CHARACTER LINE SCKETCHING FOR CONCEPTUAL DESIGN IN VIRTUAL REALITY

Michele Fiorentino, Giuseppe Monno, Pietro A. Renzulli, Antonio E. Uva

Abstract

Commonly, during the aesthetic design process, stylists sketch features called character lines over a simple and "uninteresting" geometry (e.g. a car bonnet) in order to confer personality, emotional feeling and style. This work presents an original interface paradigm for character line sketching in a virtual reality environment. Taking advantage of the 3D interface, the feature path, also called leading line, can be directly sketched on the initial surface by real-time projection. Afterwards, a semi-transparent section is selected along the path in a interactive way and then the feature profile is sketched on this plane according the user's intention. Subsequently, by moving the virtual pen forwards along the path, the character line is generated, on the contrary if the pen is moved backwards the feature is partially erased. The distance of the virtual pen from the leading line controls, in real time, the offsetting along the path of the feature which remains consistent in style and identity. Such a system has been proven to be a powerful tool for fast expression and evaluation of ideas, which can be, in subsequent design phases, integrated with detailed surfacing applications and prototyping.

Keywords: Feature-based design, constrained-based design, parametric modelling, curve and surface design

1. Introduction

In today's global market, the aesthetic aspect of products is becoming fundamental for their commercial success. Conceptual aesthetic design is becoming critically important since it provides *"the added value"* to a product which faces competition from similar goods with comparable prices and functions. In addition, the availability of new materials and manufacturing technologies make the fabrication of very complex shapes possible, thus providing greater freedom to the designers' activity.

However, the creativeness of the designer is not supported at present by CAD software systems because their interfaces do not allow quick and intuitive representation and modification methods, which are necessary for the fast and complex mental processing of a conceptual idea. Hence in common practice, the conceptual sketches are created with pencil and paper and are successively digitised into free-form parametric representations using traditional CAD systems. These surfaces are defined in terms of low level entities, such as control points (CPs), knots and weights, which require a certain mathematical knowledge in order to manipulate them. Moreover adding or changing small details can entail a large amount of work and may even lead to a total remodelling of the object.

Although the concept of regular shaped *feature* has already been introduced in mechanical modelling, *free-form features* have only recently become object of study. This kind of

features associate functional, aesthetic or manufacturing meaning to specific groups of topological elements (faces, edges, vertices) of free-form surfaces. This provides the user with an easier control of the geometry, improves modelling and offers fast evaluation of different design solutions. Among these features, the *character line* is often found in conceptual design sketches (Figure 1). This type of feature is characterized by a local surface substitution along a path of the modelled surface.
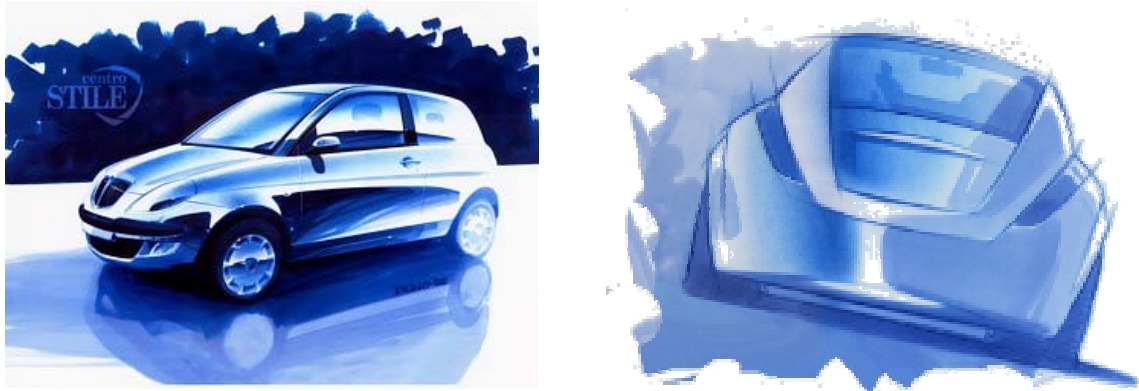

Figure 1.   Conceptual sketches and character lines (Courtesy of Centro Stile Fiat)

Character lines, although not structural elements, strongly affect the aesthetic perception of the object, conveying "smoothness, softness, aggressiveness" or even a "personality" common to a group of products of the same company. The use of these features has required a study of their taxonomy [1] [2] and a definition of parameters which describe them in a simple and intuitive manner as opposed to their native low level geometric parameters (CPs, weight and knots).

