and *sv* respectively, in matrix arrangement, where *ij* is related to S_{ua} and *sv* is associated to S_{ub}. By comparing the polyhedral position in the workspace may be identified if there is an interference between P_{aij} and P_{bsv}. So, if exist an interference between, the polyedral is replaced by boxes, and there are a chance to have intersection between them, also. Applying recursively this hypothesis over all patches of both surfaces S_{ua} and S_{ue} a raw set of polyhedral can be selected as intersected candidates.

To refine the search process will be applied to each surface a subdivision process and consequently each the polyhedral candidates has to be subdivided into order to get small polyhedral to each patch of both surfaces. These step results in two sets P_{Sa} and P_{Sb} that represents patches related to the intersection area. Patch subdivision are got by using the well known the de Casteljau algorithm (Qiulin and Davies, 1987). Each intersected patch produces four pieces of surfaces and each one are related a new small polyhedral. As the parameters of Bezier patch are always *0* to *1*, the value *0.5* can be used to subdivide the patch in both direction of parametric space. So, a recursively process can be applied successively until some threshold is reached, where the polyhedral is small enough to stop the recursion. After a set of iterations a set of boxes appears as shown in the Fig. 2, where each box represent a Bezier patch from the original Bezier surfaces.

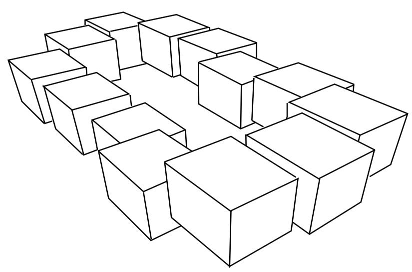
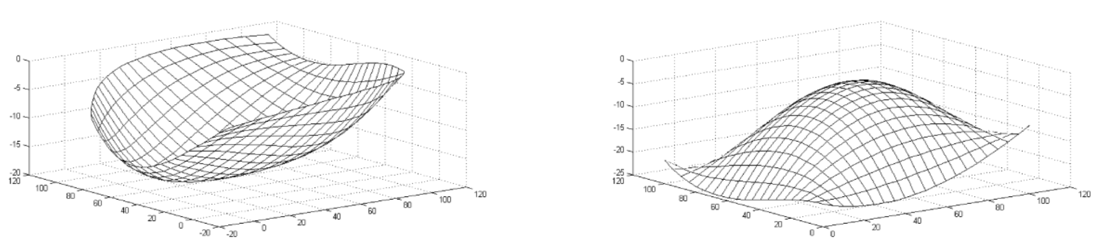


Figure 2. An illustration of iteration process by subdividing patches in terms of polyhedral.

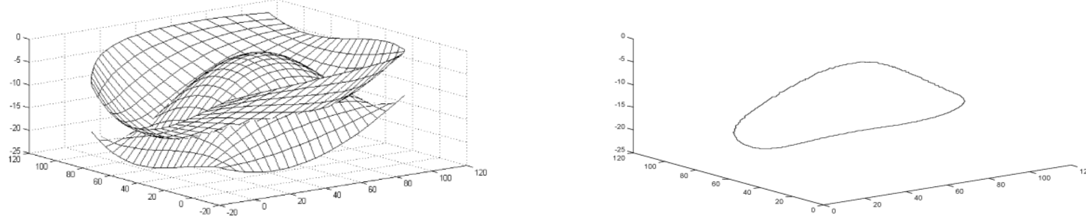
The recursion process can be stopped when the intersection between polyhedral converges to a plan (resulting in set of lines intersections between plans) or each polyhedral is small enough to be considered a point in the workspace. The set of point computed describes the intersection and, now they can be interpolated by curve representation in order to establish the intersection between two freeform surfaces, and so, the area limit of the crater on the surface.

Using the surfaces representation depicted in the Fig. 3(a) and Fig. 3(b) the method of patches subdivision was applied to them. The intersection between both surfaces is shown respectively in Fig. 4(a) and Fig. 4(b).



(a) (b)

Figure 3. An example of two Bezier surfaces patches.



