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# TWO-STEP 3-DIMENSIONAL SKETCHING TOOL FOR NEW PRODUCT DEVELOPMENT

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## ABSTRACT

This paper discusses a two-step virtual reality based conceptual design tool that enables industrial designers to create sketches of their ideas in 3-dimensional space in real time. In the developed sketching tool, the rough shapes of products are generated by tracing the trajectory of the data-gloves worn by the designer. In the model a practical solution is provided to reduce the generation of unnecessary control points. This is achieved by representing each control point by a spherical volume. Once the rough sketching is completed, NURBS surfaces are constructed by the limited number of reference points that are selected from the initial sketch by using a virtual pen. The two-steps sketching technique enables designers to perform their artistic characteristics freely in an intuitive environment and also enables designers to generate parametric representations of the surfaces to be used in CAD/CAM systems for further analysis.

## 1 INTRODUCTION

Computer aided design has been widely used in various industries and it greatly shortened the time that is needed for mechanical designs of parts. On the other hand conceptual design has not been changed over the years. Pencil and paper based 2-Dimensional (2D) sketching is still the most common technique for highlighting the configurations of the product in its initial design stage. The initial design stage is usually known as conceptual design. Although input for the conceptual design comes from variety of different sources such as customers, engineers, company policies, market trend etc, rather than a science conceptual design is still an art. Industrial designers give the basic shapes and functionalities of products by using their imaginations and talents on traditional pen and paper based platforms. Since in today's highly computerized manufacturing environments having CAD images of the products is compulsory, the need for a postprocessor that automatically converts these 2D sketches into 3-Dimensional (3D) Computer Aided Design (CAD) models is higher than ever. Today's CAD software does not provide friendly and intuitive sketching functionalities that enable industrial designers to transfer their artistic views into functional products.

Recent advancements in computer technology in both hardware and software levels made Virtual Reality (VR) a strong candidate to simulate many real life phenomenons. Recent research work and the needs, mentioned above, have created one more possible dimension to the application areas of VR which is the 3D free form sketching. Today, a well designed VR simulator can provide a naturalistic environment for industrial designers to form the initial shapes of products in 3D space. Since the initial sketches of the products are directly placed in 3D space, outputs are in digital formats. The output of such systems have two important advantages: i) initial sketch can be visually observed from many different viewpoint like as it is a physical prototype ii) initial sketches can be converted to the required CAD formats for further enhancements and analysis.

In this article we are introducing an immersive VR based free form sketching toolbox that we believe will provide an intuitive environment to industrial designers in product design process. We are investigating the possible ways of using data gloves to generate the sketches in the 3D space. Most studies in the field that we have revived use single data generating tools (similar to a pencil) such as mouse, wand or specially created 3D pens (Yoshida et al. 2000). Although surface forming becomes more challenging, use of data gloves give two important advantages to the designer i) better formed curves-shape: position of each finger helps to form the surface shape ii) a number of alternatives to create sketches: A single finger creates a splines in 3D, side of a single finger can be used to smooth existing surfaces or create surfaces, finally the whole hand enables to create multi-curvature surfaces in 3D that is a natural way of working for many artists especially sculptors. Yet the main contribution of our work is to have two-step sketching technique. In the first step we generate rough sketches of the products being designed. In the second phase we use the initial sketch as a base to select critical control points to generate smooth surfaces that represents the initial sketch best. The outcome of the process is i) intuitive and user friendly 3D free-form sketching tool; ii) accurate NURBS representation of the surfaces.

## 2 LITERATURE REVIEW

Starting early 90s VR has gained popularity in many different applications from manufacturing to educations. One of the first attempts to use VR in 3D sketching was made by Sachs, Roberts and Stoops (1991). In their model curves that are the skeleton of the product being designed are generated by using a virtual pen in front of a normal monitor. Due to the advancing technology and availability of many VR hardware and software such as trackers, shutter glasses, Head Mounted Displays (HMD), 3D mousses, and data gloves, later studies focused on fully or partially immersive VR platforms to develop free form sketching models. The HoloSketch, work of Deering (1995) allows users to work in 3D space. The limitation of similar works is that images are created by the placement of lines in 3D. In Deering's case primitives such as spheres are used to sketch objects in 3D space.