Although various approaches to feature modelling have been developed, very few interfaces have been implemented for interactive application of free form features within a CAD system. In fact most of the systems make use of a 2D interface for the feature parameter definition such as dialog boxes and sliders.

Virtual Reality (VR) techniques, besides providing a better perception of three-dimensionality and natural 3D interaction, also provide the possibility of developing interfaces for an intuitive real time feature parameter definition.

The aim of this work is to develop an interactive character line sketching tool and integrate it in Spacedesign [3], which is a VR based conceptual design application. With this tool the user should be able to control the feature parameters in a intuitive way by simple sketching in 3D space.

2.   Related work

Many approaches have been pursued for free-form surfaces modelling. In most cases the authors have tried to reduce the surface definition and modification parameters to a more manageable form. Although some of these methods were created for global surface control, their influence can be reduced to a restricted area in order to obtain local shape modification such as character line modelling.

Forsey and Bartels [4] use Hierarchical B-splines to add details via overlays that locally refine the surface shape. Local modification can be achieved by increasing the number of CPs in a certain region and displacing them accordingly. This method does not reduce or simplify the

geometric parameters, but on the contrary can lead to difficult surface control and explosion of CPs.

Qin and Terzoupoulos [5] have developed D-NURBS, an effective physics-based model which produces shape variation of NURBS surfaces in response to applied forces. Lagrangian mechanics of an elastic surface, finite element analysis and iterative numerical methods formulate the model. Physical variables such as mass, damping and elasticity are associated to geometric parameters, such as control points and weights, allowing interactive sculpting and direct manipulation of the surfaces. The algorithm is implemented on an SGI workstation, but no details are provided of how the user actually applies the 'sculpting forces' and how the physical parameters and constraints are entered.

Guillet and Leon [6] use an interesting analogy between the CPs polyhedron of the surface and a bar network of pin jointed rigid bars. The joints can be free to move without friction or can be constrained by the user. An external force, simulated by moving a plane tangent to a reference point, deforms the free-form surface. By keeping the reference point fixed or free to move, the influence of deformation can be controlled. Also, force density distributions simulate isotropic and anisotropic deformation for local or global surface modification. This method is implemented with a 2D interface, but the interaction technique to set the governing parameters is not fully described.

3DIVS by Fiorentino et al. [7] is a two-handed, gesture-based NURBS modeller in a semi-immersive environment. The workspace is composed of a stereo display, magnetic trackers and Fakespace Pinchgloves for gesture recognition. Three different virtual tools, the Picker, the Twister and the Weighter, modify positions and weights of the lattice's control points. The distance between the hands controls in real time the spatial influence of the tools. This system is appropriate for character line modelling only if the control point lattice is aligned along the feature path and if the number of CPs is sufficient for the shape representation.

Recently, feature-based approaches have been introduced. De Martino et al. [8] develop and implement an algorithm to generate character lines on a surface using ACIS [9] [10] as modelling kernel. Four main parameters are selected to influence character line definition: the path of the feature, the depth which can be negative (intrusion into the surface) or positive (extrusion out of the surface), and two distances, representing the width, which can be used to give the feature a non symmetric shape. The user's interaction paradigm is based on a traditional desktop interface.

