UTD asymptotic code used for antenna implementation on electrically large structures

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Introduction

The implementation of antennas in a complex environment still remains a problem when high frequencies are considered [3]. The Uniform geometrical Theory of Diffraction (UTD) is one of the most convenient techniques to solve this problem [1,2]. This method is applied in the software IDRA developed at IEEA.

Compared with other methods, the UTD has some interesting advantages. It is an efficient tool to understand the phenomenology because the global field results from localised contributors. For example, the cause of a high value of field can be geometrically identified. In addition, the computational time is reduced. It is frequency independent and enables the software to handle electrically large structures.

After a description of the geometries handled and the ray tracing methods used, an application of the UTD code for antenna positioning is presented.

1. Structure Geometry

In IDRA, the structure geometry isn't meshed. It is based on NURBS curves and surfaces, which are imported from common CAD formats, like for example IGES or CATIA. NURBS allow an accurate description of any arbitrary shape. The surface curvature is easily derived. It is an important parameter for UTD coefficients computation.

NURBS is the short word for "Non Uniform Rational B-Spline". It is a parametric representation of a 3D curve or surface that needs coordinates of control points ($\mathbf{p}_i$ or $\mathbf{p}_{ij}$), weights for each control point (w_i or w_{ij}) and B-spline basis functions ($B_{i,j}$):

For a curve :

$$\mathbf{c}(u) = \frac{\sum_{i=1}^{n} \mathbf{p}_i w_i B_{i,k}(u)}{\sum_{i=1}^{n} w_i B_{i,k}(u)} \qquad (1)$$

For a surface :

$$\mathbf{s}(u,v) = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \mathbf{p}_{ij} w_{ij} B_{i,k}(u) B_{j,l}(v)}{\sum_{i=1}^{m} \sum_{j=1}^{n} w_{ij} B_{i,k}(u) B_{j,l}(v)} \qquad (2)$$

The control points define the main shape of the curve. The weights define how much a control point is influent : the higher the weight is, the nearer from the control point is the NURBS. It appears to be a very flexible way to describe a structure. Figure 1 presents some examples of structures described with NURBS. In these examples, very few NURBS surfaces are needed to describe complex geometries.

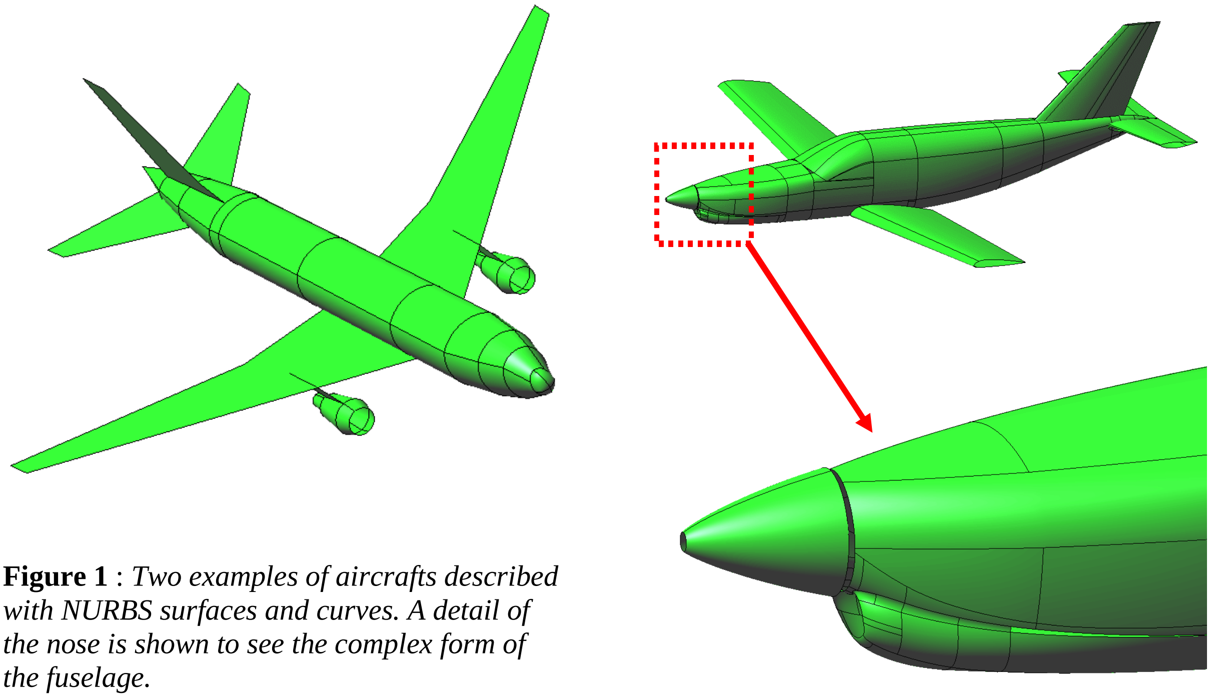

Figure 1 : *Two examples of aircrafts described with NURBS surfaces and curves. A detail of the nose is shown to see the complex form of the fuselage.*

2. Ray Tracing

Once the environment is geometrically described, the software can start the calculation. It is a two steps calculation :

- The first is ray tracing. Given a source point S and an observation point P, the software has to find the interaction point Q on the structure element. This step is repeated for each structure element. In addition, a visibility test is performed to exclude rays intercepted by another structure element.

