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# INCORPORATING 3D BODY MOTIONS INTO LARGE-SIZED FREEFORM SURFACE CONCEPTUAL DESIGN

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## KEYWORDS

Human Motion, Gestures, Freeform Surface Design, Conceptual Design

## ABSTRACT

Large-sized free-form surface design presents some challenges in practice. Especially at the conceptual design stage, sculpting physical models is still essential for surface development, because CAD models are less intuitive for designers to design and modify them. These sculpted physical models can be then scanned and converted into CAD models. However, if the physical models are too big, designers may have problems in finding a suitable position to conduct their operations or simply the models are difficult to be scanned in.

We investigated a novel surface modelling approach by utilising a 3D motion capture system. For designing a large-sized surface, a network of splines is initially set up. Artists or designers wearing motion marks on their hands can then change shapes of the splines with their hands. Literarily they can move their body freely to any positions to perform their tasks. They can also move their hands in 3D free space to detail surface characteristics by their gestures. All their design motions are recorded in the motion capturing system and transferred into 3D curves and surfaces correspondingly. This paper reports this novel surface design method associated with some case studies.

Key words: Human Motion, Gestures, Freeform Surface Design, Conceptual design

## INTRODUCTION

In product form design (aesthetic design and industrial styling), constructing freeform surfaces is essential. Especially at the conceptual design stage, various design ideas need to be tried out quickly and evaluated remotely under a distributed manufacturing environment. Use of computer aided design (CAD) models is a very effective way to demonstrate design ideas, illustrate surface and form design details with various renderings, and communicate the design within design teams geographically distributed at different sites. On the other hand, CAD models are eventually needed for downstream manufacturing applications. However, creation of CAD models is not a simple job for industrial designers because current CAD systems requires accurate 3D inputs for surfaces such as a set of 3D characteristic curves or a range of 3D points.

Traditionally, in the early product form-design stage, idea development and making mock-ups are key activities for designers to present and compare ideas during the process of product development. Designers usually use polyurethane (PU) foam or Extruded Polystyrene (EK) foam, clay, gypsum, wood, wax and so forth to make mock-ups after the ideas have been partially developed. Soft prototypes made from easily carved or sculpted materials are useful for the more complicated concepts. However, these soft prototypes need to be transferred to CAD models. Currently, reverse engineering (RE) technique [1] is widely accepted for obtaining 3D CAD models from real 3D physical prototypes (models). Typically, a range of 3D data points on the physical prototypes can be measured with various 3D Scanners. In order to create 3D CAD models, these range data have to be registered, segmented, classified and fitted properly. However, the RE technique is designed for one-off applications. It is not good for rapid conceptual design applications because they require creation of CAD models rapidly. An alternative technique has been investigated and developed to support rapid CAD model updating from the corresponding sculpted physical models [2]. But it can only support small-sized models. For a large-sized design object, if being scaled down too much, its surface curvature will change noticeably. Consequentially, the scaled small prototypes cannot represent true design ideas and intent forms.

On the other hand, research on sketch-based conceptual design has being carried out in 2D sketch recognition [3-6] and 3D virtual sketching [7-10]. Styling or industrial designers start a free-form surface design by drawing characteristic curves which describe the basic product shape characteristics with pencil and paper. The curve mesh may be regular or irregular. This is a very effective way to design a shape intuitively. These idealised 2D sketches are then transferred into 3D surface models based on design feature recognition [3], and design gestures [5,6]. However, the primary difficulty in transferring 2D sketches into 3D surfaces is that an inverse projection should be performed from the sketch plane to the 3D space. This process is mathematically indeterminate. Therefore, research on direct 3D sketching and modelling has been investigated alternatively [7-10].

A 3D digitiser (the sensor or 'pen') based on a digitising tablet was used [7] to simulate the action of free sketching. During the sketching phase, a user operated the devices solely by contacting with the 'pen' which contains the enabling switch. Free sketching movements were made in space without the need for a solid reference model. The sketch was viewed on a 2D monitor.  The drawback of the research is that it provides only 2D image as feedback. Early work in 3D shape creation with 3D input devices was explored in 3-Draw [8]. In 3-Draw, the user holds a mirroe-like plate in the left hand to rotate the whole screen display, and holds a 3D stylus in the right hand to sketch curves in 3D space. The 3D sketches are displayed on a 2D screen. Deering followed up on this work with HoloSketch [9], which allows the drawings of tubes of toothpaste by moving a tracked stylus with a glove through 3D space.  In order to provide 3D visual feedback, Surface Drawing [10] was developed to support drawing with the hand in free space. When the hand is moved through space, its path takes forms and hovers in the air as surface. This concept was realized using the Responsive Workbench [11], a large table that acts as a display surface.  Special interface hardware includes a head-tracked stereoscopic display and sensors which track the body and handheld tools allowing the artist to share the space of the artwork. Even with the stereoscopic display, Surface Drawing found that it has difficulty in making strokes touch (or intersected) due to both the complexity of 3D stroke boundaries and the noticeable error of the tracker system. Therefore, instead of using boundary curves, it uses surface strips and merges them together to form rough surfaces. It is not suitable for engineering applications. Furthermore, this work is limited by the size of the Responsive Workbench.