Van Elsas and Vergeest [11] propose a procedure for modelling displacement features such as protrusions or depressions. The authors define three main components for this feature: the original base surface, a displaced surface and a transition surface that joins them. The main parameters identified to describe the feature are: the dimensions of the displaced surface, the height of the displacement, the slope of the transition surface and the type of rounding (blending) between the surfaces. The interface which controls these parameters is represented by dialog boxes and slider bars on a traditional desktop configuration. G0 continuity between the transition surface and the other two surfaces is approximated in real time. The fact that displaced surface is always a partial instance of the base surface, limits the variety of the possible generated geometries.

In conclusion, in this section we have described various approaches for local surface modification with which it may be possible to obtain character lines. They mostly focus on the analytical approaches and not on the interface and interaction techniques. However in a conceptual design environment a direct method for defining the modelling parameters is still required. This work aims to give a original contribution in this direction.

3.   The virtual environment: Spacedesign

Spacedesign is an experimental Mixed Reality (MR) application addressed to the aesthetic design of free form curves and surfaces. The main goal is a faster design workflow and CAD data consistency via an integrated solution from concept design to mock-up evaluation. The conceptual design phase benefits from a VR environment for 3D free hand sketching, surfacing and visualization. In the mock-up evaluation phase semi-transparent stereo glasses in an Augmented Reality (AR) setup are used to over impress the digital model to the pre-production physical prototypes, in order to add corrections, additional shapes, textures and annotations. Both of these system configurations share a common interface and functionalities. Spacedesign is built upon the Studierstube library [12], for the AR/VR interface, and upon ACIS as a modelling kernel [1]. The so-called *"Pen and tablet"* metaphor is used for VR interaction: the non-dominant hand holds the transparent palette on which menus and buttons are displayed, the other handles the pen for application-related tasks.

Spacedesign supports many virtual reality 3D visualization systems by means of a simple configuration file: active and passive stereo, vertical and horizontal screens, see-thru glasses and head mounted displays (HMD). Moreover, most of the commercially available 3D tracking devices can be easily integrated in the system using the OpenTracker platform [13]. For this specific application, we used a horizontal screen, active stereo display and ART dtrack optical trackers [10] (Figure 2).
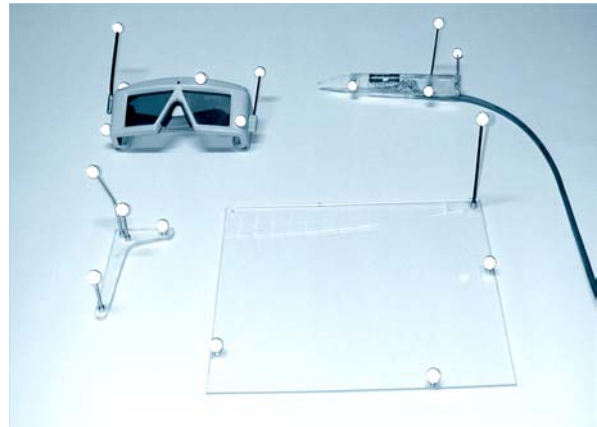

Figure 2.   The virtual Workspace

Figure 3.   The interaction devices

Four wireless tracked devices are used: the glasses, the pen, the palette and the so-called "Navigator Axis" (Figure 3). The glasses are used for the user's head position tracking and for the stereoscopic three-dimensional vision. The pen is the main interaction device and is provided of 3 buttons. The palette is a Plexiglas sheet and can be used by the user to retrieve information and to display the virtual menus and buttons. The "Navigator Axis" is a L-shaped transparent tracked body virtually connected to the position and orientation of the user's modelling coordinate system. The user can hold the Navigator Axis in his dominant hand for precise scene navigation or in the non-dominant hand as a reference frame during the sketching phase. Its particular shape allows immediate top, front and side views of the scene by simply laying it on a flat surface accordingly.

4. Methodology: The character line feature sketch tool

The most intuitive way to design features in the virtual environment is to directly deform the surface by means of tools like magnetic attractors, pinch etc. Unfortunately the high number of degrees of freedom left to the designer, added to the lack of tactile feedback, makes this process highly imprecise even for conceptual design. As a consequence we developed an approach that involves a limited number of parameters for a more manageable character line modelling.

