D3: an Immersive aided design deformation method

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Abstract

In this paper, we introduce a new deformation method adapted to immersive design. The use of Virtual Reality (VR) in the design process implies a physical displacement of project actors and data between the virtual reality facilities and the design office. The decisions taken in the immersive environment are manually reflected on the Computed Aided Design (CAD) system. This increases the design time and breaks the continuity of data workflow. On this basis, there is a clear demand among the industry for tools adapted to immersive design. But few methods exist that encompass CAD problematic in VR. For this purpose, we propose a new method, called D^3, for "Draw, Deform and Design", based on a 2 step manipulation paradigm, consisting with 1) area selection and 2) path drawing, and a final refining and fitting phase. Our method is discussed on the basis of a set of CAD deformation scenarios.

CR Categories: I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling—Curve, surface, solid, and object representations; I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques

Keywords: Real-time 3D Object Deformation, Virtual Reality, Immersive Environment, Computer-Aided Design (CAD)

1 Introduction

Virtual reality uses in the industry aim to take into account functional, geometrical and ergonomic problems, from development, engineering and also the final user points of view. To achieve this aim, the virtual reviews have to be associated as closely as possible to Computed Aided Design (CAD) with tools or methods that allow the design actors to interact with the object shapes. Two approaches of surface modifications can be considered; a free form deformation approach or a feature approach. The first approach consists with letting the designer model the object by a series of free deformation operations that will lead to the imagined final shape. The second approach consists with performing a limited number of deformations that are characterized by parameters that can be adjusted by the designer. Our goal is to find a deformation method with a fast visual feedback during the modifications, to enable interactivity and enable instant evaluation of the effects of his modifications. Such methods should be easily usable by all the design project actors, whether they are technical actors (such as technical designers) or non technical actors (such as stylists or draughtsman). This method should enable the user to modify in real time various virtual object parts, which he wishes to adjust without questioning the totality of the model design. This method has to be independent of the VR model tessellation and provide feature modifications to the CAD B-REP model.

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2 Proposed Solution

2.1 Experimental setup and Interface

We use a "Wall" type experimental setup that consists of a large-sized projection based screen with active stereoscopy. This screen will fill a large part of the user's horizontal field of view. This is to immerse the user in front of the object to be modified. A tracking system detects the movements of hands and head of the user. We chose to divide the modification process into two steps: a step of selection of the areas to be modified and a step for the deformation of this area. The splitting of every modification in two steps presents the advantage to focus the designer on a reduced task, and aims to increase his precision. It is possible during the deformation step to return to the selection step to modify it and adjust it.

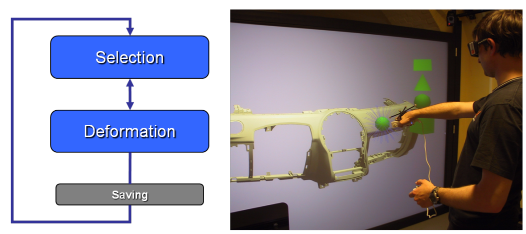

Figure 1: *Scheme of our method step and setup*

For selection, we used a drawing metaphor. By a natural gesture, the user draws with a virtual brush his selection on the object. This technique allows to select large or small areas. Since we work in 3D space, we need to provide the user with adapted brushes able to interact with 3D objects. We developed for this purpose radiant field tools. We define our radiant tools as being a 3D object, whose range of effect depends on a field defined by an interpolation function $B(x)$, on $[0,1]$ to $[0,1]$, describing field influence variation. This profile curve has to be continuous and end with a zero value. We associate to this function two parameters m and r being respectively the amplitude between $[0,1]$, and the field range between $[0,\infty[$. The scalar field E in point p, is computed as a function of the distance $D(p)$, between this point and the tools surface.

$$E(p) = m.B(\frac{D(p)}{r}) \quad (1)$$

The zero value of the field corresponds to no selection, a value of one corresponds to full selection and intermediary values corresponding to a behaviour of the points that we describe in the deformation step (see 2.3). Having such a 3D field, these tools can select volumes or surfaces. To manipulate the tool we chose to use a wireless controller in the user dominant hand that allows the user to manipulate the surface with or without colocalisation. Colocalisation is the fact that the visual space matches manipulation space. The advantage of colocalisation is that it increases the manipulation efficiency [Paljic et al. 2002] and increases user precision. But in some cases colocalisation is not possible because of physical constraints (presence of the screen) or occlusion problematic. This is why the method can be used in both situations. For this, the user interacts with two buttons on a wireless controller and an analog stick. The first button is a switch for tool/hand clutch and unclutch. In this way, the user can adjust the position of the tool relatively to his hand in a most adapted configuration, according to the area he wants to work on. This technique allows him to work remotely on an area, which is inaccessible to him. The other button is a switch to lock/unlock the orientation of the tool. This allows him to adapt tool orientation to the task. The size of the tool is controlled by means of left/right analogic stick movements. Up/down movements on this same stick control the field range r. The field is represented by normals to the surface of the tool. Their length is equal to the reach of the field. A set of basic shapes: sphere, plane, cube, cone etc. allows the user to choose his brush, and it can also be a user made shape(see Figure 2).