(a) (b)

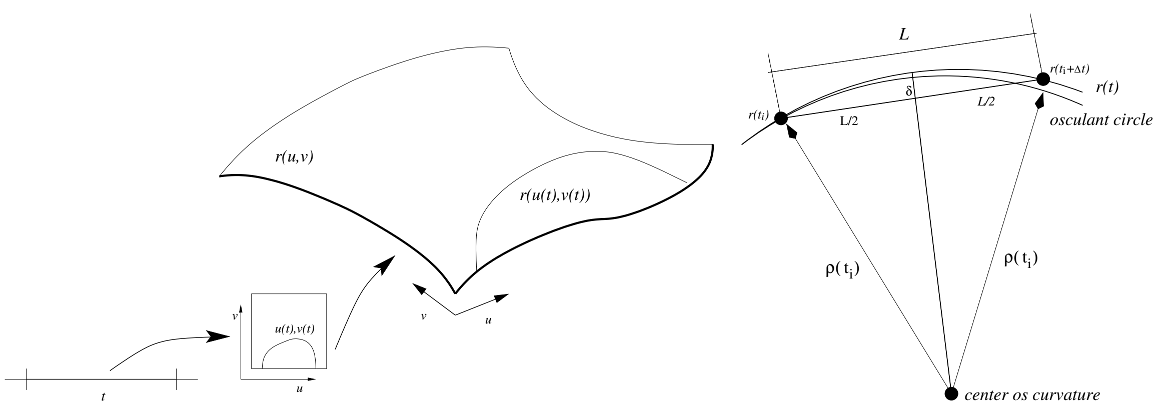
Figure 4. Bezier surfaces (a) and its intersection curve (b).

Therefore, applying recursively the method of subdividing patches all area eroded can be localized by this algorithm. It is necessary to identify all curves and to delimitate the area where the welding process have to perform to recover the surface at all. The next step is to compute the curve path that has to be followed by robot's end effector to accomplish the welding task.

3. DIFFERENTIAL GEOMETRY AND THE PARALLEL PATHS COMPUTATION

An optimized performance in the welding process is acquired mainly if the path to be followed by welding wire is parallel itself. It is desired when specification about surface finish needs to be accomplished in this manufacturing process. The parallel paths are computed by using differential geometry information got from curves and surfaces and its respective mathematical representation theory. It is based in a similar method applied to manufacturing process with 5-axis machine (Sarma and Dutta, 1997; Suresh and Yang, 1994; Loney and Ozsoy, 1987). Others methods to compute path on surfaces can be used (Tonetto and Dias, 2007), but here a precise method are going too presented.

Let's be S*(u,v)* a parametric surface (Farin, 1992) and let's be *r(u,v)* one initial path in the parametric space *u* and *v,* and now it is described in terms of new parameter *t.* The Fig. 5(a) illustrates the path curve and surface and the variables associated with the step forward on path.



(a) (b)

Figure 5. A path *r(u(t),v(t))* on the surface S*(u,v)* (a), and the manufacturing parameters (b).

An initial path *r(u(t),v(t))* will be the reference to evaluate a parallel path on the surface S*(u,v)*. Here, the parallel path is evaluated thinking in the robot's tip movement on the surface following the manufacturing parameters. The first computation refers to step forward; so, for each parameter *t,* a step value Δt is taken as function of the parameter δ**.** The parameter δ measures the error when the robot end effector gives a step along of path and surface.

Let's be $r(u(t_i),v(t_i))$ a point on the reference path. The next point $r(u(t_{i+1}),v(t_{i+1}))$ is computed by Δt, such as $t_{i+1}=t_i+ \Delta t$, like shown on Eq. (1):

$$\Delta t = \frac{2}{\| \dot{r} \|}\sqrt{\delta(\rho(t_i)-\delta)} \qquad (1)$$

where $\| \dot{r} \|$ is a $r(u(t_i),v(t_i))$ the unit tangent vector; $\rho(t_i)$ is the curvature radius on the point $r(u(t_i),v(t_i))$. The Fig. 5(b) depicted the relationship between the manufacturing parameters represented in Eq.(1).