According to the topological taxonomy presented in Fontana [1], we classify the character lines as "detailed features" which create more complex shapes by affecting a region of the original surface. Among these local modifications, we consider a subset which involves the substitution in the *primary surface* (the original unmodified geometry) of a *influence area* (the primary surface region to be modified) to create the new resulting *characterized surface* (transformed surface).The character line feature belongs to a set of *channel operations*, which are described by a path, called *leading line*, along which the feature is created. We identify the following as the main parameters for the character line feature definition: leading line, main cross section (MCS) plane, MCS profile and a depth function. Hence we define a character line design technique which is the result of several steps.

4.1. Leading line definition

The *leading line (ll)* is an important element of the feature because it "drives" the shape of its geometry along the surface. In this first phase the user traces a *ll* curve by moving the pen in 3D space close to the surface. This 3D free-hand curve is automatically projected onto the surface in order to insure that the *leading line* belongs to the *primary surface* (Figure 4).
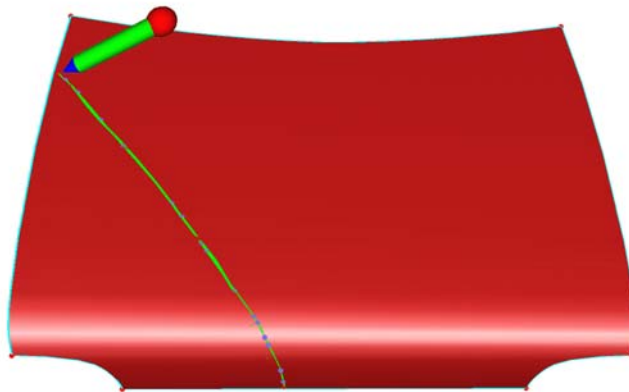

Figure 4. A surface with the projected leading line

4.2. Main Cross Section Plane definition

Once the *leading line* is defined, a semi-transparent plane is displayed. This plane passes through the nearest point between the virtual pen's actual position and the *leading line,* and it is oriented with its normal aligned with the direction of the *ll* at such point (Figure 5).
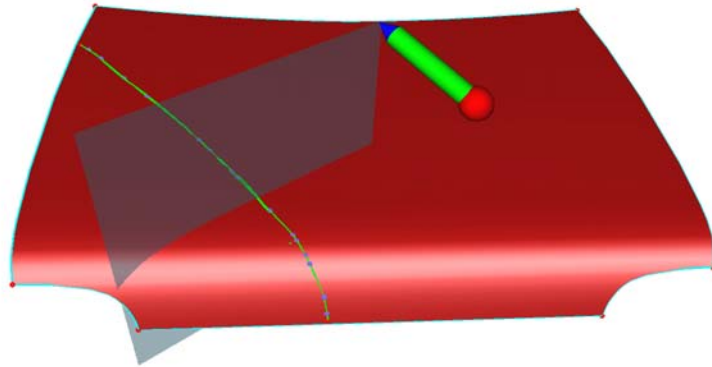
Figure 5.   The main cross section plane

The user by moving the pen in 3D space, can slide the semi-transparent plane along the *ll* to view the resulting intersection with the *primary surface* and to determine the best position to place the *Main Cross Section Plane.*

4.3. Main Cross Section Profile

The user is now asked to input on the *Main Cross Section Plane* the profile of the feature, the *Main Cross Section Profile*. He/she can perform this task in two different ways:

-   selecting a preloaded profile from a database;

-   free-sketch the profile in 3D space on the *Main Cross Section Plane*; the pen position is projected onto the plane in real time (Figure 6).