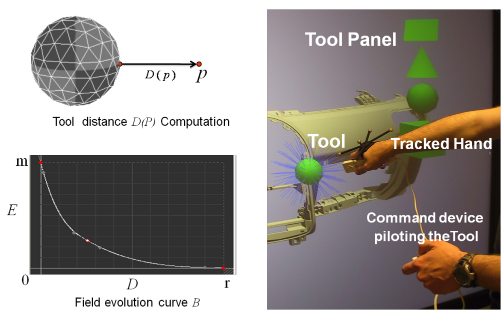

Figure 2: *Scheme of Radiant Tool and his manipulation*

2.2 Draw selection process

The selection consists of associating to each point p of the surface a selection level $S(p)$ by selection brush motion. Selection $S(p)$ at every point p is the maximum of the field level $E(p)$ generated by the tool during the selection drawing movement:

$$S(p) = \max(E(p)) \tag{2}$$

The result of the selection is shown to the user as a texture and the variations in color of this texture represent the selection value. The contrast of colors not being always perceived, it is also possible to show the magnitude of the selection gradient to better see the small selection variations.(see Figure 3)

In order to avoid unwanted selection we introduced selection constraints. These constraints can be defined either by the user or by the design analysis system. The objective is to forbid any modification of some already validated elements, or the modifications that could compromise the integrity of the model. We shall consider here only the case of constraints defined by the user. The constraint system is based on the same principle as the selection process, namely the use of radiant tools. In the same way as selection, the user defines constraint areas either by drawing or by positioning constraint radiant field tools. The only difference is the function of the scalar field $I(p)$ (I for Inhibition) where we use a function $B(x)$, describing constraint field influence variation, and the parameter r defining the range of the field between [0,∞[:

$$I(p) = 1 - B(\frac{D(p)}{r}) \tag{3}$$

The constrained selection $S'(p)$ is computed by modulating the selection $S(p)$ by the maximum of constraint field level $C(p)$ of the constraints defined on the surface:

$$C(p) = \max(I(p)) \tag{4}$$

The influence of the constraints is pre-computed in a texture. The computation of the constraint selection is a product of the corresponding values between both textures:

$$S'(p) = C(p).S(p) \tag{5}$$

When the user releases the selection tool, the working area stays defined as the combination of his selections and defined constraints.(see Figure 3)

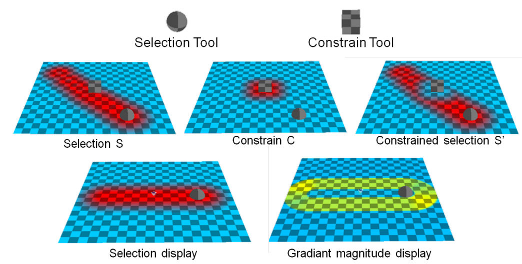

Figure 3: *Example of constraint on selection*

2.3 Deformation process

For the deformation, the gesture of the user is used to sketch either a deformation path or a transformation. Once the selection is made, the selection tools stays in place, changes appearance and becomes the handle for deformation. By grabbing and moving this handle, the user can deform the selected surface according to his movements. During the deformation phase, the system creates “key frames” (position, orientation, size) of the tool motion and inserts them into a “deformation curve”. We have a curve having a length L with a certain number of “control frames” defined throughout its length. We call these control frames $R(l)$, where l is the position along the curve. To compute the transform p' of the surface point p due to deformation movement, we compute a modulated distance L' as a product of curve length L and point selection level $S'(p)$:

$$L' = S'(p).L \tag{6}$$

We then look for the interpolated frame at position L' on the curve: $R(L')$. Finally, we use the coordinates of p in the first tool motion frame $R(0)$ as the coordinates of p' in the interpolated $R(L')$ frame. We thus obtain the deformed point P'. In the particular case where $L = 0$ for a pure rotation movement without translation, we interpolate the frame according to the order of definition of the control frames (see Figure 4).