Every terms in Eq.(1) is defined by surface and the path curve properties. The curvature radius $\rho(t_i)$ is obtained from the path curve curvature $k(t_i)$. The path curvature $k(t_i)$ comes out from the first and second fundamentals form of surface (Farin, 1992, Qiulin and Davies 1987). The first fundamental form (I) and the second fundamental form (II) of surface are written on Eq.(2) and Eq.(3), respectively, as follows.

$$I = \| \dot{r} \|^2 = (r_u \cdot r_u)\left(\dot{u}\right)^2 + 2(r_u \cdot r_v)\dot{u}\dot{v} + (r_v \cdot r_v)\left(\dot{v}\right)^2 \tag{2}$$

$$II = k\| \dot{r} \|^2 = n \cdot r_{uu}\left(\dot{u}\right)^2 + 2n \cdot r_{uv}\,\dot{u}\dot{v} + n \cdot r_{vv}\left(\dot{v}\right)^2 \tag{3}$$

where $\boldsymbol{n}$ is the normal vector on the surface; the terms of Eqs. (2) and (3) are calculated using the Frenet-Serret equations (Qiulin and Davies 1987); r_j is the $r(u,v)$ derivative related to j parameter, $\dot{u}$ and $\dot{v}$ is the u and v derivative related to parameter t.

In this way, the curvature $k(t_i)$ are now evaluated by dividing the second fundamental form by the first fundamental form of surface, resulting in $k(t_i) = {}^{II}\!/_{I}$.

The next step is to evaluate the lateral distance in the parallel path, which now is to be computed related the first path. The lateral distance and the step forward are computed again to each point on the surface, because the properties in each surface point will change according surface topology. Let's be $r_p(t_i)$ a point that belongs to the parallel path as showed in the Fig. 6. The lateral step that gives a parallel path is done by a value g. $r_p(t_i)$ is obtained enforcing two conditions: first, the vector linking the points $r(t_i)$ and $r_p(t_i)$ must be perpendicular to tangent $r(u(t_i),v(t_i))$; second, the norm distance between $r(t_i)$ and $r_p(t_i)$ must to be approximated by value g. The Fig. 6 illustrates the geometry necessary to compute a parallel path and where C is the center circle and R^* is the curvature radius, identical to $\rho(t_i)$.

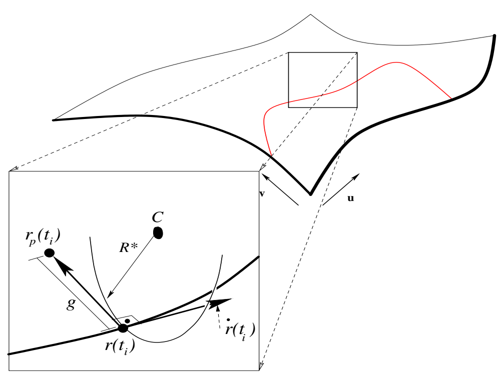


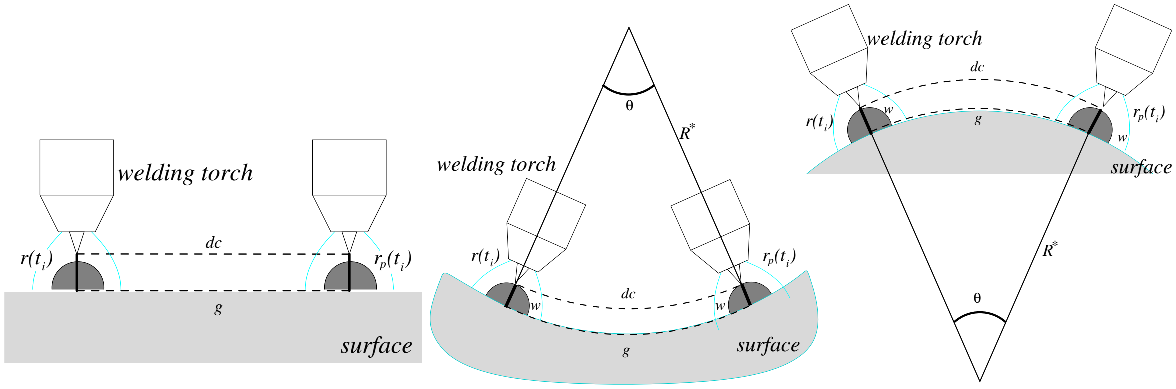
Figure 6. Geometric relationships to compute a parallel path.