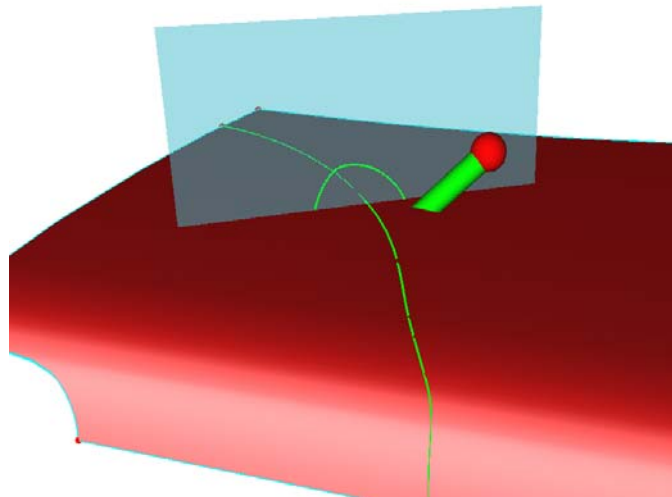In both cases the generated MCS profile is represented as a NURBS curve.

Figure 6.   MCS Profile sketched on the MCS plane

4.4. Depth function

The depth function is the quantitative expression of the influence of the feature profile along the *leading line*. In other words it represents the algebraic amount by which the MCS profile is scaled along the *ll*. A positive value of this function represents an extrusion (i.e. the *characterized surface* lies on the semi-space pointed by the normal of the *primary surface*)

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while a negative one corresponds to an intrusion into the surface. For each point along the *ll* a corresponding value of the depth function is associated.

In our approach, the depth function is defined interactively by the user by moving the virtual pen in the virtual space. As soon as the MCS profile has been defined, the distance between the last point of the MCS profile and the intersection between the MCS plane and the *leading line* is stored as the constant d_{mcs} (Figure 7). Given the actual pen position, the depth function is defined as the ratio between the minimum distance between the pen tip and the *ll* and the the constant d_{mcs}, as shown in Equation (1).
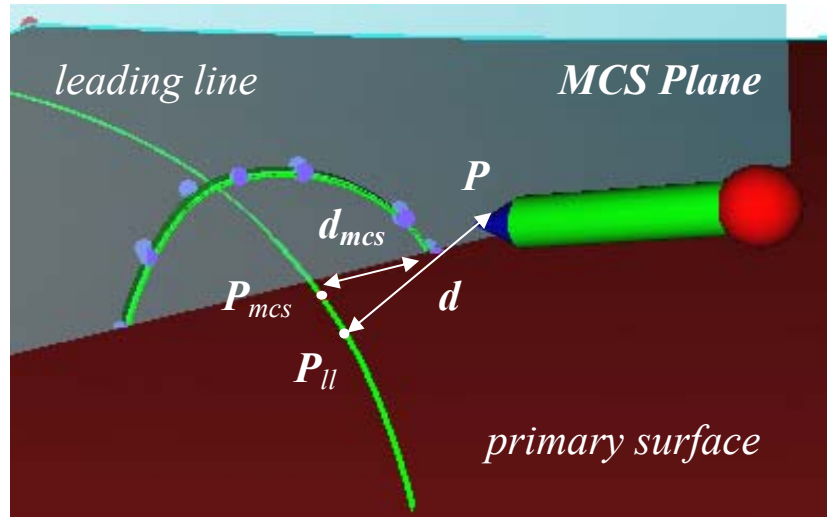

Figure 7.   Depth function parameters

$$f_{ll} = \frac{d}{d_{mcs}} \qquad (1)$$

where:

f_{ll}	is the *depth function* at point P_{ll},
P	is the position of the virtual pen,
P_{mcs}	is the intersection between the MCS plane and the *leading line*,
P_{ll}	is the point on the *leading line* nearest to P,
d_{mcs}	is the distance between the last point of the MCS profile and P_{mcs},
d	is the distance between P and P_{ll}.

