THE SPATIAL INTERPRETATION OF FREEHAND SKETCHES

USING PROGRAMMING AND RAPID PROTOTYPING

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Abstract. Freehand sketching has always been used in the conceptual design process. The importance of freehand sketching lies in its ability to freely represent various ambiguous drawing projections. This research implements a convenient sketch interpretation system called Spatial Charcoal to aid in the conceptual design process. The system interprets a designer's sketch, generates a relative digital model and then fabricates it using a rapid prototyping machine.

1. Introduction

By using drawings, the possibilities for innovative design increases, giving architects greater leeway for experimentation. For the majority of practicing architects, drawing, especially freehand sketching, is a basic method for expressing and developing a concept (Robbins, 1994). The sequential structure of designers' seeing-moving-seeing technique enables them to manage complexity. Freehand sketching helps designers to constantly alter contours within seconds and derive instant visual feedback to aid in reinterpreting the design (Schon & Wiggins, 1992). The dense ordering and ambiguity of the symbol system of sketching insure that no possibilities are excluded and help to transform one symbol into another, and the references or contents of the symbols are indeterminate (Goel, 1995). When using computer-aided design (CAD) and computer-aided manufacturing (CAM) systems, the various elements must be identified specifically, positioned and sized precisely, which reduces the design possibilities; and so should only be used in the later stages of the design process (Goel, 1995; Gross, 1996).

2. Related Work

2.1. SKETCHING IN THE COMPUTER-AIDED DESIGN ENVIRONMENT

To overcome the problems inherent in the CAD environment, researchers have proposed using a pen-based system for sketching. The Electronic Cocktail Napkin's pen-based interface provides an unstructured and direct drawing tool that enables designers to begin working on the computer at the early stages of the design process. The program supports recognition and parsing and tolerates ambiguity and the incompleteness of sketches (Gross, 1996). The Right Tool at the Right Time uses the Electronic Cocktail Napkin to prototype an integrated drawing environment, and tried to convert a 2D sketch to a 3D CAD model (Do, 1996).

SKETCH introduced a gesture-based interface for the rapid modeling of approximate 3D constructive solid geometry (CSG) models consisting of simple primitives; but it was not intended for the careful editing of precise models (Zeleznik, Herndon & Hughes 1996). Teddy presented a sketching interface to quickly and easily design freeform models such as stuffed animals and other rotund objects. The user simply drew several 2D freeform strokes on the interactive screen and the system automatically constructed plausible 3D polygonal surfaces (Igarashi, Matsuoka & Tanaka, 1999). Bimber, Encarnacao and Stork (2000) tried to make sketching an integral part of their human-computer interface. The table-like projection system let designers input representative 3D sketching language and transform it into simple freeform objects.

VR Sketchpad developed annotation and modification on different trace layers and provided diagram recognition of 2D sketches, which were converted to 3D models. These processes included simple line and circle extrusions, constructions from sketches of geometric primitives, and recognition of diagram configurations and their translation to 3D pre-made objects from a symbol library (Do, 2001). Space Pen was a collaborative work system, which allowed several distantly separated users to draw, annotate, and modify 3D representations using the 3D web environment (Jung, Gross & Do, 2001). FreeDrawer is a 3D free-form sketching system in the virtual environment that uses a tracked stylus as an input device. A curve network can be formed, describing the skeleton of a virtual model. Both hands using the editing tools can interactively edit the curves and the resulting skinning surfaces (Wesche & Seidel, 2001). Sketchand+ is an experimental 3D sketching prototype to gather information about the usage of augmented reality for the early design stages (Seichter, 2003). FRONT (2006) sketches furniture in the 3D virtual environment, offering thick sketch lines and the direct fabrication of the sketched furniture model by a computer numerical control (CNC) machine.