The constraints imposed (Sarma and Dutta, 1997; Suresh and Yang, 1994) to have a parallel path are represented mathematically by Eq. (4), and is given by

$$\begin{cases} \left(r(t_i) - r_p(t_i)\right) \cdot \left(r_u \dfrac{du}{dt} + r_v \dfrac{dv}{dt}\right) = 0 \\ \left\| r(t_i) - r_p(t_i) \right\| = g \end{cases} \tag{4}$$

where the derivatives $r_u \dfrac{du}{dt}$ and $r_v \dfrac{dv}{dt}$ are computed in the parametric space u and v in terms at point t_i.

To satisfy the welding manufacturing parameters the g value can have different specifications according the distance among the welding torch electrode distance and the surface. The distance w are to be specified by the curvature radius R^* of surface. Let's be dc the distance between two welding chord paths. So, three different conditions can be computed to evaluate g: (a) the first conditions appears when the surface is quite a plane; in this case the curvature radius R^* of surface is near infinite; (b) in the second condition the curvature radius is considered positive; and (c) third condition the curvature radius is negative. Positive and negative sign can be computed in each point by normals to the surface. The Fig. 7 depicted the three manufacturing conditions to process a welding operation.



(a) (b) (c)

Figure 7. The g variation according the curvature radius $R*$.

So, the g value is can be evaluated taking the three conditions expressed in terns of the Eq. (5), as:

$$
\begin{aligned}
&g = dc && \text{to condition (a)} \\
&g = \frac{R*}{R*+w}dc && \text{to condition (b)} \\
&g = \frac{R*+w}{R*}dc && \text{to condition (c)}
\end{aligned}
\tag{5}
$$

Now, the $r_p(t_i)$ point is spaced parallel to $r(t_i)$. Taking the derivative to u and v is equivalent to derivative on $r(t_i)$, $r_p(t_i)$ can be approximated *by* using a expansion of the equation in Taylor series, as:

$$r_p(t_i) = r(t_i) + r_u \Delta u + r_v \Delta v \tag{6}$$

where du is approximated to Δu and dv is approximated to Δv.

By taking expression $r_p(t_i)$-$r(t_i)$ on Eq.(6), and replacing it in Eq.(4), the two fundamental form of surfaces results on a nonlinear equation system in term of Δu and Δv showed by Eq.(7) (Sarma and Dutta, 1997; Suresh and Yang, 1994).

$$
\begin{cases}
E\Delta u^2 + 2F\Delta u\Delta v + G\Delta v^2 = g^2 \\
E\Delta u\dfrac{du}{dt} + F\left(\Delta u\dfrac{du}{dt} + \Delta v\dfrac{dv}{dt}\right) + G\Delta v\dfrac{dv}{dt} = 0
\end{cases}
\tag{7}
$$

where $E=r_u.r_u$, $F=r_u.r_v$ and $G=r_v.r_v$ are the first fundamental, or metric, coefficients of the surface.

Solving the nonlinear equation system, the value Δu and Δv can be computed and are given by Eqs. (8) and (9).:

$$\Delta u = \frac{g\left(F\dfrac{du}{dt} + G\dfrac{dv}{dt}\right)}{\sqrt{EG-F^2}\sqrt{E\left(\dfrac{du}{dt}\right)^2 + 2F\dfrac{du}{dt}\dfrac{dv}{dt} + G\left(\dfrac{dv}{dt}\right)^2}} \tag{8}$$

$$\Delta v = \frac{-g\left(E\dfrac{du}{dt} + F\dfrac{dv}{dt}\right)}{\sqrt{EG-F^2}\sqrt{E\left(\dfrac{du}{dt}\right)^2 + 2F\dfrac{du}{dt}\dfrac{dv}{dt} + G\left(\dfrac{dv}{dt}\right)^2}} \tag{9}$$

These relations are appropriated to a g value sufficient small in relation to $R*$.