4.5. Character line generation

In this phase the movement of the pen generates the *character line surface* interactively. This surface is represented in the form of a NURBS surface. Initially, the first row of control points is copied from the MCS profile. As the pen moves along, if the distance moved is larger than a predetermined threshold, the point P_{ll} is calculated and an algorithm checks if it is located further away from the MCS plane than the previous one. If this is so, for each new point P_{ll} on the *ll* curve a new row of CP is added to the *character line surface* in the following way:

-   the CPs of the MCS profile are copied and;

-   translated to the new position P_{ll} on the *ll* curve and;

-   rotated to be on a plane perpendicular to the tangent of the *ll* curve and;

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- scaled with P_{mcs} as the reference point, with a scale factor proportional to the *depth function (f_{ll})* value at the point P_{ll} (Figure 8, 9).
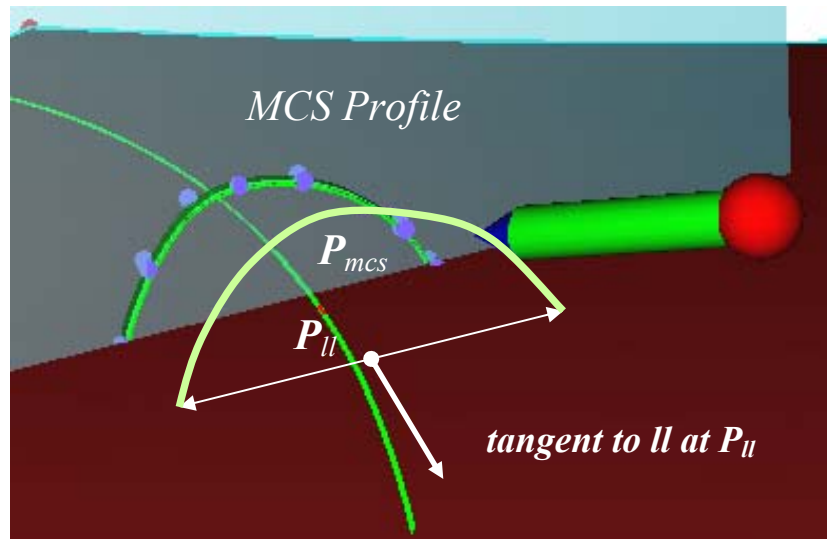

Figure 8.   Control point copy, rotation and scaling

If the calculated P_{ll} point is located closer to the MCS plane than the previous one, this implies that the user has moved backwards along the *ll* direction. Hence, if the distance moved is larger than a predetermined threshold, the system eliminates the last row of CP from the *character line surface*.
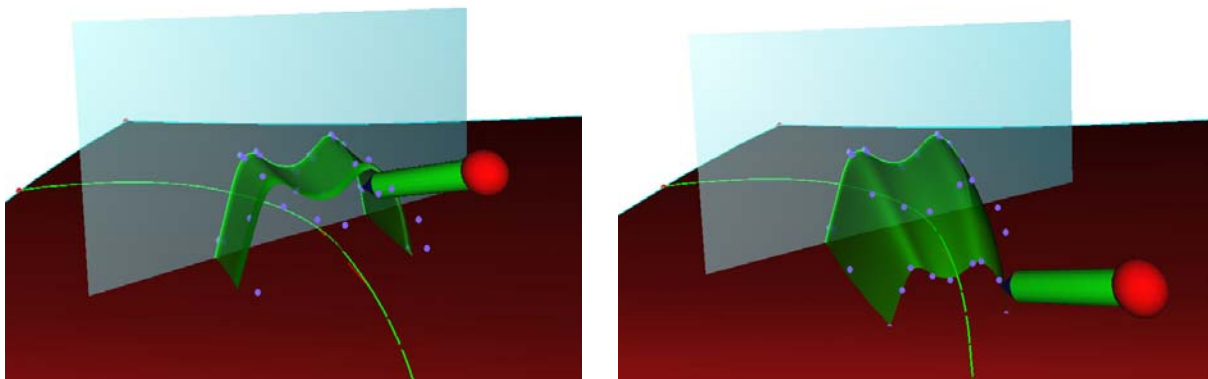