In order to support large-sized freeform surface design at the conceptual stage, we investigated a novel surface modelling approach by utilising a 3D motion capture system. Artists or designers wearing motion marks on their hands can sketch out 3D design splines when moving their body and hand in space. Literarily they can combine their body and hands movements freely to any positions within a predefined motion capturing volume to perform their design tasks. During sketching, the designers can use the working ground as the X and Y directional references and their body parts for Z directional reference. They can also use rough physical wireframes as 3D references. All their design motions are recorded in the motion capturing system and transferred into 3D curves correspondingly. Based on sketched 3D curves, a large-sized freeform surface can be obtained easily.

## METHODS

The motion-based 3D surface design process includes three phases: design scene setting up, surface design by motion capturing, design data processing and surface modelling. The system flowchart is shown in Fig. 1.

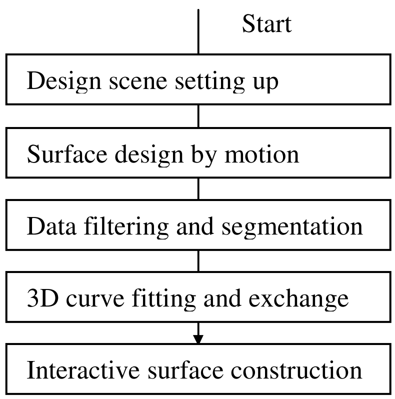


Figure 1- System flowchart

Figure 2- Design scene

### Design Scene Setting Up

The concept of surface design with motion was realized using a motion capturing system-MotionAnalysis [12]. It is a 3D optical motion capturing system that measures the movement of objects. The system combines proprietary hardware, software and electro-optical techniques with standard computer and video hardware. In our system, 7 Eagle digital cameras are used with the EvaRT 4.2 software to collect motion data. The 7 cameras can be located circularly to let the system to capture body motions within a rough volume about 5m X 8m X 4m along the $x$, $y$ directions on the ground and the vertical $z$ direction. This volume can support larger sized surface design activities. Motion is captured from reflective markers. The size of marks varies from 6 mm to 25 mm in diameter. Different sizes of markers will affect the size of the volume. After setting up the motion capturing system, a design scene with various 3D references can be set up as well in the centre of the capturing region. For example, some wood spline strips had been set up for designing a car body (Fig. 2). The design scene can provide 3D physical references for designers. These references are visible, touchable and pressure-sensible.

### Surface Design by Motion Capturing

For designing a surface by motion capturing, designers need to touch reflective sensors on their hands. If holding sensors on both hands, they can use them both for design, making body gestures more available. If they only touch sensors on one hand, they can use the other hand to hold design tools such as rulers to assist the design. Normally, one sensor on one hand is enough. It can be typically touched to the tip of fingers. During the design process, the designers can control the sensors in function or not by covering the sensors with their thumbs. When they move their body with a stretched hand (sensors are in function), the movements of the sensors against timing are captured and recorded in a data file. When they change their positions with covered sensors, no motion will be captured because the sensors are not in function. For example, the designer in Fig 2 used only one sensor on his right hand. The design motion was recorded in a Track Row Column (.TRC) file, which contains X-Y-Z position data for the reflective marker. The file is in the ASCII format that can be easily read into a spreadsheet program such as Excel™. The position data for each marker is organized into 3 columns per parker (X, Y and Z position) with each row being a new frame. The position data is relative to the global coordinate systems of the capture volume and the position values are in the units used for calibration. Missing data is represented as an empty frame of position data.

**Design Data Processing and Surface Modelling**

With obtained design motion, we first need to segment the raw motion data into 3D curves. Each segment in motion data represents a 3D design curve. For each curve segment, it is then filtered for smoothly fitting with a NURBS curve. Collectively, these design curves are characteristic lines on the intent surface. Finally, the 3D design curves are exchanged into a commercial CAD package -Alias Studio for constructing the surface.

*Segmentation:* In a .TRC file, each design curve is represented as consecutive position data, which is separated by missing data (empty frames of position data). Therefore, we initially segment design curves by finding empty frames in the motion file and then refine the segmentation by checking if two successive segments are real separated. If the time interval between the two successive segments is larger than 2 seconds and the distance between their closest end points is bigger than a threshold such as 50 mm, the two segments are two real curves. If not, the two segments should be merged together to form one curve because a design curve might be separated due to body blockage of views.