4. WELDING PARALLEL PATH ALGORITHM

The methodology to evaluate parallel path discussed in the last sections is implemented in an algorithm to simulate off line path planning evaluation for rebuilding an eroded surface by welding process. A pseudo algorithm is now presented to compute parallel path planning. It is depicted in Tab. 1.

Table 1. Pseudo algorithm to compute parallel path planning for welding process.

Pseudo algorithm to evaluate parallel paths

1. Get measurement data from laser sensor
    a. Define the Bezier surface representation to the eroded region
2. Compute the reference surface
    a. Define the Bezier surface representation reference
3. Evaluate the intersection surface and the welding limit
4. Compute the welding paths: by using parameter *dc* and by achieving the set of paths to accomplish the task
    a. From the first layer – layer 1, and until the intersection curve
        i. If the layer number is even
            1. Get the set of even paths and delimits them in the intersection limit
        ii. If the layer number is odd
            1. Get the set of odd paths and delimits them in the intersection limit
    b. Go to next weld layer, moving a layer distance - *cd*
    c. Return to step 4a.

The pseudo-algorithm shows the procedure developed in this research: it begins with the measurement process of the actual surface where a set of data point are obtained. Follows, the Bezier surface computation, and its intersections evaluation and finally the parallel paths are obtained. This algorithm was simulated by using a mathematical language, to develop the algorithm, with syntax like MatLab®, Octave® and SciLab®. The algorithm produces the images depicted in next Figs. 10(a), (b), (c), (d), (e) and (f). The figures show as the different layers of welding chord are evaluated. In the Fig. 10(a) are the first layers and the next layers are depicted in the Figs 10(b), (c), (d), (e) and (f) respectively. Simulation was programmed in agree with the following algorithm, using an eroded model surface (depicted on Fig. 8). Such curves can be translated to a language syntax appropriated to control manufacturing drivers or to a robot controller. However, each point in the surface is in the workspace area and has to be translated in adequate set of points in terms of robot's joint space.

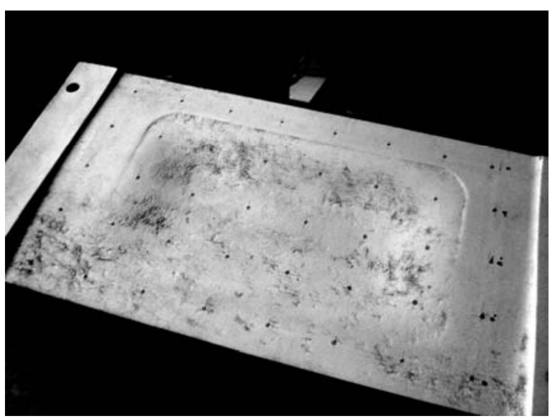


Figure 8. Real eroded surface model

The pseudo-algorithm presents a solution that was implemented in Roboturb manipulator and tested to certify the proposed path and trajectory planning methodology. By using welding manufacturing process specification the path evaluated was stored in files and a post-processed to calculate the robot join position, velocities and accelerations.

To compute the path interposing to the each layer the *dc* distance must be set to *dc/2*. From the computed paths are taking the odd paths to form the odd layer, and the even paths to form the even layers.

Defining the *dc* distance to *3mm* and layer distances *cd* to *3mm* we use a real eroded surface model shown in the Fig. 8.

Marking a set of points (shown in the Fig. 8) that completes a quadrangular patches over the surface, we use a laser sensor to measure these 3D points. Using Bezier algorithm the surface was formulated and the results were used to reference the welding algorithm. The Fig. 9 shows the formulated surface.