2.2 DIGITAL MODEL GENERATION TO COMPUTER-AIDED MANUFACTURING

In addition to linear sketching, traditional freehand sketches include surface features. Chiaroscuro facial sketches are hard to distinguish. Though not intended just for the modeling of facial sketches, van Elsas and Vergeest

(1998) implemented a new function, called the Displacement Feature Function (DFF), that allows designers to sketch a displacement feature first and then control the parameters of the displacement features during the conceptual design process. In the discussion on digital ornament, Elys (2006) explains automation for image displacement mapping to polygon models, which is applied mainly to gaming software, and proposes that digital ornament could be utilized in CNC production. Furthermore, Kai and Russell (2005) developed a complete process from the generation of the digital ornament to its final production in the CNC machine. They described three methods for creating digital surfaces: modeling surfaces in 3D CAD software; programming to generate surface topologies and ornaments; and, deriving images for a program to analyse and translate into a digital topology or structure. In the most recent CNC developments, some researchers have aimed to generate digital models and produce physical sketch surface models with generative programming and rapid prototyping. Kilian (2003) programmed to generate physical models, which when assembled out of developable strips, interconnected through a puzzle-like detail. Dritsas (2005) wrote the MiranScript for automating the processes of rapid prototyping and digital fabrication.

3. Problem Statement and Objective

This research focuses on the point that the current CAD/CAM environment cannot match the conceptual design process, and proposes the following problem: How can sketch be spatially interpreted and utilized rapid prototyping (RP) machine to generate entity conceptual model, which is sketchy and can stimulate designers' thinking?

The objective of this research is to simplify the inconvenient and complicated operating sequence in the current CAD environment by developing an improved system prototype. This prototype, Spatial Charcoal, encompasses the complete work process from the spatial interpretation of a sketch, through to its digital modeling, and on to its fabrication. Spatial Charcoal enables designers to make a sketch on paper, and then scan it, or sketch directly onto the interface using the computer pen-based system. The digital data of the sketch are interpreted spatially and a digital model is generated, which in turn is fabricated into an entity model using an RP machine (Figure 1). Designers need only to key in some simple instructions to make the procedure work.

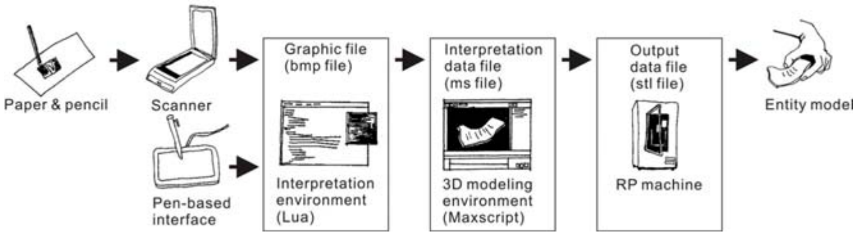

Figure 1. The procedure of Spatial Charcoal

4. Methodology and Steps

This research is comprised of three parts. The first part develops a freehand-sketching spatial interpretation method, which includes both sketch lines and surfaces. The second part discusses the progression of two kinds of basic sketch models (surface model and line model) from their generation to their fabrication. The third part discusses users reactions and gives examples of research.

4.1 INTERPRETING THE FREEHAND SKETCH

Spatial Charcoal interprets a sketch in the program written in Lua, uses the interpreted data to generate a digital model using MaxScript software, and finally outputs the stl file to a rapid prototyping (RP) software called Insight (Figure 2).

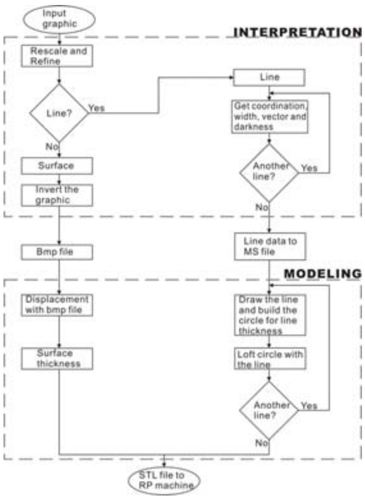

Figure 2. The Spatial Charcoal system

In the interpretation process, Spatial Charcoal begins by checking the size of the sketch; it then rescales the sketch to a suitable size for later RP output and assigns a range of heights for interpretation. The system classifies freehand sketches into lines or surfaces. A high density of lines -- where so many lines overlap it is hard to distinguish them -- is read as a surface.