Tolba, Dorsey and Mcmillan (2001) describes a system that lets users to draw a scene with 2D strokes. The 2D images are later viewed from several new locations as if a 3D scene is created by it. This is done by projecting the 2D strokes on the sphere wit the center at the eye point and then viewing them in perspective. Zheng, Chan and Gibson (1998) attempted forming a curve by locally matching with other curves. Wesche and Droske (2000) proposed some sketching tools based on an energy approach for the conceptual drawing of curves and surfaces in a particular VR is called responsive workbench. In a future work, Wesche and Seidel (2001) presented the improved module of their work in the same environment by implementing some tolls that perform indirect drawing and modification of a curve network for surface design.

The level of immersion has a significant effect on the naturalistic side of the whole sketching process yet; most recent works aim at collecting reference points from designer's inputs, defining curves by parametric equations, generating smooth surfaces and connecting different segments of the surfaces to each other to create the complete shapes of the designed objects. In their semi-immersive model, Bruno et al. (2002) uses a pen to generate reference points in the 3D space. Generated surfaces are NURBS representations of the collected reference points. Some of the well known concepts in CAD such as extrusion and revolving are used in generating the surfaces. A 3D Eraser pen is also introduced in this work to correct the curves quickly during the sketching.

The common characteristic of the works mentioned in this paper is that surfaces, lines or the control point that generate surfaces or splines are generated in an empty 3D space without any reference geometry. Furthermore, most of these works aim at generating parametric representation of the surfaces while the designer works on the sketch. Generation of the parametric equations during the sketching phase forces designers to focus on the requirements of the parametric surface generations such as the connectivity requirements of different surface segments. Focusing on the mathematical details rather than the design itself limits the designers' artistic capabilities. In this work we are presenting a two step sketching technique may become a solution to overcome some of these problems.

## 3 OUR METHODOLOGY FOR FREE FORM SKETCHING

We have developed our model in an immersive VR system. The system consists of 3 major components: Head mounted display (Hi-Res 900), data gloves (5DT Data Glove 5), and position tracker (Flock of Birds®). For graphical interface OpenGl library with Microsoft Visual C++ is used. Location and translation of the user's head and hands are tracked by the position tracker in real-time. Although more enhancements are required, in the current form of our module, we use keyboard and mouse inputs to control various commands. While user, presumably an industrial designer uses one of his/her hand wearing a data glove to shape the object in 3D by free movements, the other hand controls various supporting actions from keyboard: stop/start sketching, selection of the desired curve/surface shape (single finger or hand), color selection, correction of the curves etc (See figure 1 for the illustration). In our experiments we found that connecting the different surface segments are challenging. In most occasions, this process forces the designer to focus on the start and end points of the surfaces. Ultimately the main focus becomes how to connect surfaces not how to transfer designer's imagination into the design. Our dual step hierarchical model minimizes this problem and gives the designer a significant flexibility to draw images in the 3D space intuitively.

The described methodology in this paper generates the final shapes of the product images in two steps. First, designer generates an object in the 3D scene as the way he/she wants. There is no limitation in his/her way of creating surfaces by using his/her hand/finger (data glove). Created images may overlap to each other, or there could be significant gaps between two surface segments. (See figure 2 for examples). Final shapes are generated by connecting some selected control points from the initial sketch.

### 3.1 Control Point Generation

At this point it is important to describe the spherical vertex generation technique we adapted in the development of this