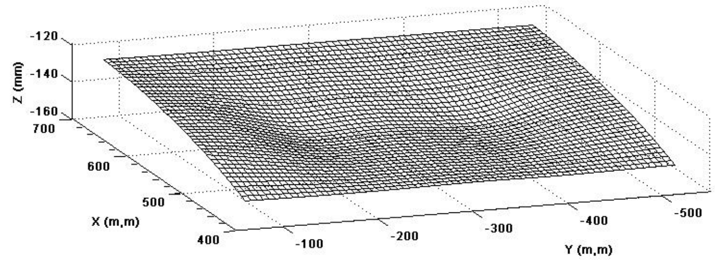
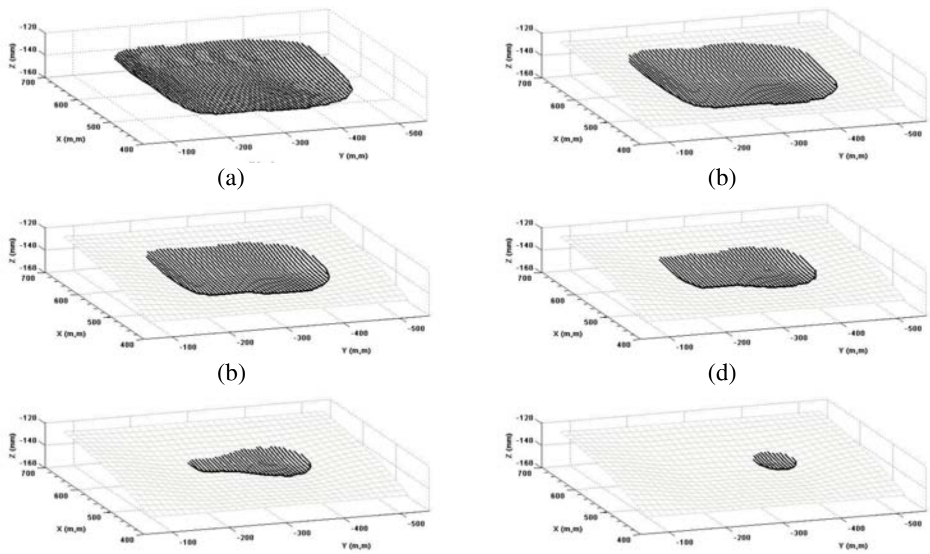


Figure 9. Formulated eroded surface

Applying the proposed solution, results in the six layers depicted in the Fig. 10.



(a) (b)

(b) (d)

(e) (f)

Figure 10. Parallel paths results to (a) first layer, (b) second layer, (c) third layer, (d) the fourth layer (e) fifty layer, and the (e) sixty layer

The layer interpose is obtained and the Fig.11 depicted the result to first and second layer.

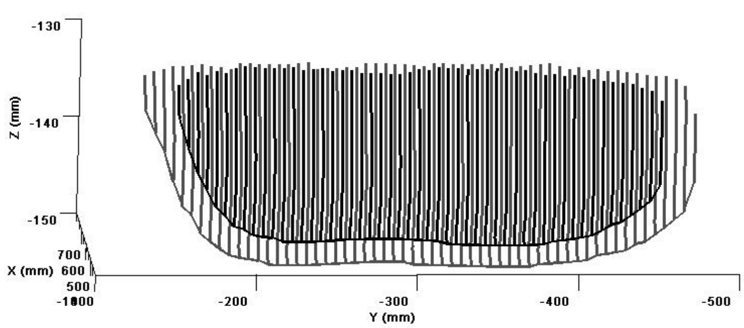


Figure 11. Interpose successive first and the second layers.

4.1 Loop on path

As any numerical method, the evaluated parallel path presents some error propagation when the surface properties are computed (Sarma and Dutta, 1997; Suresh and Yang, 1994). It can be shown that the approximation made in the measurement process to identify the reference surface as well as the surface topology used to represent the eroded surface interfere in the path evaluation on the surface. This interference refers to a tendency of appear loops on the path to certain conditions of derivatives on the surface. It will be called *loop on path*.

Depends strongly of surface properties given by E, F, and G, that are functions of first and second of derivatives properties on surfaces. An also, the value of lateral steps depends of some of those derivative in order to guarantee the parallel path. Therefore, for some conditions of step forward and lateral step, occurs the knot effect as shown in the Fig. 12. It can be observed on Fig. 12 the new parallel path keeping coherent with the reference path, exception at point P_1 and P_2, such as the respective parallel points P_{r_1} and P_{r_2} has as inverse direction.