The darkness of a sketch indicates the importance of the line to the drawer, so when defining surface height Spatial Charcoal reads darker areas to be higher and lighter areas to be lower. The modeling of the surface utilizes the displacement function in MaxScript, which assigns an image file for bitmapped displacement; the lightest area is the highest. However, Spatial Charcoal interprets the dark areas of a sketch as more important, so it invert the image before assigning it to the image file ready for MaxScript. Finally, a certain thickness is assigned to the generated surface; this ensures that the generated model can be exported to the file of the RP software.

Sketch lines may cross each other; Spatial Charcoal records the path vector in order to determine the best probability of following the right line. Just as with the surface sketch, the darkness of the pixels on the line sketch is read for the height definition of the line’s vertex, and the average thickness of the line is calculated for the later modeling. The sketch is checked thoroughly to ensure that all lines on the sketch are recorded. The modeling of the lines utilizes the loft function in MaxScript (a loft object is a two-dimensional shape extruded along a two-dimensional or three-dimensional axis). The loft object in Spatial Charcoal is a circle of the diameter of the average thickness of the original sketch line, and the path is the height definition of the line read from the degrees of darkness.

Figure 3. Interpretation method: (a) surface and (b) line

4.2 GENERATION AND FABRICATION OF SKETCH MODELS

The different areas of a sketch are interpreted as surfaces or lines according to their line density. Therefore, Spatial Charcoal can generate two basic types of models. The generated digital model in Max is exported to the stl file of the RP software Insight. The RP software slices the digital model; generating the support and its toolpaths. These steps require only simple keying in on the software interface. The entity model can be produced within few hours.

4.2.1 Surface Model

A surface model occurs when the designer fills in the entire area with different gradations of darkness and lightness; from a soft gradient to a sharp gradient (chiaroscuro). The saturation of each sketch area affects the final smoothness of the surface model -- an unsaturated sketch may generate a ragged surface -- which most designers will not expect. However, a ragged surface may not be the unprofitable interpretation that one might think. Designers may derive some unexpected compositional feedback from the model and then be able to reinterpret the design.

When a designer chooses to draw a continuous line back and forth with some pressure this becomes the darker part of the sketch. This feature of sketching is usually to be found in line sketching. As Spatial Charcoal interprets line and surface, this method is assigned to the surface sketch at the same time. Following this sketching logic, designers should understand that the nearest thing is darker and the farthest thing is lighter. It is well understood that distant objects tend to be relatively indistinct.

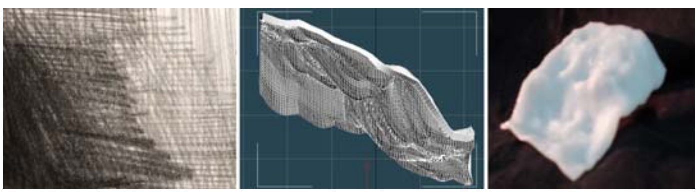

Figure 4. Surface sketch, digital and entity model

4.2.2 Line Model

The term line model refers to a continuous single stoke, or many strokes that are repeated on a single track and can be interpreted as a single line. Spatial Charcoal assigns the height coordination to the sketch model by interpreting the original sketch. Although designers would like to be able to draw the same darkness on part of one line, a single darkness track is actually very hard to achieve. As a result, darker and lighter divisions can be found within one short segment that would be regarded by designers as the same degree of darkness. This uncontrollable feature causes the interpreted line models of Spatial Charcoal to become a little ragged as a result. However, because of this, designers can receive unexpected feedback and then rework their ideas.