Figure 9.   Feature Generation

4.6. Integration in the Spacedesign modeller

At the end of the interactive feature sketching operation, the generated *character line* NURBS *surface* is converted into a Spacedesign representation. In this way all the modeller's functions can be applied to this geometry: snap, trim, booleans, blending, etc.
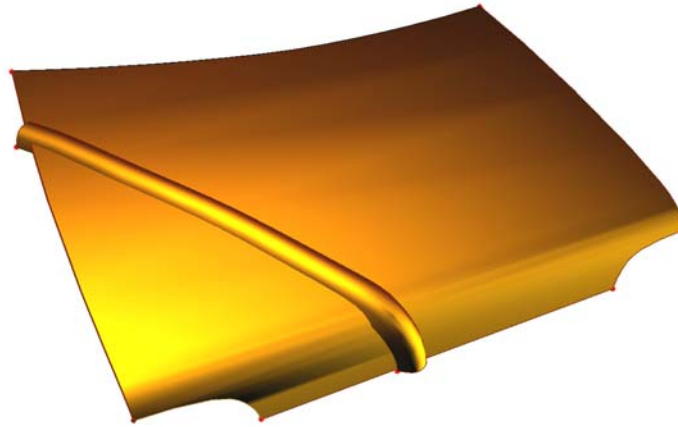
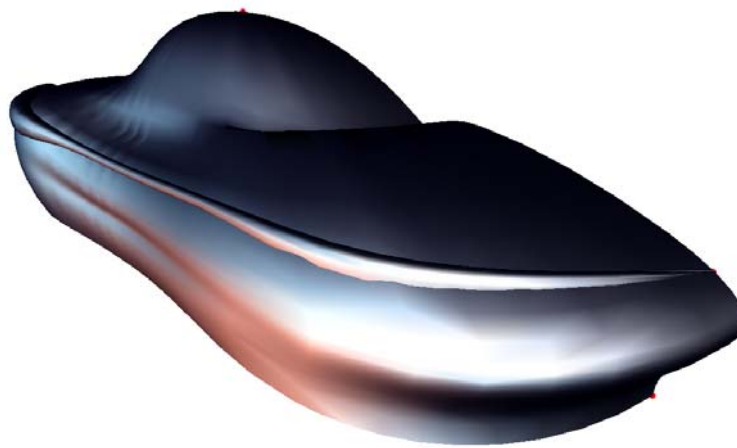Figure 10. A car bonnet with an applied character line feature

Figure 11. A conceptual car body with an applied character line feature

5.   Results and Conclusions

An original interactive character line sketching tool in a VR environment has been presented. The user can draw a path on a surface, select a major plane and sketch a profile on it. This profile is then swept and scaled by simply moving the virtual pen in 3D space forwards along the path, on the contrary if the pen is moved backwards the feature is partially erased. Some results of this method are shown in Figure 10, 11.

Although the developed system is still a prototype, the following conclusions can be drawn. Preliminary tests have shown the advantages of real time 3D interaction and of stereo visualization in a virtual reality based conceptual design application. Curves, profiles and character lines can be sketched directly onto any surface even if very complex in nature. Model navigation and evaluation can be performed in real time during the sketching phase. Moreover the possibility of erasing the generated feature in real time by simply moving the pen has been very much appreciated because it offers fast evaluation of different alternative design solutions. The approach followed for the character line definition, based on a simple control point offset algorithm, allows real time feature modelling, but presents some limitations in the resulting geometry when the path is highly curved. Future work will address such issues.

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Michele Fiorentino, dDis, Politecnico di Bari, viale Amendola 132, 70100 - Bari, Italy.
Tel: +39 080 596 3797, Fax:+39 080 554 2535, E-mail: m.fiorentino@poliba.it, URL: http://www.poliba.it