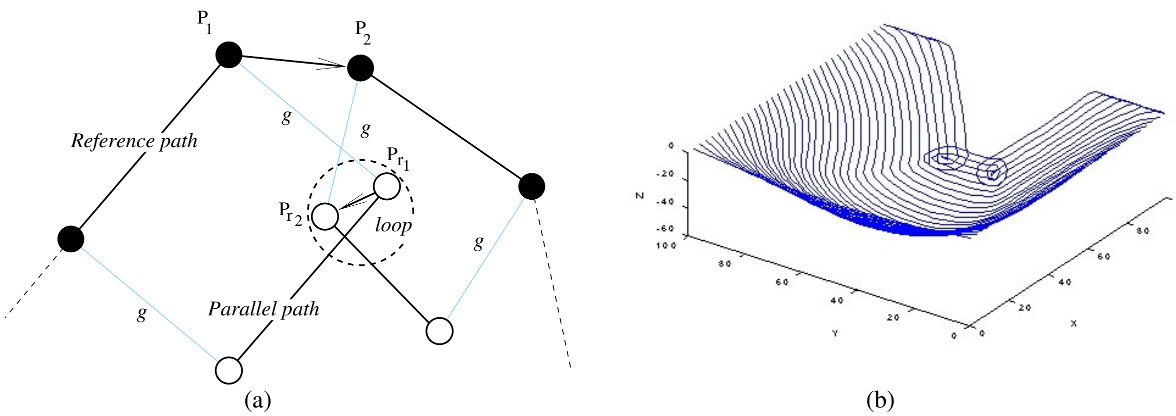


Figure 12. Knot effect rising and numerical simulation, (a) on detail and (b) result set of paths on the surface

If ones is thinking about a manufacturing process some conditions of surface topology can brings forth the loops on the path, and it has to be eliminated on path planning evaluation. Although, at first, one can try to identify the surfaces properties that could cause the loop on path, it was verified that a set of variable could interfere locally to it occur. Unfortunately, it was not solved or controlled precisely because several properties has influence in the loop rising on the surface and it was not possible distinguish accurately them in this research.

For that, it was chosen a heuristic approach to solve the loop effect on the surface. The heuristic approach proposed uses locally a cross testing to certify if a loop effect will occur for each step forward in the parallel curve. So, consider a new point $r_p(t_i)$ calculated on parallel path. The point $r_p(t_i)$ has a point (u_i, v_i) on parametric plane, such as makes a line segment l_i. If the line segment l_i crossing with another line segment of the parallel path parametric points, for example the segment l_j, this will imply on a path loop over the surface. The point that produces the loop is eliminated, by deleting it as path point; the set of point from the array position j to i-1. The Fig. 13(a) presents the l_i and l_j crossing and the set of points to be deleted.