The use of tool “key frames” as control points of the deformation curve we propose, allows to widen the deformation possibilities to twist or taper deformations. The difference between rotation and twist depends on the selection type. In order to perform a rotation, all the selected object points will rotate with the same angle, all these points are to be selected with the same selection value. To perform a twist deformation, points rotate with a different angle, their selection value is to be different. The fact that selection and deformation movements are independent is a strong advantage.

Particularly the user can choose the location in space where the deformation path is. It can be close to the surface selection or distant: This way the user has the possibility of defining the deformation curve and its reference frames at the most appropriate location. For example, it can be interesting to define a rotation center far from the selected surface to make an extrusion that has a circular path. This confers to the user a better precision for achieving such a deformation instead of trying to hand shape a perfect circular path.

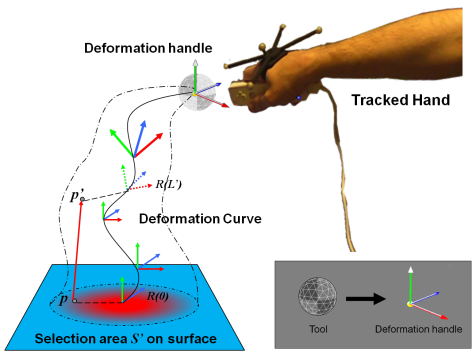

Figure 4: *Scheme of D^3 deformation method*

2.4 Design step and CAD Link

Since our objective is to provide a method allowing various design project actors to modify the model, and since jitter can occur during deformations controlled by free hand movements there is a need to provide the possibility for a final refining step. To do so, and to remain compatible with the design process, we chose to store all the modifications in a design tree [Convard and Bourdot 2004]. We define an operation node named D^3 for our deformation method. As a parameter we set the "deformation curve" that we introduced and as the reference element, the area of the surface selected for deformation (see Figure 5).

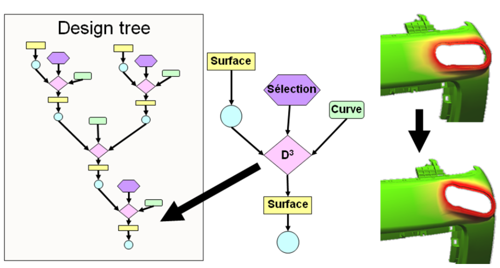

Figure 5: *Scheme of our method data saving*

This formalism aims to allow refinements of the modification in two environments: directly in the immersive environment or in the design office on a desktop CAD system. In the first -immersive- case the user could refine a deformation by moving, adding, or deleting control frames on the corresponding deformation curve. To avoid selection ambiguities in the case of merged frames, we propose a similarity measurement in position, orientation and size between the deformation handle and the controls frames. The most similar frame is the selected one. It is also interesting to provide the user with tool motion constraints and a measurement system to help him to correctly fit the control frame. We will discuss a solution in the future work paragraph. In the second "desktop" case we could merge the design tree of the part with the design tree from the immersive system, to allow desktop modification in the CAD system. But in this case the CAD system needs to support our D^3 method. We will discuss in future work another method that would allow to reconstruct the deformed surface area in the CAD system with a standard operator like sweep.

3 Evaluation and method comparison

In this part, we discuss four previously proposed deformation methods used in immersive environment. We present the advantages and disadvantages of each and propose a comparison in a table (see Table 1). Finally we introduce some practical examples performed with our approach.

The first method chosen is 3D Wrap [Renzulli et al. 2005]. This method is intuitive, but it does not offer the flexibility needed for the selection of details and large areas; it will constantly be necessary to adapt tool shape for deformation. Furthermore, this type of approach is not easily integrated in a design tree due to the number of parameters to be defined: tool geometry, tool's motion, object/tool relative position, etc. The ExtFFD [Coquillart 1990] allow a large number of deformations. But the deformation desired by the user is not always possible with a predefined / automatically generated set of FFD control points. It will then be necessary to adjust the distribution of these points to obtain the correct deformation. On the other hand, it is sometimes difficult to visualize the influence of a control point on the surface to be deformed and to define all its reach. Therefore in this case, the deformation is difficult and does not still correspond to the user's intents. The third method introduce by V. Cheutet [Cheutet 2006] is based on sketching. It allows a good control of the area to be modified. But on the other hand, it won't allow a real time visual feedback during the deformation. The deformations possibilities are also limited as: twist operations are difficult to perform. The last group of methods is based on constrained deformation, like DOGME [Gerber and Bechmann 2004] or ExtScodef [Lanquetin et al. 2006]. These methods seem to be a good compromise between intuitivity and ability to provide deformations on either small or large areas. But it is impossible to perform twist or taper deformations and the selection process is based on fixed constraint tools and doesn't allow easily to select different area types. We introduce three use cases based on industrial examples: The first example shows the modification of a ventilation outlet on a car dashboard by means of our method (see Figure 6). The deformation impacts only on the selected area and allows the modification in size and orientation of the outlet. In this second example, we tested the modification of two close objects with the same deformation performed with our method (see Figure 7). For that purpose, we enabled the tool to select a surface on two objects at once and we used the same tool to do the deformation, we thus have the same curve of deformation for both objects. In this third example, we tested the use of the smooth constraint system on a hubcap part; we set a constraint field on the end plate that the hubcap is to be fixed on. And we define as tool used for this deformation the shaft axis fixed on this part (see Figure 8).