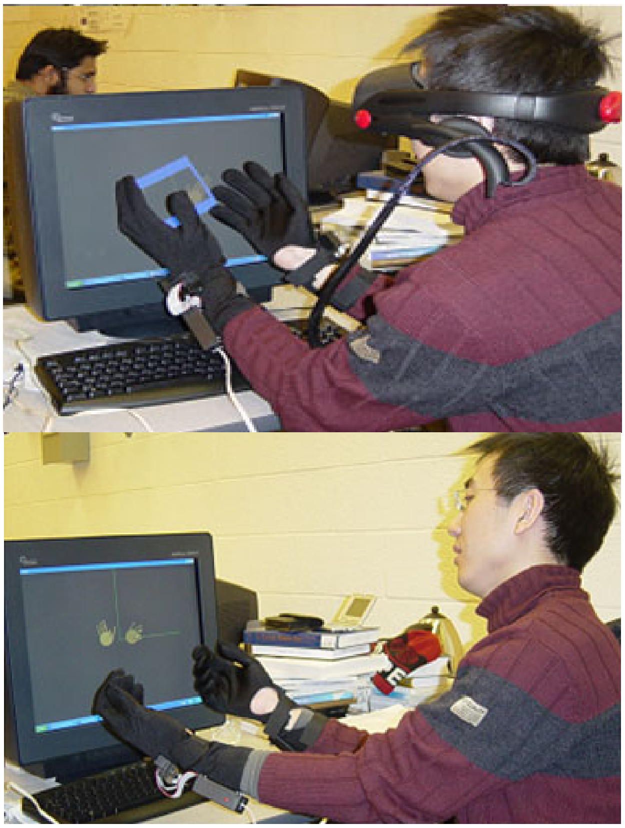

Figure 1: Free Form Sketching System

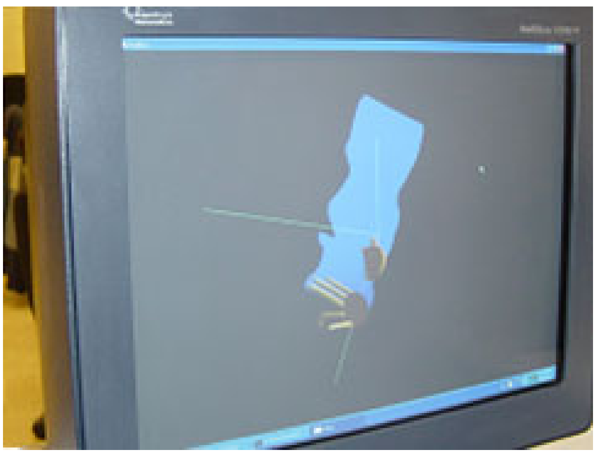

Figure 2: Free Surface Generation by Using Data Gloves

tool. Surfaces in the proposed technique are generated by triangulating the vertices that are recorded from the data glove. Up to 23 vertices can be captured from each hand (See figure 3).

The major problem in collecting the data is the sampling rate. Two simple approaches can be considered to collect user-data. Either when a motion is captured from user's hand or in each frame positions of the desired reference locations from the data-glove is registered. In the first

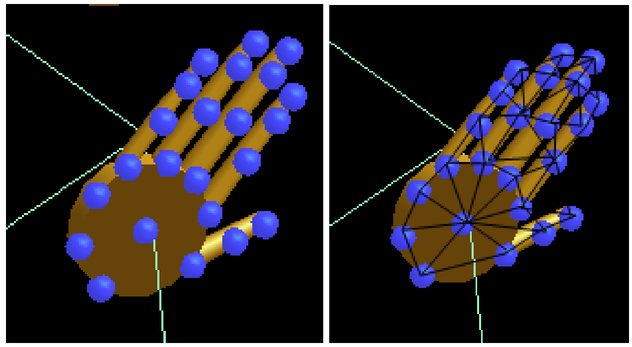

Figure 3: Reference Points from the Right-Hand and the Triangulation

instance, small vibrations or some other unintentional motions of the hands will generate reference points. In the second instance, regardless of a motion is captured or not, in each frame, reference points are collected. This creates abundant amount of unnecessary reference points or vertices of object corners in the scene. Moreover the triangulation becomes almost impossible. To overcome this problem identical sized spheres are used in the proposed model. The model does not allow the generation of additional reference points if their bounding spheres intersect with an existing sphere. Although this process is simple and practical, when the complexity object increases, number of spheres to be compared increases to a level where pair wise intersection test become computational unmanageable. Although we have not implemented in our module, the effect of this problem can be minimized by utilizing bounding volumes. Use of bounding volumes minimizes the unnecessary pair wise intersection checking. Contact check is only performed if both new vertices and the existing vertices are in the same bounding volume. Use of bounding volumes is extremely efficient in reducing the complexity of collision detection in VR simulations and in robotics. Figure 4.a illustrates the generation of vertices that are apart from each other. Figure 4.b demonstrates the position of reference points generated without any intersection control. It is obvious that the triangulation of these vertices in figure 4.b is extremely difficult and there is no visible usefulness of the most control points for defining the surface features of the designed product.