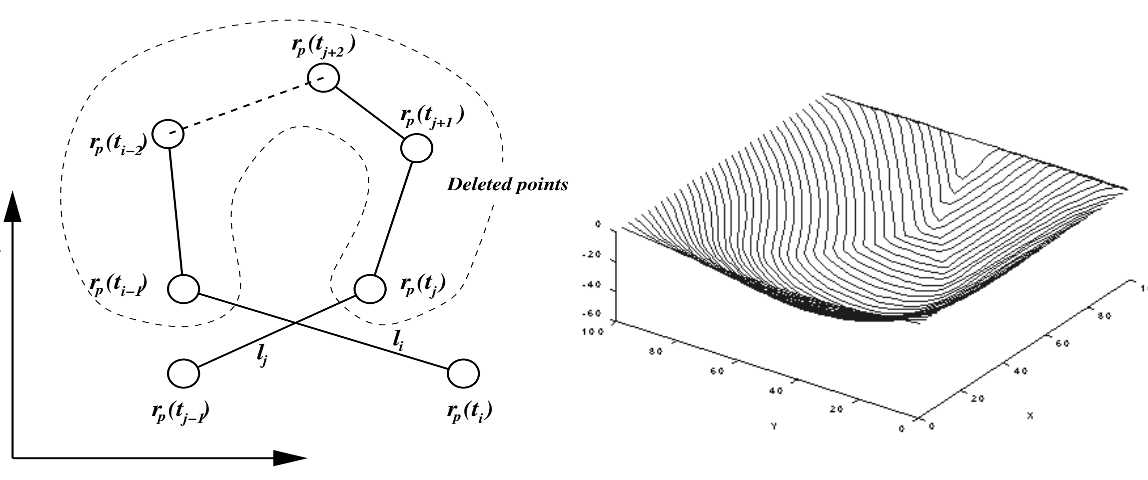


Figure 13. (a) l_i and l_j crossing on parametric space, and the set of points to be deleted, (b) final set path from simulation

The point elimination don't affect the precision on path, because in the local area where a loop could appear the step is small enough and its elimination still keeps the paths to be corrected evaluated. The Fig. 13(b) shows an image of this implementation, eliminating the loop effect initial shown in Fig. 12

5. CONCLUSION

This paper presents a methodology to compute parallel path planning for robot manipulators based on scallop-height criteria.

This methodology includes the selection of a mathematical surface to represent a given cloud of points, the computation of the eroded area limit, and an algorithm to compute robot paths on the surface inside this work region. The paths are parallel themselves on the work surface.

The proposed methodology was tested experimentally. A practical experiments was made in laboratory with Roboturb manipulator to verify the proposed algorithm and its efficiency. The welding process was simulated by robot manipulator using a pen tool, that trace a path on a surface following the parallel path planned as showed in paper text. The result was submitted only by visual inspection by welding team in order to see if the parallel path had the same behavior as planned in advance. They have approved the new methodology.

The parallel path written on the surface outlines the usefulness of the whole methodology, once the proposal algorithm improve and became the path planning process faster, when compared with the methodology applied before it. The perspective is to make real experiment in the Robótica laboratory and after over turbine blades on hydraulic plants.

In the future, a complete programming environment that include obstacles in the workspace has to be developed in order to improve and give continuity to the present research.

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7. REFERENCES

Bobrow, J. E., 1985, "Solid Modelers Improve NC Machine Path Generation Techniques" ,Computers in Engineering, 1, 439-444.

Bonacorso, N.G., 2004. "Automatização dos Processos de Medição de Superfícies e de Deposição por Soldagem Visando a Recuperação de Rotores de Turbinas Hidraúlicas de Grande Porte", Tese de doutorado, Universidade Federal de Santa Catarina.

Dragomatz, D. and Mann, S., 1994, "A Classified Bibliography of Literature on NC Milling Path Generation", Computer-Aided Design, 29, 239-247.

Farin, G., 1992, "Curves and Surfaces for CADG: A Pratical Guide", Academic Press Inc. 3d edition.

Huang, Y. and Oliver, J.H., 1994, "Non-constant Parameter NC Tool Path Generation on Sculptured Surfaces" International Journal of Advanced Manufacturing Technology, 9, 281-290.

Loney, G.C. and Ozsoy, T. M., 1987, "NC Machining of Free Form Surfaces", Computer-Aided Design, 19, 85-90.

Qiulin, D. and Davies, B. J., 1987, "Surface Engineering Geometry for Computer-Aided Design and Manufacture", Ellis Horwood Limited.

Sarma, R. and Dutta, D., 1997, "The Geometry and Generation of NC Tool Paths", Journal of Mechanics Design, 119, 253-258.

Suresh, K. and Yang, D.C.H., 1994, "Constant scallop-height machining of free-from surfaces", Transactions of ASME, 116, 253-259.

Tonetto, C. T., 2007, "Uma Proposta de Sistematização do Processo de Planejamento de Trajetórias para o Desenvolvimento de Tarefas de Robos Manipuladores", Dissertação de Mestrado, Universidade Federal de Santa Catarina.

Tonetto, C. T, Dias, A., 2007, "Rebuilding Surfaces Through Voronoi Diagram", FAIM2007 - 17th Flexible Automation and Intelligent Manufacturing, pp 158-165, Philadelphia, USA.

Zeid, I., 1991,"CAD/CAM theory and practice", Mac-Graw Hill.

8. RESPONSIBILITY NOTICE