*Filter:* After the segmentation, a design curve is represented by a great number of 3D points. By nature of sketching, the number of points is more than enough to create a smooth curve. Therefore, these raw sketching points have to be filtered. While filtering, two end points of a curve are kept and then from one end to the other, points within a distance threshold such as 100mm will be filtered out. As a result, the remaining points represent a smooth curve.

*Curve and surface construction:* When the filtering process is finished, resultant points for each curve are fitted with a NURBS curve and it is then exchanged into a CAD package, e.g., Alias Studio. In the CAD package, curves can be further treated for constructing a large-sized surface.

## RESULTS

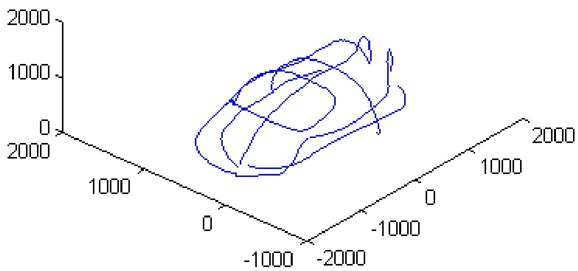


Figure 3- Segments of motion curves

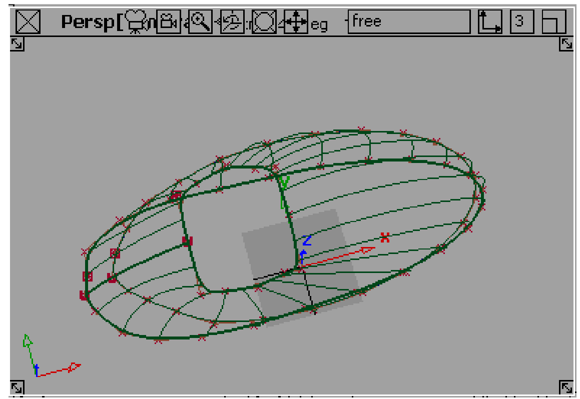


Figure 4- Construction of surfaces from exchanged curves with modifications

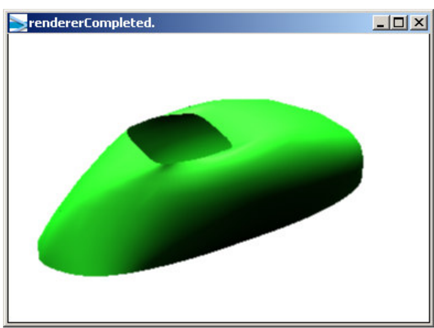


Figure 5- Initial surface rendering for evaluation

The proposed novel design method for modeling larger-sized freeform surfaces has been tested with examples. For instance, we set up the design scene (Fig.2) to demonstrate a large conceptual surface design. The initial motion data was recorded in a .TRC file. After segmentation, each curve was displayed in Fig. 3. Figure 3 also shows the sizes of the intent surface: about 4m long X 2m wide X 1.5m high. It is a large-sized object. The segmented curves contain all raw motion data. Thus, they were further filtered to make them smooth with a distance threshold of 100mm. From this filtering process, the number of points for each curve was reduced by about 20%. The new curve data (points) were then fitted with NURBS curves and the curves were exchanged into Alias Studio through its .OBJ file. In the Studio, the input curves were further modified to form a network for surface construction (Fig. 4). Figure 5 shows the resulting surface with its rendering model. This model can be used for design evaluation.

## DISCUSSION

The proposed method is based on 3D body motion capturing. It is difficult for designers to generate a characteristic curve with well-defined connections. For example, end-points of related curves should meet together. Therefore, a 3D tidy-up process (or beautification) may be needed before exchanging curves into a commercial CAD package to connect curves correctly and identify design intents such as symmetry. On the other hand, it is necessary to modify exchanged curves in the CAD package because current CAD systems cannot support surface constructions from arbitrary curve networks. Otherwise, the exchanged curves can be directly used for surface modeling.

## CONCLUSIONS

Large-sized free-form surface design presents some challenges in practice. We investigated a novel surface modeling approach by utilizing a 3D motion capture system. For designing a large-sized surface, a network of splines is initially set up. Artists or designers wearing motion marks on their hands can then change shapes of the splines with their hands. Literarily they can move their body freely to any positions to perform their tasks. They can also move their hands in 3D free space to detail surface characteristics by their gestures. All their design motions are recorded in the motion capturing system and transferred into 3D curves and surfaces correspondingly. From the experimental tests, it is shown that the method is useful and practical for designing large-sized freeform surfaces.

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