Most of the studies in 3D free form sketching attempts to shape the desired object in an empty space (Bruno et al. 2002). Since the common goal of most of the research work is generating images that can be represented by some standard geometric formats and later can be converted to desired CAD formats, the main focus is creating shapes with certain geometric and mathematical properties. Our experiments shows that models so called free-form sketching that attempts to generate surfaces from mathematical models fail to provide the intuitive environment to designers. In such platforms, designers' main focus becomes the details of the mathematical requirements rather than product as a whole. This limits the artistic sides of the designers

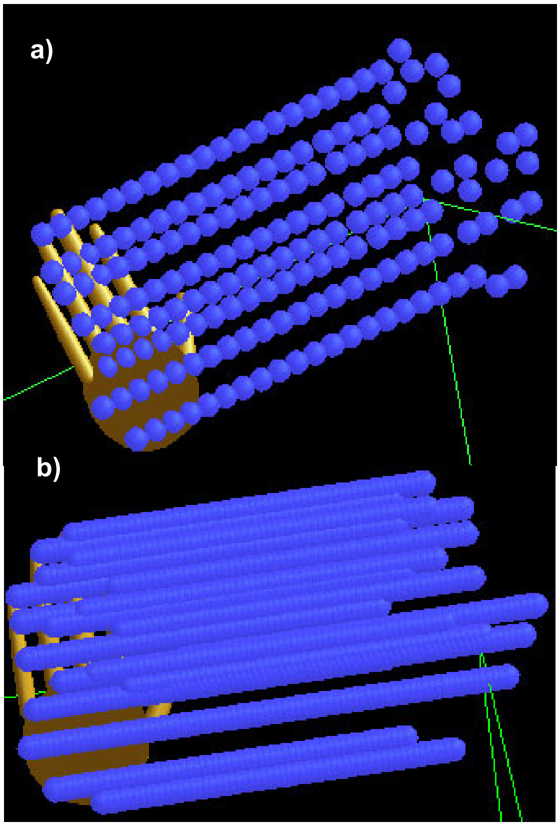


Figure 4: a) Reference Points Separated from Each Other by Sphere Radius; b) Reference Points Collected without any Distance Control

significantly. From this aspect we decided to focus on developing a system that enables designers to express their feeling freely when they design new products in 3D. Yet our goal is also to find solutions to generate images that can automatically be converted into desired CAD formats.

As we discussed earlier, in our prototype module rough sketch of the product is created in 3D by the designer. This process is completely free and the outcome may have many undesired data points or redundant surfaces. Yet, the outcome of the initial process, basic shape, is an approximate representation of the designed product that satisfies the designer's requirements. Next, this rough sketch is used as a base to construct smooth surfaces to define the final product. Since the sketch that is created in the first phase is somewhat acceptable design, created smooth surfaces from selected reference points represents the initial sketch best. To accomplish this first reference points are selected from the initial sketch by using a virtual pen. Once the necessary amount of reference point is selected, an NURBS surface is generated. If the theoretical surface representing the sketch satisfies the designer, we go to next segment to generate more surfaces. Otherwise new data points are selected in the same region or selected vertices are translated in the space to improve the fitness of parametric surfaces.

### 3.2 Control Point Selection Process

Initial sketches in the described model are generated by triangulating many control points. Yet, in computational geometry only a sub set of vertices are satisfactory to approximate the desired surface segments. Later surface segments are connected to each other by following simple continuity rules (zero order, first order and second order continuities). At this point the goal is to identify the necessary control points from the rough 3D sketch. In order to select the necessary vertices a virtual pen is used. Distance between all the vertices and the end-point of the pen is calculated and the vertex that is in the closes range is highlighted by changing its color. If the designer satisfy with the selection, by a keyboard input he/she accepts the vertex as one of the control points. Otherwise pen is moved to another direction. The process is repeated until necessary number of vertices is selected. One can easily see that this process is not computationally acceptable. Although we have not implemented, the complexity problem again can be minimized by introducing the bounding volume hierarch model into the process. The space where the initial sketch is positioned can be divided by the bounding volumes which are a frequently used technique to solve complexity problems in collision detection algorithms in robotics and computer graphics (Klosowski et al. 1998). Then the distances are computed between the end-point of the virtual pen and the vertices that are in the same bounding volume.