Figure 5. Line sketch, digital and entity model

5. Evaluation and Discussion

5.1 EXAMPLES IN PRACTICE

Experimentation and experience played a key role in the development of the Spatial Charcoal sketch model. One experiment used the interpretation of surface sketches to design furniture. In the table design (Figure 6), three white rectangles were inserted and drew fully on the other sketch parts. The large contrast made the rectangles appear as three table feet and the remaining dark area as the tabletop. Although it was difficult to design a flat tabletop on Spatial Charcoal, this provided a chance to design different types of tabletops

In the chair design (Figure 7), three parallel strips of graded darkness intensity were drawn on a sketch. Spatial Charcoal generated a continuous surface model; as a result, the three strips became connected to each other physically. This connection generated some obvious deformation, which was very similar to vertical partition in space. However, one must bear in mind that other designers would draw the gradient surface sketch differently. Some designers are able to control the gradient very easily and others not very well. Obviously, the direction, saturation and thickness of the sketch line can also affect the interpretation.

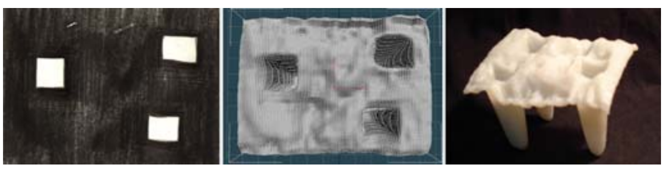

Figure 6. Table design sketch, digital and entity model

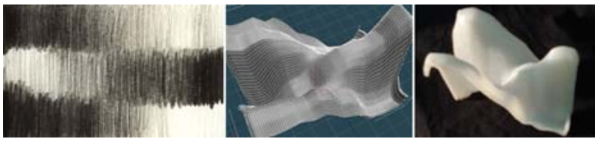

Figure 7. Chair design sketch, digital and entity model

5.2 USER EXPERIENCE

The designers who tested Spatial Charcoal can be classified into two groups: those who though that Spatial Charcoal was not an intuitive system; they had to reorganize their thinking before they could draw sketches using Spatial Charcoal. This group of designers was familiar with the current CAD software or the isometric perspective drawing method, and they thought that Spatial Charcoal only provided a single faceted designing tool. In addition, Spatial Charcoal can only generate models with one layer, which is not conducive to the needs of architects who think in terms of multi-floored buildings. The second group thought that Spatial Charcoal was quite interesting. This group of designers was familiar with sketching and charcoal drawing. They thought that Spatial Charcoal was the reverse of the process followed for drawing an entity object, so they felt they would be able to adapt to Spatial Charcoal very easily and thought it could be useful.

5.3 PROGRESSIVE WORK

Spatial Charcoal is a work in progress. Our current interpretation of line sketching is at the basic stage; the crossing and overlapping of lines will be studied further (Figure 8a). It is hoped that, in the future, ongoing research will assure that both surface and line sketches will be able to be interpreted as one single sketch. The system will interpret the line first and then rebuild the surface below, thereby ensuring that two kinds of sketch models will be able to fabricate together as one entity model. (Figure 8b).

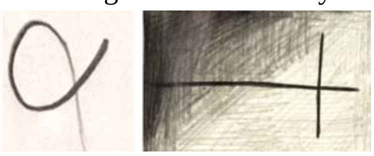

Figure 8. (a) Line overlaps itself (b) Crossed lines on the surface sketch

6. Conclusion

Spatial Charcoal proposes a creative and simple design process and replaces the past laborious work of digital modeling. After designers gradually become familiar with it, their experience prompts feedback on their sketching, and then they can modify ways of drawing lines to produce the desired degree of darkness to generate the entity model. Designers can also modify the digital model directly using CAD software prior to entity model fabrication. Furthermore, designers are able to modify the entity sketchy model by sketching, which should stimulate the designers' imagination regarding three-dimensional forms. As well as generating conceptualized sketch-design models, Spatial Charcoal can also be applied to relief or ornamentation production.

One of the limitation of Spatial Charcoal is that it is only compatible with RP machine, which is suitable for beginners because it makes assembling by hand unnecessary. However, the long output time, high price and size limitation of RP machines may present certain difficulties for more advanced students. Future advances could interpret sketches to allow automation flattening or the segmentation of the digital model, which would utilize a laser-cutting machine and assemble into a large-scale entity model.

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