- Once the interaction point is found, information about angles and curvatures are gathered to compute the UTD coefficients and the corresponding field [2]. The details of the UTD coefficients will not be explained here. They are directly derived from classical results [1,2,4].

The following simple ray contributions are taken into account in the computation : incident ray, reflected ray, diffracted from edges or corners, diffracted from curved surfaces, or also called creeping rays. Higher order contributions are also computed : doubly reflected, doubly diffracted from edges, reflected and diffracted from edges, or diffracted from edges and then reflected by surfaces, the same with corner diffraction.

For simple shapes, the ray tracing is straightforward. The Descartes-Snell laws can be directly applied to find the reflection point on a plate surface. The Keller's cone properties are used to compute the position of the diffraction point on a straight edge. The laws are still true for any shape, but they aren't easy to implement on arbitrary geometries.

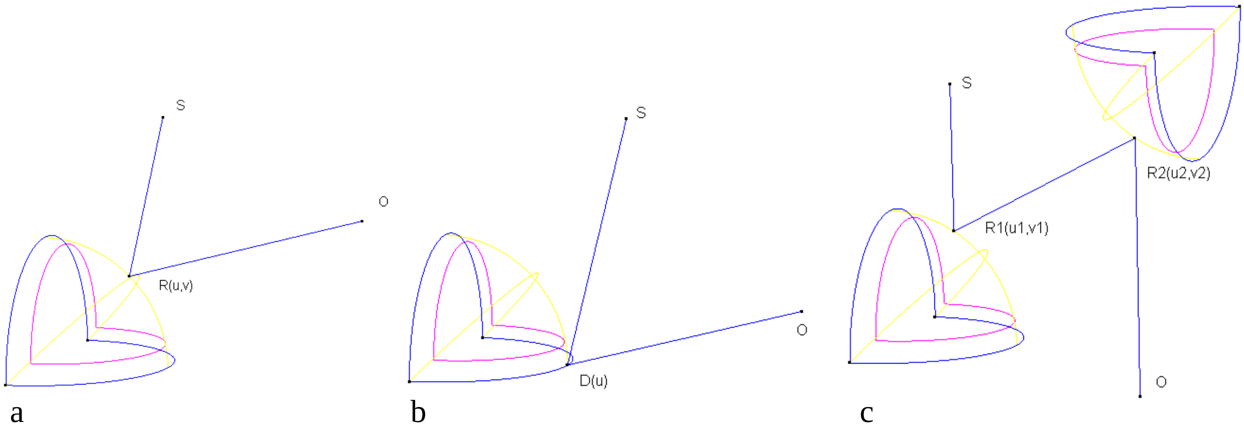

Figure 2 : *ray tracing on arbitrary NURBS curves or surfaces : simple reflection (a), simple diffraction (b), double reflection (c).*

The ray tracing method used on arbitrary shaped NURBS will be explained for the case of reflection. The geometry is presented in figure 2a. The total length of the ray path from source S to observation O (incident ray + reflected ray) depends on the position of a point R on the NURBS surface. This point follows the NURBS parametric equation. That’s why the length is a function of two parameters (u, v). According to Fermat’s Principle, the reflection point is found when the length reaches an extremum. A conjugate gradient routine is used to compute the parameters u and v minimizing or maximizing the ray length.

The method can be generalized to all interactions. In figure 2b, the position of the diffraction point depends on only one parameter u defining its position on the NURBS curve. This parameter is found by minimizing or maximizing the ray path length. The same technique is used to compute doubly reflected rays (figure 2c). In that case, four parameters have to be found to localize the two reflection points. It is not difficult to extend the method to all interactions, except one : the creeping rays.