### 3.3 Parametric Curves

The described methodology has one important advantage which is the connectivity of the surface segments becomes manageable in real time without sacrificing from the main objective of the 3D sketching which is the intuitive and creative artistic design. Once the desired shapes are generated (Figure 6 illustrates the possible outcomes of the rough sketching), in the second phase of the process the NURBS surfaces are generated. NURBS surface is created from the vertices selected from the initial sketch. If the constructed surface satisfies the industrial designer's expectations the surface is finalized and move to the next segment in the sketch. If the surface is not satisfactory different reference points are selected around the sketch to obtain the best design. Most techniques, some of are reviewed in this paper; create the NURBS surfaces without a benchmark shape. In the described methodology in this paper first the desired shapes of the products are generated in primitive forms. When smooth surfaces are generated by parametric equations, initial sketch becomes a visual benchmark for comparison. The proposed hybrid model is much more user friendly to the designers especially in creation of smooth surfaces. Training of the users is also easier than many other 3D sketching techniques. The user of our module can focus on the details of their designs rather than struggling with many complicated curve and

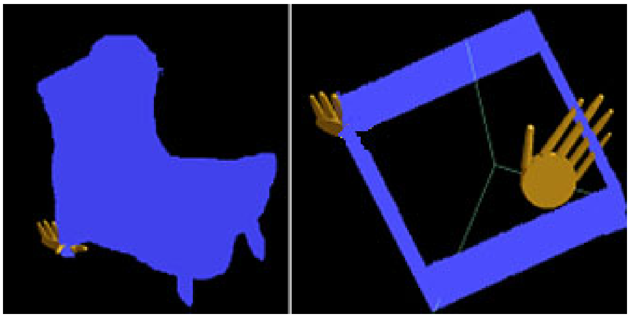

Figure 6: Outcome of the First Phase of Sketching

reference point relationships. Finally, in our model many user generated drawing errors can be ignored since the initial rough sketch is only temporary and used as a base for the final model. Although generating images in the 3D space by using hand (data glove), pen, or 3D mouse subject to create many undesired curves in our model users do not have to waste time for correcting them. Once the final NURBS representations are generated, the initial sketch is completely eliminated from the system.

## 4 EXAMPLES

In figure 7a we illustrate the rough sketch of an oriental style seat. As shown in the figure, designer does not pay attention to geometric details during the sketch. Continuity of the surface curvatures is mostly ignored. In figure 7b, we demonstrate the NURBS surface of the same table generated by the vertices selected from the initial sketch. The new surface is smooth and the geometric continuity can easily be sustained when connected with other surfaces.

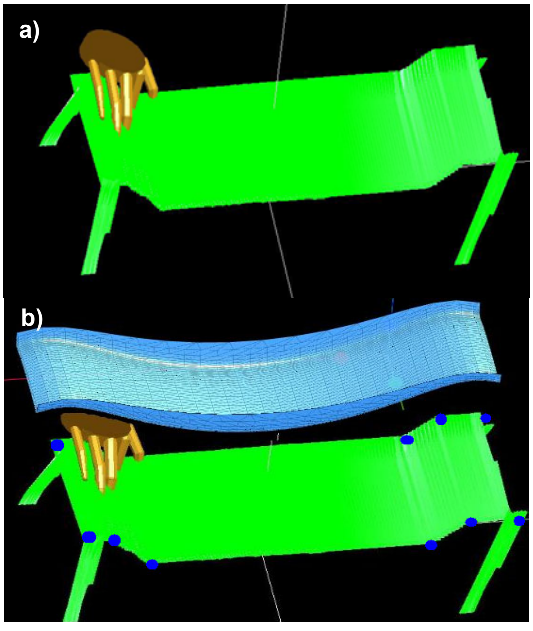


Figure 7: Two-Step Free Form Sketching Results: a) Rough Design; b) NURBS Surface Creation

## 5 CONCLUSIONS AND FUTURE REMARKS

In this work we presented a two-step methodology that enables industrial designers to sketch the initial models of the product they develop in 3D space. While the proposed model enables designers to transfer their feelings and imaginations into the design freely, the final images can also be converted to the desired CAD format for the future analysis and enhancements. Although we have developed an initial framework for the proposed 3D free form sketching tool, a number of additional futures should be included to increase the efficiency and the usability of it. Implementation of the bounding volume hierarchies is crucial for the model to perform well with large projects. Also we are aiming at designing the objects in the space using inputs from both hands. The present model requires one hand to control the keyboard to select certain command from the menu. In the future the menu commands can be controlled by the speech recognition technique so the both hands could be utilized in shaping the object. Use of both hands is much more intuitive to designers to shape the products in 3D.

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