Figure 6: *Deformation on dashboard ventilation outlet.*

Deformation method	Real time feedBack	Design tree	Constraint system	Colocalisation/Distant manipulation	Multi Part deformation	Deformation Posibility
D^3	Yes	Yes	Yes	Both	Yes	Twist, Bend, Swell, Taper, Stretch
3DWrap	Yes	No	No	Coloc.	N/A	Twist, Bend, Swell, Taper, Stretch
DOGME or Ext Scodef	Yes	N/A	No	Coloc.	N/A	Bend, Stretch
FFD or Ext FFD	Yes	No	No	Distant manip.	N/A	Twist, Bend, Swell, Taper, Stretch
Sketches	No	Yes	No	Coloc.	No	Bend, Swell, Taper, Stretch

Table 1: *Methods Comparison*

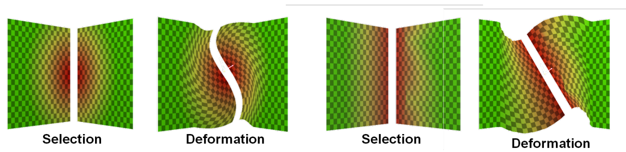

Figure 7: *One pass deformation on two close planes with a spherical selection tool with a rotation of 30 degrees. Left) A dot selection is performed, Right) A straight-line selection is realized*

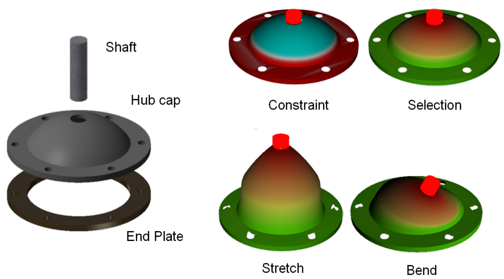

Figure 8: *Example of selection constraint on a hubcap*

4 Conclusion and Future Work

We proposed a 3D object deformation method in an immersive environment dedicated to the development and optimization of industrial parts designed with CAD. This method is divided in three steps: selection by Drawing, Deformation, and a final Design step. The selection is based on a drawing metaphor meant to increase selection possibilities and intuitivity. The deformations are driven by user's gestures, who sketches the deformation shape. This shape is stored into a deformation curve, which includes key frames for reediting, and allows complex deformations like twist, bend, taper or swell. The deformation information is stored into a design tree that allows rollback to a previous step and later modification.

As future work, we propose to explore various radiant field display methods to improve previsualisation of the selection tool field. We plan to propose an analytic definition of the selection area based on contour map selection defined by splines, directly on the object surface. The objective is to use a lighter-weight alternative compared to textures, and less dependent of the object tessellation. The second advantage is to provide some topological elements that could help the CAD system to rebuild the deformed surfaces (see Figure 9). This contour map could also detect high selection gradient areas, where the surface needs to tessellated more finely. The contour map computation could be transparent from the user point of view and could take place between the selection and the deformation step. We plan also to propose constraints on the tool motion that aim to reduce the problem of hand jittering and could guide the designer during the deformation step. This kind of constraint could be a formalism of repulsive or attractive fields on references elements like points, lines, planes, or curves. Such constraint could be used to draw an circle or straight line on the object surface. A more detailed evaluation of the proposed D^3 method is required on a heterogeneous user population including persons from the design area. The objective is to adapt this method to existing design practices.

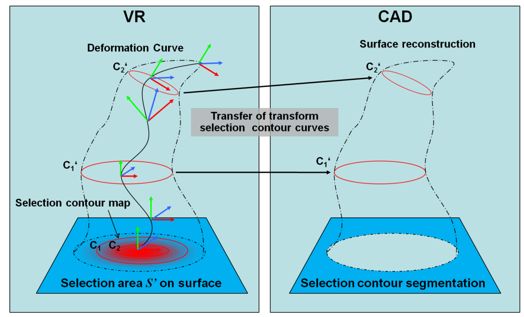

Figure 9: *Scheme of our deformation method with level spline selection techniques and CAD modification Export.*

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