A creeping wave propagates on a surface along a geodesic path. The ray tracer has to find a whole curve and not only a finite number of points. The geodesic path is described by equation 3 on a parametric surface. Equation 3 allows finding a relation between parameters u and v of each point on the creeping ray. This relation involves the Christoffel Symbols depending on the surface curvature.

$$\frac{d^2v}{du^2} = \Gamma^1_{22}\left(\frac{dv}{du}\right)^3 + \left(2\Gamma^1_{12}-\Gamma^2_{22}\right)\left(\frac{dv}{du}\right)^2 + \left(\Gamma^1_{11}-2\Gamma^2_{12}\right)\left(\frac{dv}{du}\right) - \Gamma^2_{11} \quad (3)$$

For simple shapes, the geodesic paths may be easily computed : on developable surfaces (cylinders or cones), they are straight lines; on spherical surfaces, they are great circle. But for an arbitrary shaped geometry, equation 3 must be solved numerically. In IDRA, the ray tracer uses a Runge-Kutta solver. Figure 3 present an example of solution of equation 3 in the case of a source point and an observation point placed on a piece of fuselage.

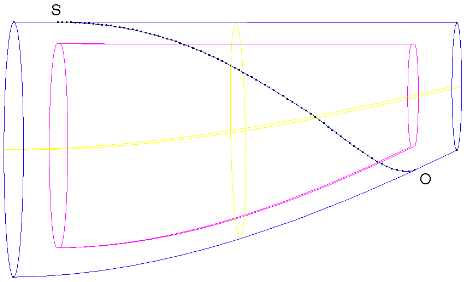

Figure 3 : *geodesic path computed from a source S to an observation point O located on a curved surface*

3. Application : Antenna implementation

Once the rays are traced, the UTD coefficients are applied to compute the electric field. Figure 4 presents an example of output : the far field radiation pattern of an antenna near diffracting structures. Other outputs can also be provided like near field maps or coupling matrix. These values are important parameters for antenna design and may be highly dependent on the antenna environment.

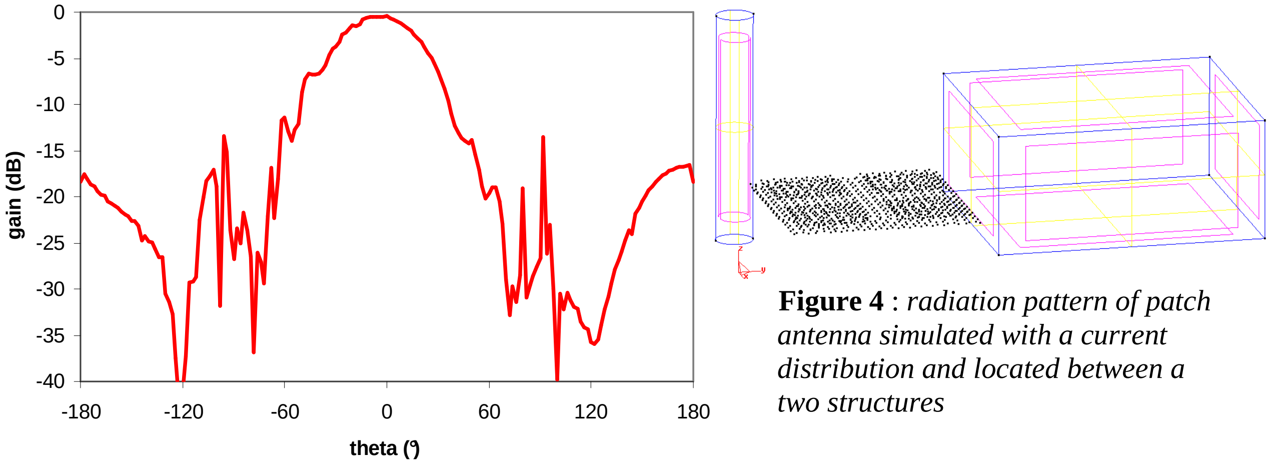

Figure 4 : *radiation pattern of patch antenna simulated with a current distribution and located between a two structures*

As the computation speed is very high, many iterations may be done in limited time. This feature makes the software very suitable for optimisation routines. The input of the problem is the position of the antenna. The cost function is the difference between the parameter to reach and the computed value of this parameter. For example, the cost function may be the difference between the free space radiation pattern and the computed radiation pattern. In that case, the aim is minimizing the influence of the environment. In other cases, the aim may be using the environment to reduce the coupling between two antennas.

As the gradient of the cost function is not known the optimisation routines can only use the cost function value. However, the gradient may be computed by finite differences. An interesting class of optimisation methods is the genetic algorithms (or other related stochastic methods). There are usually very few information on the cost function. In addition, this function may have several local extrema. The genetic algorithms are able to manage this situation.

Conclusion

As a conclusion, the software IDRA based on UTD provides an efficient solution for fast evaluation of the radiation pattern of an antenna mounted on an electrically large carrier, or of the coupling between two antennas in a complex environment. Coupled with a set of optimisation utilities, it is an optimal tool for antenna implementation on structures.

References

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